845 Brook Street, Rocky Hill, CT 06067
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CONNECTICUT GREEN BANK

April 21, 2017

Dear Connecticut Green Bank Board of Directors:

We have a regular meeting of the Board of Directors scheduled on Friday, April 28, 2017 from 9:00 to 11:00 a.m. in the Colonel Albert Pope Board Room of the Connecticut Green Bank at 845 Brook Street, Rocky Hill, CT 06067.

On the agenda we have the following items:

- **Consent Agenda** – approval of the meeting minutes for the March 10, 2017 special board meeting, methodology for reporting environmental emissions benefits, and IT vendor management policy. Also included are financial statements through February of 2017 and progress to targets through Q3 of FY 2017. We will also be recognizing Pat Wrice for her service to the Connecticut Green Bank.

- **New Member Welcome** – we will be welcoming Betsy Crum and Gina McCarthy to the Board of Directors.

- **Committee Recommendations** – the ACG Committee will be recommending approval of the CT Solar Lease 2, LLC audit as well as provide updates on the Auditors of Public Account findings and a 2017 legislative and regulatory update.

- **Staff Transaction Recommendations** – we will have several transactions that we are recommending for your review and approval, including:

    a. **Infrastructure** – we will begin with an overview of progress to targets. As a follow-up from the strategic retreat, we will discuss a proposed RSIP PBI payout to manage our balance sheet. We will also be proposing Steps 11 through 13 of the RSIP, including a new grid modernization and climate change pilot as a follow-up to the strategic retreat.

    b. **Commercial and Industrial Sector** – we will begin with an overview of progress to targets. We will be requesting additional resources for the Meriden hydropower project and a budget set aside to support DEEP's microgrid program.

    c. **Residential Sector** – we will provide an overview of progress to targets.

- **Other Business** – we have a number of exciting things to report out.

If you have any questions, comments or concerns, please feel free to contact me at any time.

We look forward to seeing you next week. Until then, enjoy the March for Science and Earth Day tomorrow.

Sincerely,

Bryan Garcia
President and CEO

AGENDA

Board of Directors of the
Connecticut Green Bank
845 Brook Street
Rocky Hill, CT 06067

Friday, April 28, 2017
9:00-11:00 a.m.

Staff Invited: George Bellas, Craig Connolly, Mackey Dykes, Brian Farnen, Bryan Garcia, Ben Healey, Dale Hedman, Bert Hunter, Kerry O'Neill, and Eric Shrago

1. Call to order

2. Public Comments – 5 minutes

3. Consent Agenda* – 10 minutes

    a. Approval of Meeting Minutes for March 10, 2017*
    b. AVERT and Environmental Impact Metrics with DEEP and EPA*
    c. Information Technology Vendor Management*
    d. Financial Statement for February 2017
    e. FY 2017 Q3 Progress to Targets
    f. Acknowledgement and Recognition

4. Welcome New Members to the Board of Directors – Betsy Crum and Gina McCarthy – 5 minutes

5. Committee Recommendations and Updates* – 15 minutes

    a. Audit, Compliance, and Governance Committee – 15 minutes

        i. CT SL2 LLC Audit*
        ii. State Auditor Report Findings for 2014 and 2015
        iii. 2017 Legislative and Regulatory Update

6. Staff Transaction Recommendations and Updates – 70 minutes

    a. Infrastructure Sector Program Updates and Transaction Recommendations – 40 minutes

        i. Update on Progress to Targets – 5 minutes
        ii. Residential Solar Investment Program – PBI Commitment Payout* – 15 minutes

iii. Residential Solar Investment Program – Steps 11 through 13* – 20 minutes

b. Commercial, Industrial, and Institutional Sector Program Updates and Transaction Recommendations – 25 minutes

i. Update on Progress to Targets – 5 minutes
ii. Meriden Hydropower Project* – 10 minutes
iii. DEEP Microgrid Program – CT Green Bank Financing – 10 minutes

c. Residential Sector Program Updates and Transaction Recommendations – 5 minutes

i. Update on Progress to Targets – 5 minutes

7. Other Business – 10 minutes

8. Adjourn

*Denotes item requiring Board action

Join the meeting online at https://global.gotomeeting.com/join/289853229

Or call in using your telephone:
Dial (872) 240-3412
Access Code: 289-853-229

Next Regular Meeting: Friday, June 23, 2017 from 9:00-11:00 a.m.
Connecticut Green Bank, 845 Brook Street, Rocky Hill, CT

RESOLUTIONS

Board of Directors of the
Connecticut Green Bank
845 Brook Street
Rocky Hill, CT 06067

Friday, April 28, 2017
9:00-11:00 a.m.

Staff Invited: George Bellas, Craig Connolly, Mackey Dykes, Brian Farnen, Bryan Garcia, Ben Healey, Dale Hedman, Bert Hunter, Kerry O'Neill, and Eric Shrago

1. Call to order

2. Public Comments – 5 minutes

3. Consent Agenda* – 10 minutes

   a. Approval of Meeting Minutes for March 10, 2017*

Resolution #1

Motion to approve the minutes of the Board of Directors Meeting for March 10, 2017

   b. AVERT and Environmental Impact Metrics with DEEP and EPA*

Resolution #2

WHEREAS, the Connecticut Green Bank and the Connecticut Department of Energy and Environmental Protection (DEEP) working with the U.S. Environmental Protection Agency (EPA) to assess the Avoided Emissions and Generation Tool (AVERT) to estimate emission benefits resulting from clean energy deployment;

WHEREAS, DEEP and the EPA have demonstrated support for the environmental emissions methodology; and

WHEREAS, the Audit, Compliance, and Governance Committee at a meeting on April 20, 2017, reviewed and now recommend that the Board of Directors approve through the Consent Agenda the proposed Connecticut Green Bank and DEEP Evaluation Framework – Societal Perspective – Environmental Benefit Methodology documentation;

NOW, therefore be it:

RESOLVED, that the Board approves the proposed Connecticut Green Bank and DEEP Evaluation Framework – Societal Perspective – Environmental Benefit Methodology documentation to be used for reporting, communication, and other purposes as deemed necessary.

c. Information Technology Vendor Management*

Resolution #3

RESOLVED, that based on the recommendation of the Audit, Compliance and Governance Committee, the Board of Directors of the Connecticut Green Bank hereby approves the proposed Vendor Management Policy.

d. Financial Statement for February 2017
e. FY 2017 Q3 Progress to Targets
f. Acknowledgement and Recognition

4. Welcome New Members to the Board of Directors – Betsy Crum and Gina McCarthy – 5 minutes

5. Committee Recommendations and Updates* – 15 minutes

a. Audit, Compliance, and Governance Committee – 15 minutes

i. CT SL2 LLC Audit*

Resolution #4

WHEREAS, Article V, Section 5.3.1(ii) of the Connecticut Green Bank ("Green Bank") Operating Procedures requires the Audit, Compliance, and the Governance Committee (the "Committee") to meet with the auditors to review the annual audit and formulation of an appropriate report and recommendations to the Board of Directors of the Green Bank (the "Board") with respect to the approval of the audit report;

NOW, therefore be it:

RESOLVED, that the Committee hereby recommends to the Board, and the Board approves the proposed draft CT Solar Lease 2 LLC audited financial statements the year ended December 31, 2016 contingent upon no further adjustments to the financial statements or additional required disclosures which would materially change the financial position of CT Solar Lease 2 LLC as presented.

ii. State Auditor Report Findings for 2014 and 2015
iii. 2017 Legislative and Regulatory Update

6. Staff Transaction Recommendations and Updates – 70 minutes

a. Infrastructure Sector Program Updates and Transaction Recommendations – 35 minutes

i. Update on Progress to Targets – 5 minutes

ii. Residential Solar Investment Program – PBI Commitment Payout* – 15 minutes

Resolution #5

WHEREAS, the Green Bank designed and implemented a Residential Solar Photovoltaic Investment Program ("RSIP") in order to achieve a minimum of three hundred (300) megawatts of new residential PV installation in Connecticut before December 31, 2022;

WHEREAS, pursuant to Section 106 of the Act, the Green Bank offers direct financial incentives, in the form of performance-based incentives ("PBI") or expected performance-based buydowns ("EPBB"), for the purchase or lease of qualifying residential solar photovoltaic systems.; and

WHEREAS, the Green Bank seeks to opportunistically reduce some of its obligations under the PBI program by purchasing the obligations at a discount.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors ("Board") authorizes the allocation and use of up to $5,000,000 of unrestricted Green Bank funds to buy-out PBI obligations consistent with this memorandum dated April 21, 2017;

RESOLVED, that the Board further authorizes Green Bank staff to conduct an auction whereby the Green Bank solicits bids from third-party owners to maximize the discount at which PBI obligations may be bought-out; and

RESOLVED, that subject to confirmation with the Deployment Committee, the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned auction.

iii. Residential Solar Investment Program – Steps 11 through 13* – 20 minutes

Resolution #6

WHEREAS, Public Act 15-194 "An Act Concerning the Encouragement of Local Economic Development and Access to Residential Renewable Energy" (the "Act") requires the Connecticut Green Bank ("Green Bank") to design and implement a Residential Solar Photovoltaic ("PV") Investment Program ("Program") that results in no more than three-hundred (300) megawatts of new residential PV installation in Connecticut before December 31, 2022 and creates a Solar Home Renewable Energy Credit ("SHREC") requiring the electric distribution companies to purchase through 15-year contracts the Renewable Energy Credits ("RECs");

WHEREAS, as of March 21, 2017, the Program has thus far resulted in nearly one-hundred and sixty megawatts of new residential PV installation application approvals and completions in Connecticut;

WHEREAS, pursuant to Conn. Gen Stat. 16-245a, a renewable portfolio standard was established that requires that Connecticut Electric Suppliers and Electric

Distribution Company Wholesale Suppliers obtain a minimum percentage of their retail load by using renewable energy;

WHEREAS, real-time revenue quality meters are included as part of solar PV systems being installed through the Program that determine the amount of clean energy production from such systems as well as the associated RECs which, in accordance with Public Act 15-194 will be sold to the Electric Distribution Companies through a master purchase agreement entered into between the Green Bank, Eversource Energy, and United Illuminating, and approved by the Public Utility Regulatory Authority;

WHEREAS, pursuant to the Act, the Green Bank has prepared a declining incentive block schedule ("Schedule") that offers direct financial incentives, in the form of the expected performance based buy down ("EPBB") and performance-based incentives ("PBI"), for the purchase or lease of qualifying residential solar photovoltaic systems, respectively, fosters the sustained orderly development of a state-based solar industry, and sets program requirements for participants, including standards for deployment of energy efficient equipment as a condition for receiving incentive funding;

WHEREAS, pursuant to the Act, to address willingness to pay discrepancies between communities, the Green Bank will continue to provide additional incentive dollars to improve the deployment of residential solar PV in low to moderate income communities.

WHEREAS, pursuant to the Act, to address sustained orderly development of a state-based solar industry, the proposed grid modernization and climate change pilot will provide incentives for solar PV to offset the additional energy load from clean energy sources and storage needs.

WHEREAS, pursuant to Section 16-245(d)(2) of the Connecticut General Statutes, a Joint Committee of the Energy Conservation Management Board and the Connecticut Green Bank was established to "examine opportunities to coordinate the programs and activities" contained in their respective plans (i.e., Conservation and Load Management Plan and Comprehensive Plan);

WHEREAS, the Global Warming Solutions Act of 2008 requires Connecticut to reduce its greenhouse gas emissions by 80 percent from 2001 levels by 2050, all the while transportation and the thermal heating and cooling of buildings representing the largest emitting sectors;

WHEREAS, residential solar PV can provide cleaner, cheaper, and more reliable sources of energy for electric vehicles and renewable thermal technologies while creating jobs and supporting local economic development;

WHEREAS, the Deployment Committee has reviewed and recommends that the Board approves of the Schedule of Incentives as set forth in Tables 5, 6, and 7 of the memo dated April 28, 2017 20.0 MW from Step 11, 20.0 MW from Step 12, and 20.0 MW from Step 13.

NOW, therefore be it:

RESOLVED, that the Board, including the Commissioner of the Department of Energy and Environmental Protection, approves of the Schedule of Incentives as set forth in Tables 5, 6 and 7 of the memo dated April 28, 2017 20.0 MW from Step 11, 20.0 MW from Step 12, and 20.0 MW from Step 13.

b. Commercial, Industrial, and Institutional Sector Program Updates and Transaction Recommendations – 25 minutes

    i. Update on Progress to Targets – 5 minutes
    ii. Meriden Hydropower Project* – 10 minutes

Resolution #7

WHEREAS, the Green Bank Board of Directors (the "Board"), at its February 26, April 22, June 22, July 6, July 22, October 21, and December 16, 2016 meetings (the "Prior Meetings") authorized the following elements of the development of a small hydroelectric facility at the Hanover Pond Dam on the Quinnipiac River in Meriden ("Project"):

i) A guaranty to a third-party lender for construction financing in an amount not to exceed $3.9 million,

ii) Funding from the Green Bank's balance sheet in an amount not to exceed $1,400,000,

iii) A working capital guaranty in an amount not to exceed $600,000 for the benefit of New England Hydropower Company ("NEHC"), the project developer, with a 24-month maturity under the Green Bank's existing working capital facility partnership with Webster Bank;

iv) Term financing based on:

i. Proceeding with the conditions precedent to the issuance of New Clean Renewable Energy Bonds ("CREBs") in an amount not to exceed $3,100,000 within 405 days of the original date of authorization by the Board of Directors (that is, February 26, 2016); and,

ii. Securing the issuance utilizing the Special Capital Reserve Fund ("SCRF") subject to further Board, Office of the Treasurer, and Office of Policy and Management approval;

v) A minimum debt service reserve fund required for the SCRF in an amount not to exceed $300,000;

vi) The creation of a Special Purpose Entity to be wholly owned by the Green Bank, to own, operate, and manage the Project, as required by CREBs regulations;

vii) The official intent that payment of Project construction and financing costs may be paid from temporary advances of other available funds and that such advances shall be reimbursed from the proceeds of the CREBs financing; and

viii) A loan to CGB Meriden Hydro LLC (the “Borrower”), a wholly-owned subsidiary of the Green Bank, for its purchase of the Project, as referred to and pursuant to a Loan Agreement, by and between the Green Bank and the Borrower (the “Loan Agreement”);

WHEREAS, staff has determined that the Project has and may incur additional costs and that the economics of the Project are still viable, notwithstanding these additional costs, as more fully explained in a memorandum to the Board dated April 21, 2017;

NOW, therefore be it:

RESOLVED, that the Green Bank is authorized to provide funding from the Green Bank’s balance sheet to the Project in an amount not to exceed $1,900,000 (previously approved at the not to exceed amount of $1,400,000); and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned legal instruments.

iii. DEEP Microgrid Program – CT Green Bank Financing* – 10 minutes

Resolution #8

WHEREAS, in accordance with (1) the statutory mandate of the Connecticut Green Bank (“Green Bank”) to foster the growth, development, and deployment of clean energy sources that serve end-use customers in the State of Connecticut, (2) the State’s Comprehensive Energy Strategy (“CES”) and Integrated Resources Plan (“IRP”), and (3) Green Bank’s Comprehensive Plan for Fiscal Years 2017 and 2018 (the “Comprehensive Plan”) in reference to the CES and IRP, Green Bank continuously aims to develop financing tools to further drive private capital investment into clean energy projects;

WHEREAS, pursuant to Green Bank’s and Department of Energy and Environmental Policy (DEEP’s) shared desire to support microgrids in a programmatic, efficient, and scalable effort, Green Bank Microgrid Program Funds, supported by loan loss reserve funding from DEEP, have the potential to maximize the amount of private capital leveraged into microgrid projects per limited public dollars at risk, resulting in a greater ability to develop and finance eligible projects.

WHEREAS, staff recommends support for the Green Bank Microgrid Program in the form of term loans not to exceed $5,000,000 in aggregate and supported by DEEP Loan Loss Reserve funds;

WHEREAS, Green Bank staff recommends that the Green Bank Board of Directors (“Board”) approve an allocation of $5,000,000 (over FY2018 and FY2019 to finance microgrid projects as an expansion of the Green Bank’s previous efforts to support microgrid development in the state.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors hereby approves the allocation not to exceed $5,000,000 for the Microgrid Program as described in the memorandum to the Board dated April 21, 2017; and

RESOLVED, that the President of the Green Bank and any other duly authorized officer is authorized to take appropriate actions to make the term loan funding available to Microgrid Program applicants; and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned Term Loans.

c. Residential Sector Program Updates and Transaction Recommendations – 5 minutes

   i. Update on Progress to Targets – 5 minutes

7. Other Business – 10 minutes

8. Adjourn

*Denotes item requiring Board action

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Access Code: 289-853-229

Next Regular Meeting: Friday, June 23, 2017 from 9:00-11:00 a.m.
Connecticut Green Bank, 845 Brook Street, Rocky Hill, CT

Board of Directors Meeting

April 28, 2017

Board of Directors

Agenda Item #1

Call to Order

Board of Directors

Agenda Item #2

Public Comments

Board of Directors
Agenda Item #3
Consent Agenda

Consent Agenda
Resolutions 1 through 3

1. **Meeting Minutes** – approval of meeting minutes of March 10, 2017
2. **Environmental Impact Methodology** – approval of recommendation from ACG Committee for using DEEP and EPA supported AVERT model for environmental emissions
3. **Vendor Management** – approval of recommendation from ACG Committee on IT Vendor Management Policy

- **Financial Statements** – through February of 2017
- **Progress to Targets** – through Q3 of FY 2017
- **Statements of Financial Interest** – please submit by May 1, 2017 for those BOD members that served in 2016
- **Acknowledgement and Recognition**

Connecticut Green Bank
Board of Directors (Recognition)

Pat Wrice
Former Executive Director
Operation Fuel
“First Lady of Warmth”
…and now Director of Community Outreach and Partnerships for “The Sheff Movement”

Board of Directors

Agenda Item #4 – Welcome New Members to the Board of Directors

Connecticut Green Bank

Board of Directors (New Members)

Betsy Crum
Executive Director
Women's Institute for Housing
& Economic Development
[Appointed by Rep. Aresimowitz]
Replaces Pat Wrice of Operation Fuel

Gina McCarthy
Senior Leadership Fellow at the
Harvard T.H. Chan School of Public Health,
Former Administrator of the EPA, and
Former Commissioner of CT DEP
[Appointed by Gov. Malloy]
Replaces Mun Choi of UCONN

Board of Directors

Agenda Item #5 – Committee Recommendations and Updates

ACG Committee

CT SL2 LLC Audit Recommendation

Financial Highlights

	2016	2015	2014
Solar facilities placed in service	73,689,992	50,393,267	8,891,871
Total assets	81,234,056	78,055,106	20,586,776
Revenues from rentals	1,263,742	373,944	30,558
Revenues from PPAs	581,247	58,199	-
Revenus from RECs	300,363	82,108	-
Revenues from PBIs	1,110,669	537,512	59,196
Cash flows from operating activities	221,082	(1,243,358)	8,531

ACG Committee
CT SL2 LLC Audit Recommendation

- CT Solar Lease 2 LLC engaged the firm Marcum LLP to audit its financial statements for the years ending 12/31/2016 and 12/31/2015 and to provide an Independent Auditors' Report.

- Marcum plans to issued a report in which they opined that the financial statements for the years ended December 31, 2016 and 2015 are presented fairly in accordance with accounting principals generally accepted in the United States of America.

- Marcum has not made us aware of material weaknesses or deficiencies in the internal accounting control system of CT SL2.

ACG Committee

State Auditor Report Findings (2014-2015)

Audit findings addressed the following areas:

1. Board approval of financing agreements
   (2011 Fuel Cell Amendment)

2. PSA with strategic partners
   (CGB will develop a policy to issue RFP's for core strategic services on a periodic basis)

3. Untimely submission of statutory reports
   (internal controls previously strengthened to ensure compliance with reporting requirements)

ACG Committee

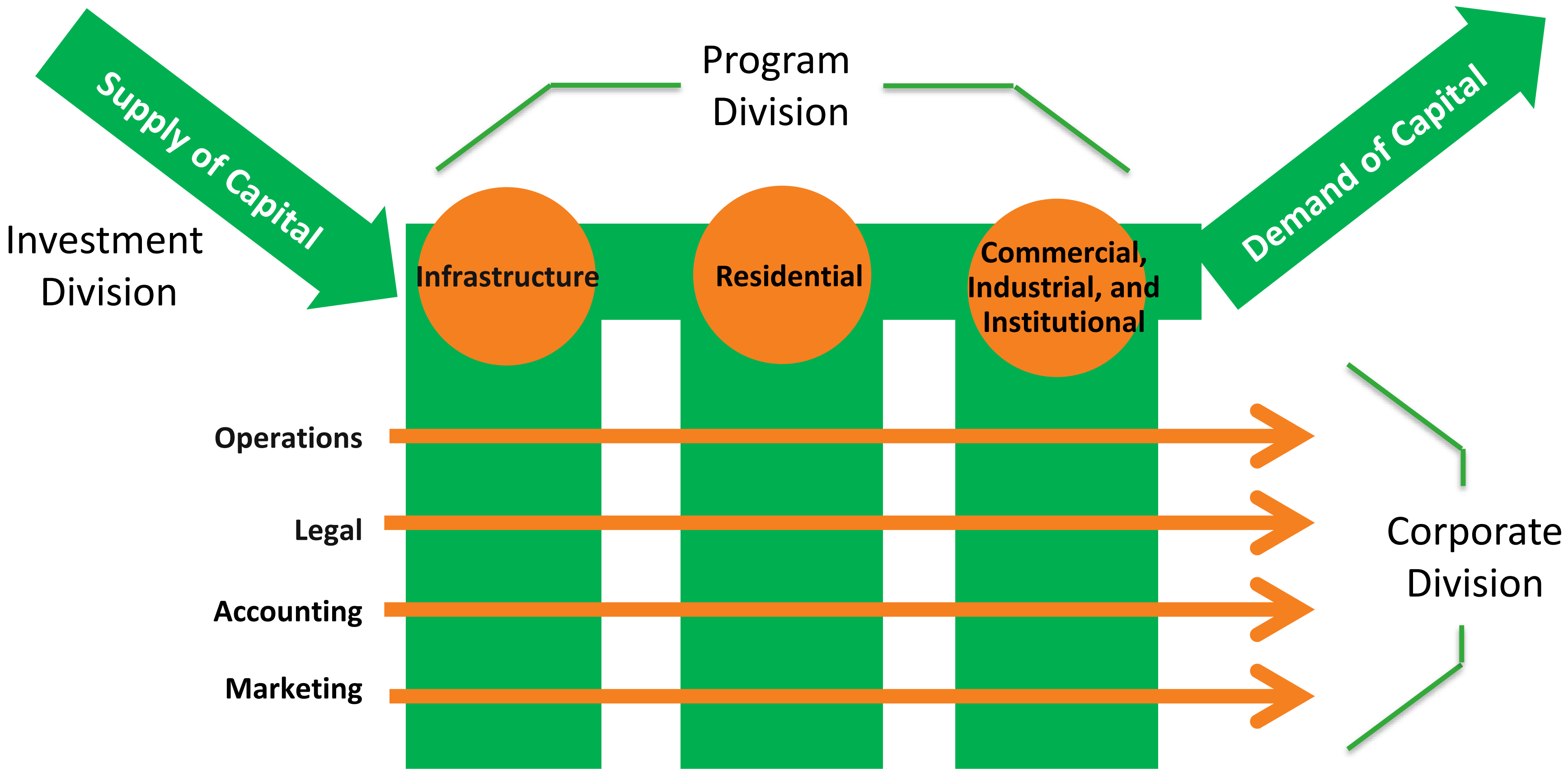
2017 Legislative and Regulatory Update

- **Defense**
- CPACE Technical Fix
- RPACE Update
- Senate Bill 106
- Anaerobic Digestion and Agricultural

Board of Directors

Agenda Item #6 – Staff Transaction Recommendations and Updates

Connecticut Green Bank
Organizational Overview



Board of Directors

Agenda Item #6a – Infrastructure Sector Program Updates and Transactions

Board of Directors

Agenda Item #6ai – Infrastructure Sector Progress to Targets through Q3 of FY 2017

Infrastructure Sector

Progress to Targets (Q3 of FY 2017)

Product/Program	Projects Closed	Projects Target	Capital Deployment Closed	Capital Deployment Target	Capacity Closed	Capacity Target
Infrastructure Sector						
Anaerobic Digesters	0	1	$ -	$ 18,000,000	0.0	1.6
CHP	1	0	$ 3,401,392	$ -	0.8	0.0
Residential Solar	3684	6000	$ 101,640,845	$ 173,165,071	28.5	47.4
S&I Total	**3685**	**6001**	**$ 105,042,237**	**$ 191,165,071**	**29.3**	**49.0**

- **Anaerobic Digesters** – Projects are approved but permitting and financing are in progress. The project originally expected to close this year looks to be postponed until next year.
- **RSIP** – Some installers have faced cash management issues leading to a slowdown in projects. Other installers are continuing to install in the state but are not availing themselves of the RSIP and are monetizing the REC in MA, demonstrating market transition.

Board of Directors

Agenda Item #6aii – Infrastructure Sector
RSIP – PBI Commitment Payout

Overview

PBI Payout for "Non-SHREC"

- Discussions with third-party system owners (TPOs) indicate interest in an early "buyout" of the long-term payment streams of PBIs
  - ✓ Allows TPO's to realize cash value now instead of over the remaining term of the PBI performance period
  - ✓ Efficient use of cash – Green Bank eliminates long-term payment obligations at a discount
- Approximately $20.2 million of PBI payments left as of Jan 1, 2017 for "non-SHREC" projects (i.e., those approved prior to Jan 1, 2015)

Top 5 Third Party Owners	PBI Systems	Estimated Total PBI	Estimated Remaining PBI	Percentage of Total Remaining PBI
SolarCity	3,073	$18,383,433	$13,016,541	64.3%
NRG Residental Solar Solutions LLC	629	$3,578,050	$2,704,483	13.4%
Sunrun Inc	443	$2,700,221	$1,952,990	9.6%
Sunnova	408	$1,630,111	$1,310,569	6.5%
Kilowatt Financial Inc	85	$721,079	$510,966	2.5%
Other	162	$1,273,865	$747,406	3.7%
Grand Total (all TPOs)	**4,800**	**$28,286,760**	**$20,242,955**	**100.0%**

Buyout Format
PBI Payout for "Non-SHREC"

- Buy-out capital allocation: $5,000,000 to be deployed prior to June 30th.
- Blind sealed-bid auction:
  - ✓ Waterfall according to discount rate (that is, priority given to discount rates in descending order)
  - ✓ No reserve price, but the Green Bank may choose to not proceed with any bids at our sole discretion
  - ✓ Other variables fixed (e.g., expected generation, timing, etc.)

Illustrative Auction - $5,000,000 Allocation

	PBI Amount (present value)		Bid	Ending Rate Sealed	Nominal PBI	
Participant 1	$	500,000	7%	7%	$	609,314
Participant 2	$	1,500,000	6%	6%	$	1,779,435
Participant 3	$	3,000,000	5%	5%	$	3,462,930
Participant 4	$	1,000,000	3%	Did not win	$	5,851,679
Savings	$	851,679				

Timeline

PBI Payout for “Non-SHREC”

Date	Action
May 5th:	Communicate to TPOs the Green Bank’s intent to conduct an auction
May 5th – 19th:	Answer TPO questions and agree upon nominal PBI cash flows
May 31st:	Bid submission deadline
June 5th:	Notify winners and the amount of funding eligible to buy-out their obligations
June 5th – June 28th:	Documentation
Prior to June 30th:	Execute buy-out

- Staff will confirm auction results with Deployment Committee before finalization and execution

Request
PBI Payout for “Non-SHREC”

- That the Green Bank Board of Directors (“Board”) authorizes the allocation and use of up to $5,000,000 of unrestricted Green Bank funds to buy-out PBI obligations consistent with this memorandum dated April 21, 2017; and
- That the Board further authorizes Green Bank staff to conduct an auction whereby the Green Bank solicits bids from third-party owners to maximize the discount at which PBI obligations may be bought-out; and
- That subject to confirmation with the Deployment Committee, the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned auction.

Board of Directors

Agenda Item #6aiii – Infrastructure Sector RSIP – Steps 11 through 13

RSIP
Update

- Over 160 MW of approved or completed projects of 300 MW goal – about 55% of the 2022 goal.
  - Over 21,000 projects
  - 54 MW are “pre-SHREC” (i.e., prior to January 1, 2015)
  - About 30% are EPBB or homeownership
  - Incentives reduced by over 80% from Step 1 to Step 10
- Substantial progress being made making solar PV more accessible and affordable to LMI market segment.
  - <60% AMI census tracts now 3.2 times less than 100-120% AMI – versus 10 times back in 2014
  - 60-80% AMI census tracts now 1.7 times less than 100-120% AMI – versus 3 times back in 2014
  - 80-100% AMI census tracts now 1.4 times less than 100-120% AMI – versus 2 times back in 2014.

RSIP
Update (cont'd)

Residential Solar PV Market Comparison, Q1 2017	CT	MA	NJ	NY
Electric Retail Rate ($/kWh) - EIA	$0.193	$0.196	$0.158	$0.173
Installed Cost of Homeowner Owned System ($/W)	$3.70	$4.00	$3.67	$3.98
State Incentives ($/W)	$0.40	$2.59	$2.10	$1.06
Federal ITC (30%)	$0.99	$0.42	$0.47	$0.88
Net Cost to Consumer after all Incentives	$2.31	$0.99	$1.10	$2.05
LCOE to Customer after all Incentives[5]	$0.125	$0.096	$0.088	$0.117
Net Cost to Consumer as % of Installed Cost	62%	25%	30%	51%
Installed Capacity in CY 2016 (MW)	59	165	165	206
Installed Capacity in CY 2016 per capita	16	24	18	10
Installed Capacity per State Incentives Invested (W/$)	3.0	0.4	0.5	0.9
Energy Efficiency (EE) Requirement	energy audit required for all projects	energy audit required if using Mass Solar Loan	none	none
% Third Party Owned (CY 2016)	81%	72%	85%	59%
Installed Cost of TPO System ($/W)	$3.49	$3.46	$3.65	$4.34
Net Metering Policy	yes	yes	yes	yes*

RSIP
Update (cont'd)

- Master Purchase Agreement (MPA) approved by PURA in Docket No. 16-05-07 on January 25, 2017
- Aggregation for "Non-SHREC" RECs approved by PURA in Docket No's. 16-06-06 (30.00 MW) on August 3, 2016, 16-06-07 (14.45 MW) on August 3, 2016 and 16-08-44 (2.73 MW) October 5, 2016
- Aggregation for "SHREC" RECs are being approved by PURA in Docket No. 16-08-45 (7.58 MW) [APPROVED], with 17-03-37 (20.60 MW), 17-03-38 (6.90 MW), 17-03-39 (4.30 MW), 17-03-40 (6.43 MW) and 17-03-41 (8.73 MW) [OUTSTANDING]

RSIP
Steps 11 through 13

- **Race to the Rooftop** – 20 MW per step for a total of 60 MW for Steps 11 through 13 – getting us to about 230 MW (or over 75% of the public policy goal)
- **Launch Date** – Step 11 will begin at the conclusion of Step 10
- **Incentive Level** – the following incentive levels for EPBB, PBI, LMI PBI, and proposed grid modernization and climate change pilot:

RSIP Steps 11 through 13

EPBB and PBI Incentive

RSIP Incentive Step	EPBB ($/W)			PBI ($/kWh)	
	≤5 kW	5 to 10 kW	>10kW	≤10 kW	>10 kW
1	$2.450	$1.250	$0.000	$0.300	$0.000
2	$2.275	$1.075	$0.000	$0.300	$0.000
3	$1.750	$0.550	$0.000	$0.225	$0.000
4	$1.250	$0.750	$0.000	$0.180	$0.000
5	$0.800		$0.400	$0.125	$0.060
6	$0.675		$0.400	$0.080	$0.060
7	$0.540		$0.400	$0.064	$0.060
8	$0.540		$0.400	$0.054	
9	$0.513		$0.400	$0.046	
10	$0.487		$0.400	$0.039	
11	$0.487		$0.400	$0.039	
12	$0.463		$0.400	$0.035	
13	$0.463		$0.400	$0.035	

↓5%

Continue with Step 10 levels (i.e., $16-$28 ZREC eq. price) in Step 11, and then reduce 5% in Step 12

RSIP Steps 11 through 13

LMI PBI Incentive

RSIP Incentive Step	LMI-PBI ($/kWh)	
	≤10 kW	>10 kW
8	$0.110	$0.055
9	$0.110	$0.055
10	$0.110	$0.055
11	$0.110	$0.055
12	$0.100	$0.050
13	$0.090	$0.045

↓10%
↓10%

Continue with Step 10 levels (i.e., $45 ZREC eq. price) in Step 11, and then reduce 10% in each of Step 12 and Step 13

RSIP Steps 11 through 13

Grid Mod / Climate Change Pilot

- **Requirements** – in order to access the pilot incentives, the following three items must occur:
  - **Home Energy Solutions** – household must undertake assessment before solar PV system is designed or installed. Household will be provided incentives to pursue “deeper” energy efficiency (e.g., low interest Smart-E Loan)
  - **Smart Inverters** – as part of the balance of plant, a smart inverter must be installed to enable households, utilities, and TPO’s to share information about the value of DER.
  - **Data Release and System Access** – households must sign a data release form for the production of solar PV and consumption of energy from their homes for research purposes. Allowance to utilities and TPO’s will be granted to access stored energy so that household benefits can be shared with the grid.

RSIP Steps 11 through 13

Grid Mod / Climate Change Pilot (cont'd)

- **EPBB, PBI, and LMI-PBI Incentives** – will stay at Step 11 levels for RH&C and EV additional loads

RSIP Incentive Step	EPBB ($/W) or PBI ($/kWh) for Grid Mod Pilot	LMI PBI ($/kWh)
11	$0.487 / $0.039	$0.110
12	$0.487 / $0.039	$0.110
13	$0.487 / $0.039	$0.110

- **Example** – if an air source heat pump requires 3 kW of additional solar PV to cover the load, then the RSIP incentive will stay at $0.487/W (or $0.039/kWh for PBI or $0.110 for LMI-PBI) versus dropping to $0.400/W for systems above 10 kW.

RSIP Pilot
Battery Storage Incentive Example

- **<u>Battery Storage</u>** – new additional incentive for balance of plant on solar PV system

RSIP Incentive Step	Battery Storage Capacity	
	($/kWh)	($/kW)
11	$60.000	$50.00
12	$60.000	$50.00
13	$60.000	$50.00

- **Requirements in addition to Grid Mod / Climate Change:**
  - ✓ Must go on their EDC's Time-Of-Day Residential Rate
  - ✓ Must discharge battery storage system a minimum of 40% during peak hours
- **<u>Example</u>** – if a 7 kW solar PV system is installed and 14-kWh of storageand 8 kW power rating battery, then the RSIP incentive for the system would be $4,649, which includes $3,409 for the solar PV system and an additional $840 (at $60/kWh storage capacity) and $400 (at $50/kW nominal power rating).

Board of Directors

Agenda Item #6b – Commercial, Industrial and Institutional Sector Program Updates and Transactions

Board of Directors

Agenda Item #6bi – CI&I Sector

Progress to Targets through Q3 of FY 2017

CI&I Sector
Progress to Targets (Q3 of FY 2017)

Product/Program	Projects		Capital Deployment		Capacity	
	Closed	Target	Closed	Target	Closed	Target
Commercial, Industrial, Institutional Sector						
CPACE	27	56	$ 9,861,020	$ 27,930,000	1.9	7.3
Commercial Lease	10	28	$ 3,070,999	$ 21,000,000	0.9	7.0
Comprehensive Energy Strategy	1	0	$ 4,538,212	$ -	0.2	0.0
CEBS	1	0	$ 1,648,000	$ -	0.0	0.0
CI&I Total	**36**	**74**	**$ 17,924,530**	**$ 41,430,000**	**4.8**	**11.8**

- **C-PACE** – Behind target due to project lead times.
- **Commercial Lease** – Behind target due to longer than anticipated time spent in launching the new Onyx lease fund.

Board of Directors

Agenda Item #6bii – CI&I Sector
Meriden Hydropower Project

Hanover Pond Hydro Project: Summary and Context

- **193kW hydroelectric facility** (Project) in Meriden, CT employing Archimedes Screw Generator (ASG)
- **Board's previous approvals:**
  - ✓ Guaranty to private lender for construction financing in an amount NTE $3.9 MM
  - ✓ Funding from Green Bank's balance sheet in an amount NTE $1.4MM
  - ✓ Term financing:
    - Issuance of New Clean Renewable Energy Bonds (CREBs) in an amount NTE $3.1 MM
    - Securing the bond issuance utilizing the Special Capital Reserve Fund (SCRF)
    - Creating a Special Purpose Entity to own the facility
    - Minimum debt service reserve fund in an amount NTE $300,000, required for the SCRF
    - A $100,000 annual Project contribution (to be released each year out of excess cash flow)
    - Adoption of Project's Self-Sufficiency Findings

Hanover Pond Hydro Project Construction & Financing Updates

- **Construction:** Project has reached substantial completion

Archimedes Screw Generator installed

Project completed and operational

- **Financing: $2.9 million** in **CREBs** issued on Feb. 4, 2017**:**
  - Green Bank's **first Green Bond**
  - First time Green Bank has made use of SCRF
  - Net effective interest rate of <1% over 20-year term due to:
    - 70% Federal Tax Credit Rate from the CREBs structure
    - 1% interest rate buydown from PURA

Hanover Pond Hydro Project
Project Budget Updates

CONNECTICUT GREEN BANK

<u>Board presentation July 2016</u> **<u>Updated Figures</u>**

REDACTED

1. ~$1M (~18%) increase in cost

2. ~$.4M increase in CREBs amount

3. ~$.6M increase in BS contribution

REDACTED

1. Increase in costs primarily due to:
   - CT use/sales tax (44%) – this is a *potential* cost, request submitted to DRS to clarify
   - FERC Dam Safety additional compliance (26%)
   - FERC Dam Safety 3-month delay (22%)
   - Additional costs associated with winter build (8%)

2. CREBs amount increase due to a lower interest rate (0.56% over 20-year term)

3. Increase in Balance Sheet contribution to cover the additional cost in an amount NTE $1.9MM (previously approved amount of $1.4MM)

Hanover Pond Hydro Project
Project Cash Flows

Board presentation July 2016

REDACTED

New Figures

REDACTED

- Higher NPV due to a lower discount rate (CREBs cost of capital)
- Despite higher costs, Green Bank still recovers its proposed $1.9M balance sheet investment with a positive NPV over project lifetime

Hanover Pond Hydro Project
Project Cash Flows

Board Presentation July 2016

REDACTED

Minimal change in net cumulative income between original budget presentation and revised figures

New Figures

REDACTED

Hanover Pond Hydro Proposed Resolutions

- Authorize funding from the Green Bank’s balance sheet to the Project in an amount not to exceed $1,900,000 (previously approved at the not to exceed amount of $1,400,000); and
- Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned legal instruments.

Board of Directors

Agenda Item #6biii – CI&I Sector Microgrid Financing Program

Microgrid Financing Program
DEEP Microgrid Program Summary

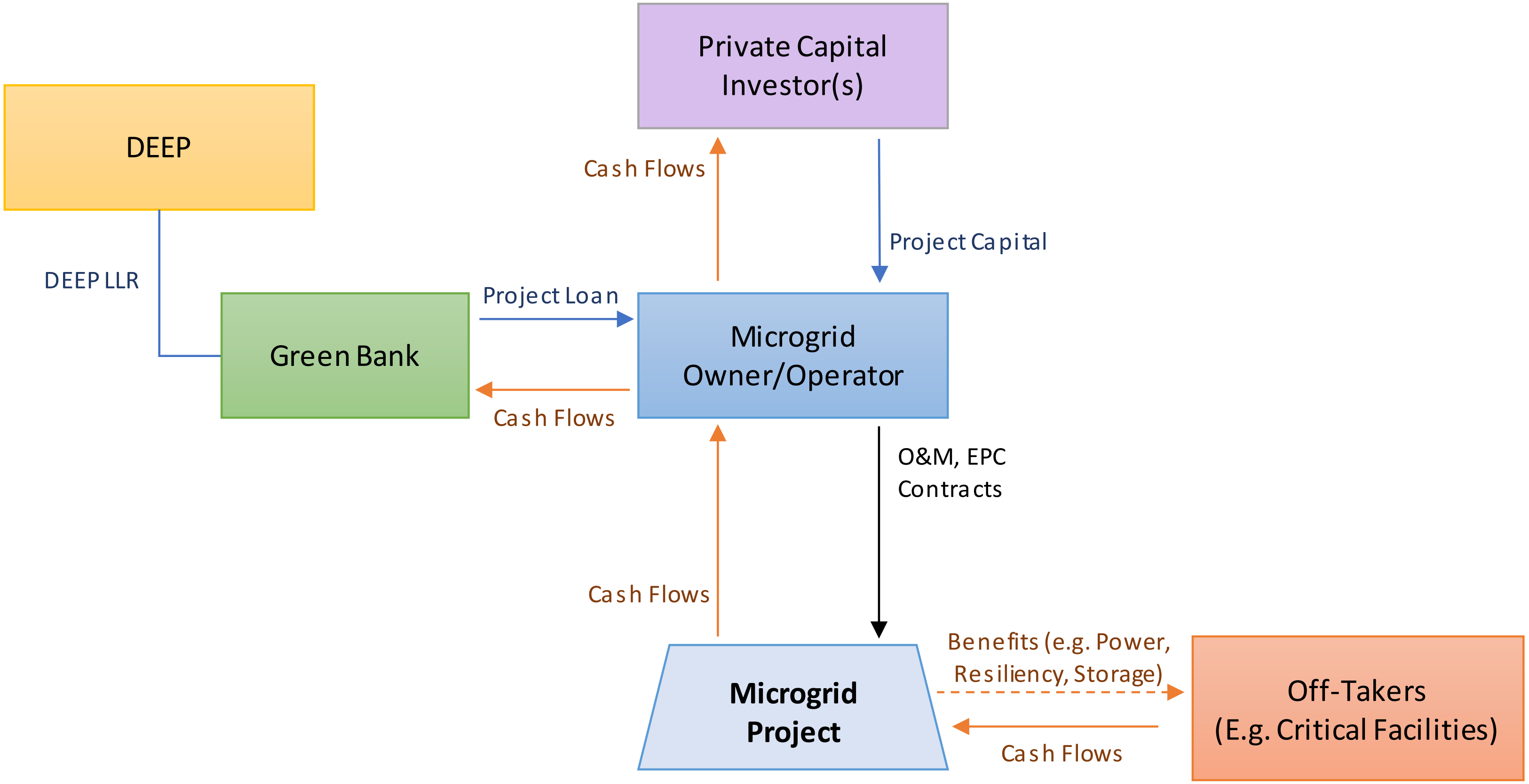
- DEEP Microgrid Program
  - Created in 2012 to help support local distributed energy generation for critical facilities
  - Developed in response to recommendation of Governor's Two Storm Panel to minimize impacts to critical infrastructure associated with emergencies, natural disasters, and other events when these cause loss of grid power
  - Awarded funding for approximately 10 microgrid projects
  - In November 2016, the State Bond Commission approved an additional $30 million in funding to expand DEEP's Microgrid Program
- Partnership with Green Bank
  - DEEP program expansion presents opportunity for partnership with Green Bank to approach microgrid project funding in coordinated, efficient, and scalable way
  - Deployment of microgrids aligns with Green Bank's Grid 2.0 and infrastructure modernization goals in Comprehensive Plan

Microgrid Financing Program
Financing Summary

- **$5 million** in available Green Bank term loan financing
  - Request up to $2.5 million in FY18 and up to $2.5 million in FY19
  - Supported by $1 million DEEP-funded Loan Loss Reserve
  - Green Bank term loans to be made for microgrid projects that are successful in securing funding through DEEP Microgrid Program
  - 3.00% - 7.00% Expected Interest Rate
  - 15 - 20 Year Expected Term
  - Extension of previous Green Bank allocations for microgrids
- Green Bank anticipates investment multiples of 2x to 5x for Green Bank financing relative to DEEP LLR, and again for Green Bank financing relative to third-party private capital

Microgrid Financing Program

Capital Flow Diagram



Microgrid Financing Program
Resolutions

RESOLVED, that the Green Bank Board of Directors hereby approves the allocation not to exceed $5,000,000 for the Microgrid Program as described in the memorandum to the Board dated April 21, 2017; and

RESOLVED, that the President of the Green Bank and any other duly authorized officer is authorized to take appropriate actions to make the term loan funding available to Microgrid Program applicants; and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned Term Loans.

Board of Directors

Agenda Item #6c – Residential Sector Program Updates

Residential Sector

Progress to Targets (Q3 of FY 2017)

Product/Program	Projects		Capital Deployment		Capacity	
	Closed	Target	Closed	Target	Closed	Target
Residential Sector						
Smart-E	200	254	$ 4,371,013	$ 5,873,447	0.7	1.1
Low Income Loans/Leases (PosiGen)	497	500	$ 14,004,180	$ 15,250,000	3.1	3.4
Multi-Family (Term Only)	10	17	$ 18,075,109	$ 11,140,000	0.9	0.9
Resi Total	**707**	**771**	**$ 36,450,302**	**$ 32,263,447**	**4.8**	**5.4**

- **Smart-E** – On target to meet or exceed project targets due to strong performance from the HVAC channel and Capital for Change, but portfolio average loan amount is lower than projected, which may cause lower capital deployed results.
- **Low-to-Moderate Income (PosiGen)** – strong performance by PosiGen as it is poised to exceed its targets for the year.
- **Multifamily** – exceeded capital deployment targets for the year, seeing much larger deals than projected.


BEN
ISABELLE
ED
Sara
ROB

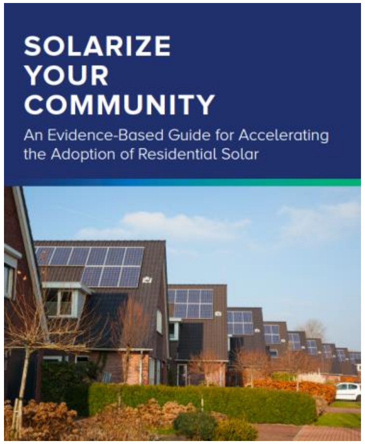
Board of Directors

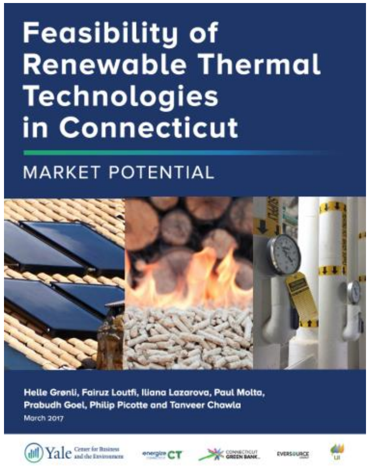
Agenda Item #7 – Other Business

Other Business
Updates

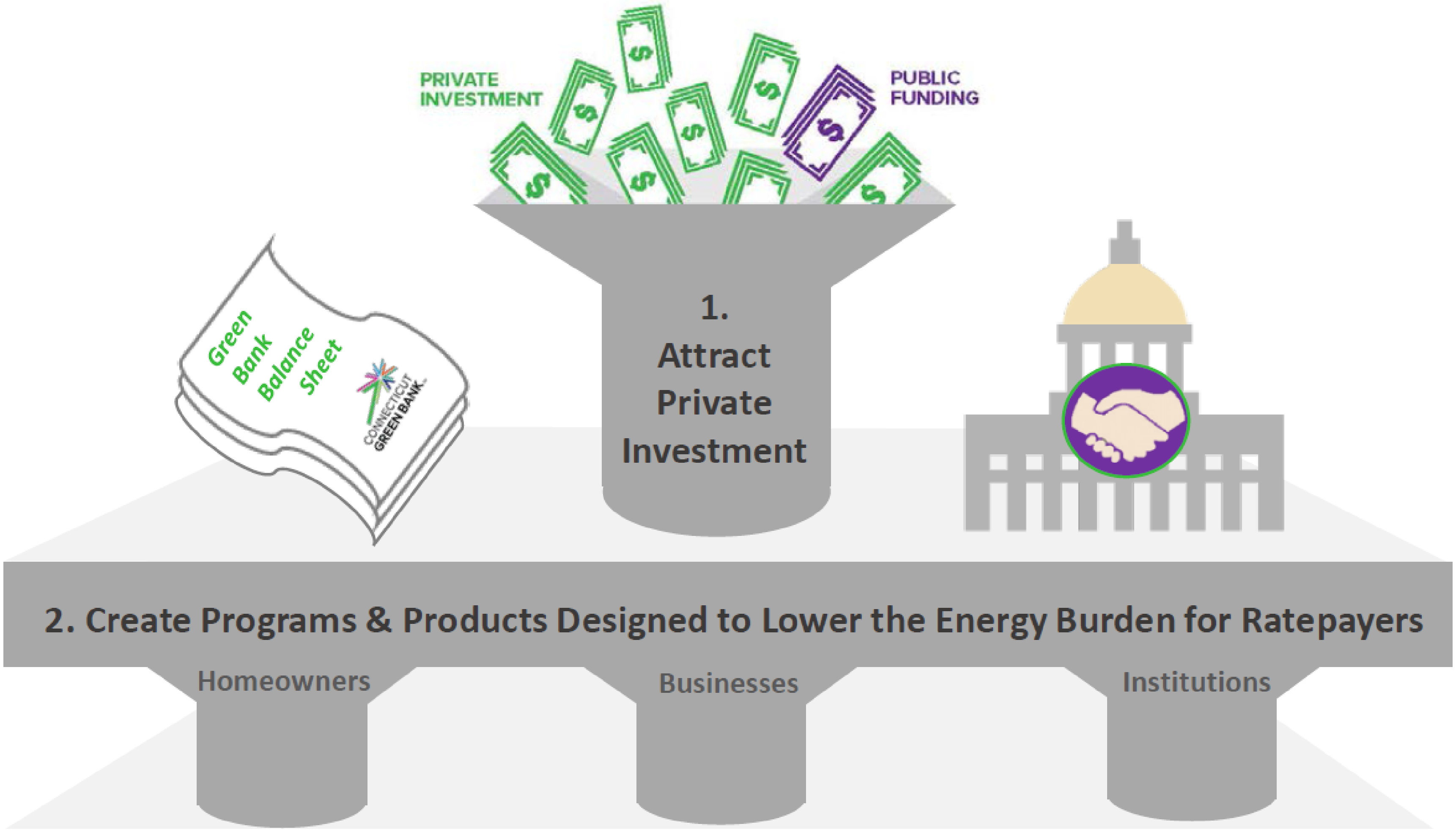
CONNECTICUT GREEN BANK

- **<u>Nissan Leaf Promotion</u>** – can't beat this deal! $10,000 off at point-of-sale from the manufacturer
- **<u>Innovations in Government Awards</u>** – 1 of 11 finalists in the Harvard Ash Center for Democratic Governance and Innovation (top 2% of applicants)
- **<u>Yale Partnerships</u>** – SEEDS grant from DOE involving Yale, Duke, SmartPower and CGB led to Solarize applied research study…RTT study led by Yale involving UI, Eversource, DEEP, and CGB





Other Business
Economic Engine and Fact Sheet



Board of Directors

Agenda Item #8 – Adjourn

CONNECTICUT GREEN BANK

Board of Directors
Draft Minutes
Friday, March 10, 2017

A special meeting of the Board of Directors of the **Connecticut Green Bank (the "Green Bank")** was held on March 10, 2017 at the office of the Green Bank, 845 Brook Street, Rocky Hill, CT, in the Colonel Albert Pope board room.

1. **Call to order**

   Catherine Smith, Chairperson of the Green Bank, called the meeting to order at 2:06 p.m. Board members participating: Tracy Babbidge (designee) for Rob Klee (by phone), John Harrity (by phone), Norma Glover (by phone), Reed Hundt (by phone), Bettina Bronisz (by phone), Kevin Walsh (by phone) and Matt Ranelli (by phone).

   Members Absent: Tom Flynn

   Others Attending: Mike Bishop, Kurt Goddard and Elliott Gnedy from FCE. (by phone) and Guy West from Clean Energy Group.

   Staff Attending: Cheryl Samuels, Bert Hunter, Bryan Garcia, Mackey Dykes (by phone), Chris Magalhaes, Eric Shrago, Craig Connolly, Brian Farnen, Dale Hedman, George Bellas and Kerry O'Neill (by phone).

2. **Public Comments**

   There were no public comments.

3. **Consent Agenda**

   a. **Approval of Meeting Minutes for January 20, 2017***

      Upon a motion made by John Harrity, and seconded by Catherine Smith, with an abstention by Bettina Bronisz, the Meeting Minutes from the January 20, 2017 Meeting, were approved.

   Resolution #1

   Motion to approve the minutes of the Board of Directors Meeting for January 20, 2017

4. **Staff Transaction Recommendation**

   a. **Residential Sector Program Transaction Recommendations**

      i. **ARRA-SEP Credit Enhancements**

Kerry O'Neill provided an overview on the Residential Sector. She discussed the plan to free up monies for Interest Rate Buy downs. She also discussed the current ARRA programs. She explained that the idea is to shift money into Interest Rate Buy Downs and utilize Green Bank dollars in Loss Reserves.

Kerry O'Neill discussed the request to replace Smart E Loan Loss Reserves, CT Solar Lease Loss Reserves, and a portion of the LIME Loan Loss Reserve (all funded with ARRA-SEP funds) with Green Bank funds.

Catherine Smith inquired about the impact on the Green Bank's Balance Sheet. George Bellas stated that it will take the unrestricted cash balances and restrict them.

Tracey Babbidge questions how much longer will CGB (and DEEP) be expected to report to DOE. Kerry O'Neill stated that she feels that it will still be a couple of years to fully use the ARRA-SEP funds for interest rate buydowns.

Catherine Smith stated that they're going to pick up the pace at which they're using the IRB's. Kerry O'Neill stated that programmatically the Green Bank is going to become much more aggressive.

Upon a motion made by Kevin Walsh, and seconded by Bettina Bronisz, the Board voted unanimously in favor.

Resolution #2

WHEREAS, in July of 2011, the Connecticut General Assembly passed Public Act 11-80, "AN ACT CONCERNING THE ESTABLISHMENT OF THE DEPARTMENT OF ENERGY AND ENVIRONMENTAL PROTECTION AND PLANNING FOR CONNECTICUT'S ENERGY FUTURE," which created the Connecticut Green Bank (the "Green Bank") to develop programs to finance and otherwise support clean energy investment in residential projects per the definition of clean energy in CGS Section 16- 245n(a);

WHEREAS, in February of 2013, the DEEP released the Comprehensive Energy Strategy ("CES") for Connecticut that includes developing financing programs that leverage private capital to make clean energy investments more affordable, including the pilot Smart-E Loan residential financing program;

WHEREAS, the Governor's Council on Climate Change has identified the need to support renewable heating and cooling and electric vehicles to support the implementation of the Global Warming Solutions Act goal of reducing 80 percent of greenhouse gas emissions from a baseline year of 2001 by the year 2050;

WHEREAS, in May of 2013, Green Bank launched the Smart-E Loan program, currently operating statewide, with 10 credit unions and community banks and one community development financial institution providing low cost and long-term financing for measures that are consistent with the state energy policy and the implementation of the CES. The Smart-E Loan currently includes $4.3 million of credit enhancement, including both repurposed ARRA-SEP and Green Bank funds, to attract nearly $30 million of private investment from local financial institutions;

WHEREAS, the Deployment Committee recommended on February 27, 2017 that the Board of Directors approve the proposed relocation of ARRA-SEP funds in amounts materially consistent with the Memorandum presented to the Committee dated February 21, 2017.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors (the "Board") approves funding for loan loss reserves and interest rate buydowns ("Credit Enhancements") through the use of repurposed American Recovery and Reinvestment Act State Energy Program ("ARRA-SEP") program funds be approved for Green Bank's Cozy Home Loans, Smart- E Loans, CT Solar Loan, and LIME Loan programs (the "Programs") in amounts materially consistent with the Memorandum presented to the Board dated March 3, 2017.

RESOLVED, that the Board approves ARRA-SEP funds for the Programs in the not- to-exceed set forth below and that the President of the Green Bank; and any other duly authorized officer of the Green Bank, is authorized to use their best discretion to utilize the most effective use of the entirety of the ARRA-SEP Credit Enhancements in amounts not to exceed:

a. $28,793 for Cozy Home Loans;
b. $7,564,227 for Smart-E Loans;
c. $468,600 for CT Solar Loan; and
d. $300,000 for LIME Loan.

RESOLVED, that the Board approves Green Bank funds for Loan Loss Reserves for the Smart-E Loan Program in the not-to-exceed amount of $1,869,884 including $1,110,608 of additional funds and $759,276 of already approved FY17 budgeted funds.

RESOLVED, that the Board approves Green Bank funds for Loan Loss Reserves for the CT Solar Lease Program in the not-to-exceed amount of $3,500,000.

RESOLVED, that the Board approves Green Bank funds for Loan Loss Reserves for the LIME

Loan Program in the not-to-exceed amount of $325,000.

b. Commercial, Industrial, and Institutional Sector Program Transaction Recommendations

i. C-PACE Transaction (Brookfield)*

Mackey Dykes discussed the Brookfield C-PACE project. He stated that they did offer a discount in the hopes of getting additional projects. He stated that they are working on a Solar addition to the project, but that they are working with Eversource on some issues.

Kevin Walsh questioned if the Diocese was the borrower. Mackey Dykes stated that the borrower is the local Parish.

Kevin Walsh questioned if this was not approved if they would go through their own private sources. Mackey Dykes stated that their private financiers were not interested in doing the entire project.

Upon a motion made by Kevin Walsh, and seconded by John Harrity, the Board voted unanimously in favor.

<u>Resolution #3</u>

WHEREAS, pursuant to Section 16a-40g of the Connecticut General Statutes, as amended, (the "Act"), the Connecticut Green Bank (the "Green Bank") is directed to, amongst other things, establish a commercial sustainable energy program for Connecticut, known as Commercial Property Assessed Clean Energy ("C-PACE");

WHEREAS, the Green Bank Board of Directors (the "Board") has approved a $40,000,000 C-PACE construction and term loan program;

WHEREAS, the Green Bank seeks to provide a $449,519 construction and (potentially) term loan under the C-PACE program to St. Joseph's Church, the building owner of 5 Obtuse Hill, Brookfield, Connecticut (the "Loan"), to finance the construction of specified clean energy measures in line with the State's Comprehensive Energy Strategy and the Green Bank's Strategic Plan; and

NOW, therefore be it:

RESOLVED, that the President of the Green Bank and any duly authorized officer of the Green Bank is authorized to execute and deliver the Loan in an amount not to be greater than one hundred ten percent of the Loan amount with terms and conditions consistent with the memorandum submitted to the Board of Directors dated March 10, 2017, and as he or she shall deem to be in the interests of the Green Bank and the ratepayers no later than 120 days from the date of this authorization;

RESOLVED, that before executing the Loan, the President of the Green Bank and any other duly authorized officer of the Green Bank shall receive confirmation that the C- PACE transaction meets the statutory obligations of the Act, including but not limited to the savings to investment ratio and lender consent requirements; and

RESOLVED, that the proper the Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned legal instruments.

c. Statutory and Infrastructure Sector Program Transaction Recommendation*

i. Danbury FuelCell Energy Project*

Chris Magalhaes discussed the Danbury FuelCell Energy (FCE) Project. He stated that the Green Bank is looking at the High Efficiency technology unit, stated that it creates value to everyone including environmental benefits.

Chris Magalhaes stated that there are no long-term contracted revenue streams associated with the project. He explained that there are certain measures in place to make sure the Green Bank investment is shielded from the risks. He explained that the Green Bank will receive the first priority lien on all project assets and cash flows as well as in a lump sum of cash collateral starting in year eight of the financing term and sized to match the principal outstanding. He explained that this helps to shield the Green Bank from financing exposure.

Matt Ranelli voiced his concerns regarding the fact that there are no long-term contracts in place. He questioned who identifies who would provide the multi-year pricing strip for project value streams, and what the resources are before year 8 (when the cash collateral becomes available), in the event of a bankruptcy.

In response, Chris Magalhaes stated that due to the merchant nature of the project, FCE has put in a significant amount of equity. He stated that the project is being financed through cash from FCE as well as construction financing from third parties. He explained that the $5 million term loan will sit on top of a significant cushion. He stated that FCE has already received quotes from Energy Service providers for the multi-year pricing strip of project value streams. He stated that having such contracts in place will be a condition for the Green Bank advance. He stated that the Green Bank is expecting an appropriate return over the 20-year term. He explained that the cash collateral available starting at year 8 is meant to help mitigate the risk that the Green Bank faces.

Kevin Walsh requested some specifics to show that this will get through the downside. Chris Magalhaes stated that they've modeled downside scenarios where the wholesale power rates began at around the 4 cents per kWh range, and for the REC's, the early years valued at $25 per MWh and the latter years valued at $15 per MWh. He stated that under those stress scenarios that they've modeled, the Green Bank's exposure is reasonably contained and allows for a full return of principal, and reasonable return, over the 20-year term.

Bettina Bronisz voiced her concerns with the 20-year term. She questioned if there was a way to pay it back sooner. Bert Hunter stated that there is definitely potential for that. He explained that they could explore that option with FCE. Bettina Bronisz questioned if those provisions are written in the documents. Bert Hunter stated that they are not at this point.

Kevin Walsh stated that in the market for merchant projects there is typically a 100% cash sweep in the early years to pay the principle down quicker. Catherine Smith stated that that would be a good idea to get the cash out first to the lender. After discussion, the resolution was revised to address this additional requirement for a cash sweep to the Green Bank.

Mike Bishop of FCE stated that these types of projects do have the opportunity to have long term purchase agreements. Catherine Smith reiterated the request that the Board have the cash sweep.

Norma Glover questioned how involved the Green Bank would be in the technology. Bert Hunter stated that the Green Bank would get monthly performance reports. He stated that staff constantly assesses the performance of the operating asset the Green Bank has invested in. He stated that the Fuel Cell in Bridgeport has performed as expected.

Matt Ranelli questioned if there is use of the waste heat. Elliott Gnedy of FCE stated that there is still some residual waste heat – even with the higher efficiency and that the waste heat will be used to heat a local office building. He explained that it will not be a revenue stream.

Upon a motion made by Kevin Walsh, and seconded by John Harrity the Board voted unanimously in favor of the Resolution, as amended.

<u>Resolution #4</u>

WHEREAS, in accordance with (1) the statutory mandate of the Connecticut Green Bank ("Green Bank") to foster the growth, development, and deployment of clean energy sources that serve end-use customers in the State of Connecticut, (2) the State's Comprehensive Energy Strategy ("CES") and Integrated Resources Plan ("IRP"), and (3) Green Bank's Comprehensive Plan for Fiscal Years 2017 and 2018 (the "Comprehensive Plan") in reference to the CES and IRP, Green Bank continuously aims to develop financing tools to further drive private capital investment into clean energy projects;

WHEREAS, FuelCell Energy, Inc., of Danbury, Connecticut ("FCE") has used previously committed funding (the "Bridgeport Loan") from Green Bank to successfully develop a 15 megawatt fuel cell facility in Bridgeport, Connecticut (the "Bridgeport Project"), and FCE has operated and maintained the Bridgeport Project without material incident, is current on payments under the Bridgeport Loan, and has requested financing support from the Green Bank to develop a 3.7 megawatt high efficiency fuel cell project in Danbury, Connecticut (the "Project");

WHEREAS, staff has considered the merits of the Project and the ability of FCE to construct, operate and maintain the facility, support the obligations under the Loan throughout its 20 year life, and as set forth in the due diligence memorandum dated March 10, 2017, has recommended this support be in the form of a term loan not to exceed $5,000,000, secured by all project assets, contracts and revenues as well as an unconditional performance and payment guarantee of FCE (the "Term Loan");

WHEREAS, Green Bank staff recommends that the Green Bank Board of Directors ("Board") approve of the Term Loan, in an amount not to exceed $5,000,000.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors hereby approves the Term Loan in an amount not to exceed $5,000,000 for the Project, as a strategic selection and award pursuant to Green Bank Operating Procedures Section XII; and

RESOLVED, that the President of the Green Bank and any other duly authorized officer is authorized to take appropriate actions to make the Term Loan to FCE (or a special purpose entity wholly-owned by FCE) in an amount not to exceed $5,000,000 with terms and conditions consistent with the memorandum submitted to the Board dated March 10, 2017, ***and with the additional inclusion of a 100% cash sweep of Project cash flows applied to interest and principal of the Term Loan so long as the combination of contracted cash flows and unencumbered cash collateral is insufficient to fully secure the Term Loan,*** and as he or she shall deem to be in the interests of the Green Bank and the ratepayers no later than 180 days from the date of authorization by the Board of Directors; and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned Term Loan.

5. Adjourn

Upon a motion made by Kevin Walsh, and seconded by Matt Ranelli, the Meeting was adjourned at 2:54 p.m.

Respectfully Submitted,

____

Catherine Smith, Chairperson

845 Brook Street, Rocky Hill, CT 06067
T 860.563.0015
ctgreenbank.com

CONNECTICUT GREEN BANK

Memo

To: Keri Enright-Kato, Director, Office of Climate Change, Technology, & Research, Connecticut Department of Energy and Environmental Protection and Robyn DeYoung, Environmental Specialist, US Environmental Protection Agency;

CC: Denise Mulholland, Senior Analyst - State Climate and Energy Program, US Environmental Protection Agency

From: Lucy Charpentier, Manager of Evaluation, Measurement and Verification; Eric Shrago, Director of Operations

Date: February 6, 2017

Re: Connecticut Green Bank use of AVERT for Air Pollution Avoidance Measurement for Individual Projects

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BACKGROUND

The Connecticut Green Bank (Green Bank) would like to standardize its methodology on quantifying the air emission benefits (e.g., nitrogen oxides (NO_x), sulfur dioxide (SO_2) and carbon dioxide (CO_2)) from its energy efficiency and renewable energy investments.

The Green Bank currently calculates an expected annual and lifetime kWh savings of energy and production of clean energy[1] with associated CO_2, NO_X and SO_2 emissions per project using ISO-New England information. This methodology was followed by our predecessor, the Connecticut Clean Energy Fund, which used the results of the 2007 New England Marginal Emission Rate Analysis.

The U.S. EPA created the Avoided Emissions and Generation Tool (AVERT).[2] In an effort to update its methodology, which both DEEP and NREL recommended we review, the Green Bank explored the use of AVERT.

Once the methodology for the use of AVERT is standardized, the Green Bank will:

- Calculate and disclose the air emissions benefits anticipated from the issuance of “green” bonds that finance clean energy projects; and

---

[1] It should be noted that the Connecticut Green Bank collects actual clean energy production data from all renewable energy projects it has invested in.
[2] https://www.epa.gov/statelocalclimate/avoided-emissions-and-generation-tool-avert

- Publicly report the air emissions benefits resulting from its investment activity in clean energy through its Comprehensive Annual Financial Report.

OVERVIEW

AVERT uses regional Air Market Program Data (AMPD) from the EPA Clean Air Markets Division (CAMD) for nearly all operating fossil-fuel energy generating units with generating capacities great then 25 MW[3]. Data collected in AMPD include reported gross generation (MWh), steam output (tons from CHP facilities), heat input (in MMBtu), emissions of sulfur dioxide, oxides of nitrogen (NO_x), and carbon dioxide (CO_2).

The current structure of AVERT requires the submission of a single project or aggregate of multiple projects into the Microsoft Excel model at a time. This takes significant time by Green Bank staff to input each project to retrieve air emission benefits. To operationalize these calculations, the Green Bank is proposing using factors derived by average projects through AVERT and then taking an average based on technology. The factors using ISO-New England 2015 emissions data are the following (see Table 1):

Table 1. Factors

Technology	CO_2 tons factor	NO_X lbs factor	SO_2 lbs factor
Solar PV	0.5446	0.6630	0.6535
Energy Efficiency	0.5409	0.6167	0.6208
Wind	0.5456	0.6123	0.6787

To confirm these factors, the Green Bank has run indicative projects (based on average size) through the models and replicated these results and compared to results obtained from AVERT. The average of the differences is as follows (see Table 2):

Table 2. Average differences from AVERT

Technology	CO2 tons Difference	CO2 % Difference	NOX lbs Difference	NOX % Difference	SO2 lbs Difference	SO2 % Difference
Solar PV	-16.67	0.00	-33.33	0.00	-166.67	0.00
Energy Efficiency	0.00	0.00	0.00	0.00	0.00	0.00
Wind	0.00	0.00	-16.67	0.00	-66.67	0.00

RECOMMENDATION

[3] The AVERT 2015 Northeast Regional Data File contains 328 fossil units. Generation is fully represented for CT, MA, ME, NH, NY, RI and VT and NJ is partially represented (23%). See the Disclaimers tab for additional details.

The Green Bank proposes to automate the calculation of these avoided emissions (multiplying the expected generation by the factors) initially manually and eventually through our data warehouse. The Green Bank will implement a process to update the factors annually, using the same methodology used to derive the above factors, once the EPA updates the model with new emissions factors based on the ISO-New England generation mix. The Green Bank will evaluate building an API to query the AVERT model once it is available online.

Factors will be used to determine actual emissions avoided for the year's factor used and for projected future avoidances. Future avoidances will be projected using the newest factor. The Green Bank will continue to use EGRID to estimate actual emissions avoided for projects completed prior to January 1, 2015.

Connecticut Department of ENERGY & ENVIRONMENTAL PROTECTION

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Memo

To: Bryan Garcia, President and CEO, Connecticut Green Bank

CC: Lucy Charpentier, Manager of Evaluation, Measurement and Verification, Connecticut Green Bank; Eric Shrago, Director of Operations, Connecticut Green Bank

From: Keri Enright-Kato, Director, Office of Climate Change, Technology, & Research, Connecticut Department of Energy and Environmental Protection

Date: March 15, 2017

Re: Request by the Connecticut Green Bank on February 6, 2017 for Review and Approval of the use of AVERT to Calculate Air Pollution Avoidance Measurement and Societal Perspective/ Evaluation Framework Draft Fact Sheet

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Background

At the Department of Energy and Environmental Protection's (DEEP) suggestion, the Connecticut Green Bank ("Green Bank") reviewed available tools for estimating the organization's contribution to support emissions reductions and is now seeking to adopt the Environmental Protection Agency's model AVoided Emissions and geneRation Tool (AVERT) as their official tool for measuring these impacts. The Green Bank assembled the following materials for DEEP's review and approval:

- Memo (February 6, 2017);
- AVERT Overview and Step-by-Step Instructions (July 2016);
- AVERT User Manual (March 2017);
- Evaluation Framework: Societal Perspective (Environment) – Draft Fact Sheet by the Green Bank;
- Letter from EPA (March 15, 2017).

Review

The Green Bank wants to estimate the extent to which investments in clean energy create value from a societal perspective as it relates to the mitigation of greenhouse gas emissions and other air pollutants. For Green Bank programs this will be measured as the amount of clean energy deployed and the resulting renewable energy produced and energy saved. At DEEP's suggestion, the Green Bank examined the AVERT model from the EPA. The tool considers regional generation fleets and profiles to quantify the amounts of Carbon Dioxide (CO_2), Nitrous Oxide (NOx), and Sulfur Dioxide (SO_2) that will not be emitted due to generation from existing sources being offset due to, for example, Green Bank supported projects. The outputs are in tons of CO_2 and pounds of NOx and SO_2.

The Green Bank, working with DEEP and the EPA, has developed a process to operationalize running the AVERT model and will create and update estimates for all their projects on an annual basis.

Findings

DEEP reviewed The Green Bank's Memos, AVERT Manual, AVERT Overview, and Draft Fact Sheet. Our view is that the AVERT is a well-developed tool that accurately describes the impacts of Green Bank projects to support the reduction of regional emissions. DEEP approves the use of AVERT for emissions benefit calculations and the summary fact sheet.

EVALUATION FRAMEWORK
SOCIETAL PERFORMANCE

CONNECTICUT GREEN BANK

Environmental Impact Overview

An important measurement of success for the Connecticut Green Bank (Green Bank) and its programs is how our investment activity improves the air quality of the state. This will be measured by the decrease in the amount of nitrogen oxides (NO_x), sulfur dioxide (SO_2) and carbon dioxide (CO_2) emitted by the region's fossil fuel electric generation due to Green Bank projects.

The Green Bank will use the US Environmental Protection Agency's (EPA) Avoided Emissions and Generation Tool (AVERT) to calculate and report on the environmental benefits of the Green Bank's clean energy investment activity in Connecticut.

Estimated Generation/Savings for 2015 is calculated by using the Avert emissions factors in **Table 1**:

Table 1: AVERT Factors

Technology	CO_2 tons / MWh	NO_x lbs / MWh	SO_2 lbs / MWh
Solar PV	0.5446	0.6630	0.6535
Energy Efficiency	0.5409	0.6167	0.6208
Wind	0.5456	0.6123	0.6787

Using this method, the following is an example of changes to emissions based on 1MW additions of either clean generation or improved energy efficiency:

Table 2: AVERT Examples

Capacity:	1 MW			
Technology	Annual expected generation change (MWh)	CO_2 savings (tons)	NO_x savings (lbs)	SO_2 savings (lbs)
Solar PV	1,200	700	800	800
Energy Efficiency	900	500	600	600
Wind	1,700	900	1,000	1,200

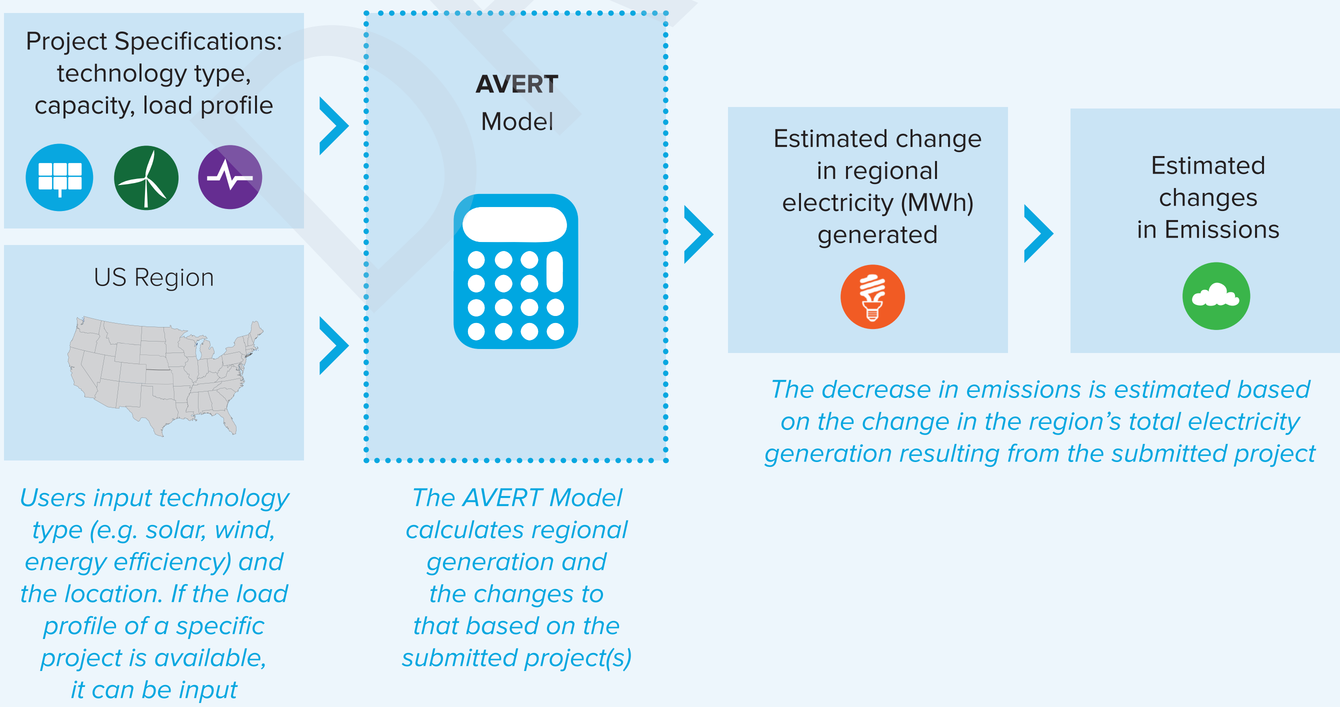
Using the type of calculation outlined above, the Green Bank will include Societal Perspective benefits as well as the environmental impact of its programs in its Comprehensive Annual Financial Report, green bonds issuances, and other communications. Further information about AVERT is available at: https://www.epa.gov/statelocalclimate/avoided-emissions-and-generation-tool-avert

Methodology

Previously, the Green Bank and its predecessor, the Connecticut Clean Energy Fund, estimated these impacts by using the results of the 2007 New England Marginal Emission Rate Analysis to calculate the expected annual and lifetime kWh savings of energy and production of clean energy. After working with the Connecticut Department of Energy and Environmental Protection (DEEP) and the US Environmental Protection Agency, the Green Bank has adopted the EPA's Avoided Emissions and Generation Tool (AVERT) to calculate the air quality benefits associated with Green Bank projects.

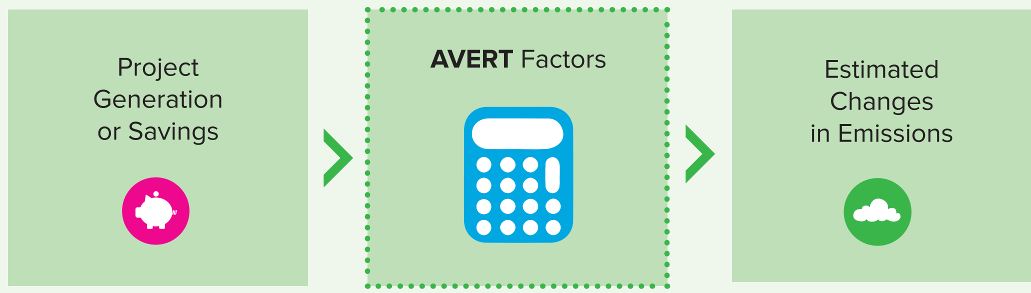
AVERT is a complex model that represents the dynamics of electricity dispatch based on the history of actual generation in a selected year for a specified region. For Green Bank purposes, the model generates the expected annual change to regional electricity generation based on a specific clean energy project or projects, then calculates the decline in emissions based on the reduction in resources required. The graphic below is a simplified representation of the model.

Figure 1: AVERT Flow



To maximize the model's accuracy, the Green Bank has derived average project emissions factors by technology (solar, wind, EE) from its completed projects. It then applies these factors to the annual projected generation for individual projects to calculate the estimates of the expected NO_x, SO_2, and CO_2 savings. The Green Bank will update these factors annually based on changes to the regional generation profile and typical project sizes, as well as any other changes EPA may make to the AVERT Model (type of emissions avoided, location, etc.).

Figure 2: Green Bank AVERT Operationalized Flow



The Green Bank multiplies individual projects' generation and/or savings in kWh by the derived AVERT emissions factors to estimate changes in emissions.

Example of Environmental Equivalencies

The Green Bank uses the EPA's AVERT tool to translate the contributions made by Green Bank projects to the region's air quality. The decreases in CO_2 and NO_x in the example in **Table 2** above can also be demonstrated through common activities or environmental equivalencies as shown in **Table 3** below.

Table 3: Environmental Equivalencies

Capacity:	Equivalencies							
1 MW	Greenhouse gas emissions from:		CO_2 emissions from:				Carbon sequestered by:	
Technology	Miles driven by an average passenger vehicle	Tons of waste recycled instead of landfilled	Gallons of gasoline consumed	Pounds of coal burned	Homes' energy use for one year	Incandescent lamps switched to	Tree seedlings grown for 10 years	Acres of U.S. forests in one year
Solar PV	1,781,112	236	83,624	793,028	79	26,344	19,260	703
Energy Efficiency	1,281,479	170	60,166	570,570	57	18,954	13,857	506
Wind	2,280,746	302	107,082	1,015,487	100	33,734	24,663	901

Further information about the EPA equivalency Calculator is available at:
https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

In the example above, the Connecticut Green Bank would apply the Societal Perspective to report the environmental impact results in its Comprehensive Annual Financial Report in the following manner: "In FY 2015, there was a total deployment of nearly 60 MW of Residential Solar PV in Connecticut. Through the Connecticut Green Bank's support, approximately 41,100 tons of CO_2, 37,300 pounds of NO_x, and 34,100 pounds of SO_2 emissions were saved, which is equivalent to 4,762,817 gallons of gasoline consumed, 1,500,431 incandescent lamps switched to LEDs, or the carbon sequestered by 40,067 acres of U.S. forests in a year in Fiscal Year 2015[1]."

[1] It should be noted that in the example above, the Renewable Energy Credits (RECs) created as a result of the Connecticut Green Bank's Residential Solar Investment Program (RSIP), are to be purchased by the electric distribution companies for the purposes of meeting their Class I Renewable Portfolio Standard (RPS) obligations.

continued >

About the Connecticut Green Bank

The Connecticut Green Bank was established by the Connecticut General Assembly on July 1, 2011 as a part of Public Act 11-80. As the nation's first full-scale green bank, it is leading the clean energy finance movement by leveraging public and private funds to scale-up renewable energy deployment and energy efficiency projects across Connecticut. The Green Bank's success in accelerating private investment in clean energy is helping Connecticut create jobs, increase economic prosperity, promote energy security and address climate change. For more information about the Connecticut Green Bank, please visit www.ctgreenbank.com.

About the Department of Energy and Environmental Protection

The Connecticut Department of Energy and Environmental Protection (DEEP) was established on July 1, 2011 with the consolidation of the Department of Environmental Protection, the Department of Public Utility Control, and energy policy staff from other areas of state government. It is charged with conserving, improving and protecting the natural resources and the environment of the state of Connecticut as well as making cheaper, cleaner and more reliable energy available for the people and businesses of the state. The agency is also committed to playing a positive role in rebuilding Connecticut's economy and creating jobs – and to fostering a sustainable and prosperous economic future for the state. For more information about the Connecticut Department of Energy and Environmental Protection, please visit www.ct.gov/deep.

About the United States Environmental Protection Agency

The mission of the EPA is to protect human health and the environment. For more information about the United States Environmental Protection Agency, please visit www.epa.gov.

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CONNECTICUT GREEN BANK

Memo

To: Audit, Compliance and Governance Committee

From: Eric Shrago, Director of Operations

Date: April 13, 2017

Re: Draft Vendor Management Policy

In consultation with the Green Bank's information technology service provider (ADNET) and the organization's operations control consultant (Marcum), the staff of the Green Bank identified the need to establish standards and processes to govern the selection of vendors. The organization's staff partnered with Marcum to craft the Vendor Management Policy.

This Vendor Management Policy seeks to mitigate the organization's risk with regard to its reliance upon external vendors from various perspectives. The policy seeks to limit risk due to dependency on vendors in maintaining key technology systems that are often developed specifically for Green Bank use. Additionally, the policy seeks to mitigate the risks associated with external parties having access to Green Bank and customer data that is at times private and sensitive.

The Vendor Management Policy establishes requirements and a regular review process for specific vendors that puts the Green Bank in line with best practices amongst similar institutions.

Resolution

RESOLVED, that based on the recommendation of the Audit, Compliance and Governance Committee, the Board of Directors of the Connecticut Green Bank hereby approves the proposed Vendor Management Policy.

Vendor Management Policy

OVERVIEW

The purpose of this policy is to provide guidance relative to the management of vendor relationships. Senior management and the Board of Directors recognize that the development of relationships with vendors is established as a way for the Connecticut Green Bank (the "Green Bank") to offer certain products and services without the need to develop the products and services "in house." Such "outsourced" relationships benefit the Green Bank through reduced costs, improved performance, increased business competitiveness, access to a superior knowledge base and the need for a limited in-house staff to support the Green Bank's business needs.

Senior management recognize that they are ultimately responsible for managing activities conducted by vendors, and identifying and controlling the risks arising from such relationships, to the same extent as if they were handled within the Green Bank. Senior management also recognize that vendor relationships present potential risks that must be properly managed on an ongoing basis, beginning with a sound due diligence process at the outset and continuing with annual or more frequent reviews of all vendor relationships. It is recognized that the extent of risk varies with each vendor relationship. Among the most common vendor-related risks are lack of vendor oversight by the Green Bank which could result in the Green Bank experiencing operational risks, privacy risks and reputation risks.

The Board of Directors holds senior management accountable for the review and evaluation of all new and existing vendor relationships. Management is responsible for ensuring that adequate controls are in place to protect the Green Bank and its customers from the risks associated with vendor relationships.

It is the goal of management to ensure compliance with this policy with respect to every vendor relationship. However, management recognize that certain existing contracts may not comply with all aspects of this policy. It is management's responsibility to continuously seek opportunities to renegotiate changes (e.g., at contract renewal, etc.) to existing vendor contracts to achieve full compliance with this policy.

Management will review this policy at least annually and present it to the Board of Directors for their review and approval.

VENDOR RISKS

There are numerous risks that may arise from the Green Bank's use of vendors. Some of the risks are associated with the underlying activity itself, like the risks faced if the Green Bank conducted the activity. Other potential risks arise from or are heightened by the involvement of a vendor.

Not all of the following risks will be applicable to every vendor relationship; however, complex or significant arrangements may have definable risks in most areas. The following summary of risks is not considered all-inclusive.

Strategic Risk

Strategic risk is the risk arising from adverse business decisions, or the failure to implement appropriate business decisions in a manner that is consistent with the Green Bank's strategic goals. The use of a vendor to perform banking functions or to offer products or services that do not help the Green Bank achieve corporate strategic goals and provide an adequate return on investment exposes the Green Bank to strategic risk.

Reputation Risk

Reputation risk is the risk arising from negative public opinion. Vendor relationships that result in dissatisfied customers, interactions not consistent with Green Bank policies, inappropriate recommendations, security breaches resulting in the disclosure of customer information, and violations of law and regulation are all examples that could harm the reputation and standing of the Green Bank in the community. Also, any negative publicity involving the vendor, whether or not the publicity is related to the Green Bank's use of the vendor, could result in reputation risk.

Operational Risk

Operational risk is the risk of loss resulting from inadequate or failed internal processes, people, and systems or from external events. Vendor relationships often integrate the internal processes of other organizations with the Green Bank's processes and can increase the overall operational complexity.

Transaction Risk

Transaction risk is the risk arising from problems with service or product delivery. A vendor's failure to perform as expected by customers or the Green Bank due to reasons such as inadequate capacity, technological failure, human error, or fraud, exposes the Green Bank to transaction risk. The lack of an effective business resumption plan and appropriate contingency plans increase transaction risk. Weak control over technology used in the vendor arrangement may result in threats to security and the integrity of systems and resources. These issues could result in unauthorized transactions or the inability to transact business as expected.

Credit Risk

Credit risk is the risk that a vendor, or any other creditor necessary to the vendor relationship, is unable to meet the terms of the contractual arrangements with the Green Bank or to otherwise financially perform as agreed. The basic form of credit risk involves the financial condition of the vendor itself. Some contracts provide that the vendor ensures some measure of performance related to obligations arising from the relationship, such as loan origination programs. In these circumstances, the financial condition of the vendor is a factor in assessing credit risk. Credit risk also arises from the use of third parties that market or originate certain types of loans, solicit and refer customers, conduct underwriting analysis, or set up product programs for the Green Bank. Appropriate monitoring of the activity of the vendor is necessary to ensure that credit risk is understood and remains within board approved limits.

Compliance Risk

Compliance risk is the risk arising from violations of laws, rules, or regulations, or from noncompliance with internal policies or procedures or with the Green Bank's business standards. This risk exists when the products or activities of a vendor are not consistent with governing laws, rules, regulations, policies, or ethical standards. Liability could potentially extend to the Green Bank when vendors violate laws, rules, regulations or other required practices. Compliance risk is exacerbated when an institution has inadequate oversight, monitoring or audit functions.

Other Risks

The types of risk introduced by the Green Bank's decision to use a vendor cannot be fully assessed without a complete understanding of the resulting arrangement. Therefore, a comprehensive list of potential risks that could be associated with a vendor relationship is not possible. In addition to the risks described above, vendor relationships may also subject the Green Bank to liquidity, interest rate, price, foreign currency translation, and country risks.

RISK MANAGEMENT PROCESS

The key to the effective use of a vendor in any capacity is for the Green Bank's management to appropriately assess, measure, monitor, and control the risks associated with the relationship. While engaging another entity may assist management and the Board in achieving strategic goals, such an arrangement reduces management's direct control. Therefore, the use of a vendor increases the need for oversight of the process from start to finish. There are four main elements of an effective vendor risk management process: (1) risk assessment, (2) due diligence in selecting a vendor, (3) contract structuring and review, and (4) oversight.

While these four elements apply to any vendor activities, the precise use of this process is dependent upon the nature of the vendor relationship, the scope and magnitude of the activity, and the risks identified. This comprehensive risk management process, which includes management of any vendor relationship, enables management to ensure that capital is sufficient to support the Green Bank's underlying risk exposures and that the vendor is operating in a manner consistent with Federal and state laws, rules, and regulations, including those intended to protect consumers.

RISK ASSESSMENT

Risk assessment is fundamental to the initial decision of whether to enter into a vendor relationship. The first step in the risk assessment process is to ensure that the proposed relationship is consistent with the Green Bank's strategic planning and overall business strategy.

Next, management must analyze the benefits, costs, legal aspects, and the potential risks associated with the vendor under consideration. Expanded analysis is warranted if the product or service is a new activity or product for the Green Bank. Management must develop a thorough understanding of what the proposed relationship will accomplish for the Green Bank, and why the use of a vendor is in the Green Bank's best interests. A risk/reward analysis must be performed for significant matters, comparing the proposed third-party relationship to other methods of performing the activity or product offering, including the use of other vendors or performing the function in-house. For such matters, the analysis must be considered integral to the Green Bank's overall strategic planning, and should thus be performed by senior management and reviewed by the Board or an appropriate committee.

Responsible Green Bank personnel must have the requisite knowledge and skills to adequately perform the analysis. Certain aspects of the risk assessment phase may include the use of internal auditors, compliance officers, technology officers, and legal counsel. This phase must also identify performance criteria, internal controls, reporting needs, and contractual requirements that would be critical to the ongoing assessment and control of specific identified risks.

After completing the general assessment of risks, particularly relative to the Green Bank's overall strategic plan, management should review its ability to provide adequate oversight and management of the proposed vendor relationship on an ongoing basis. While identifying and understanding the risks associated with the vendor are critical at the outset, the long-term management of the relationship is vital to success. For significant third-party relationships, the Board may consider appointing a senior manager (i.e., the Director of Operations) to be responsible for the relationship, including due diligence, implementation, ongoing oversight, and periodic reporting to the

Board. This management official should have the requisite knowledge and skills to critically review all aspects of the relationship. The Board and management should also ensure that the Green Bank's compliance management system is adapted to effectively address the vendor relationship and appropriately respond to emerging issues and compliance deficiencies.

A final part of the initial risk assessment phase for significant relationships involves carefully estimating the long-term financial effect of the proposed vendor relationship. The Board should take into account all aspects of the long-term potential of the relationship, as well as the managerial expertise and other associated costs that would result from the decision to use a vendor, and not be unduly influenced by short-term cost savings. The long-term financial risk resulting from an initial incomplete accounting of costs and/or an overestimation of benefits can undermine appropriate decisions in other phases of the risk management process.

DUE DILIGENCE IN SELECTING A NEW VENDOR

Following an assessment of risks and a decision to proceed with a plan to establish a vendor relationship, management must select a qualified entity to implement the activity or program. The due diligence process provides management with the information needed to address qualitative and quantitative aspects of potential vendors to determine if a relationship would help achieve the Green Bank's strategic and financial goals and mitigate identified risks.

Not only should due diligence be performed prior to selecting a third party, but it should also be performed periodically during the course of the relationship, particularly when considering a renewal of a contract. The scope and depth of due diligence is directly related to the importance and magnitude of the Green Bank's relationship with the vendor.

Comprehensive due diligence involves a review of all available information about a potential vendor, focusing on the entity's financial condition, its specific relevant experience, its knowledge of applicable laws and regulations, its reputation, and the scope and effectiveness of its operations and controls. The evaluation of a third party may include the following items:

Technical and Industry Expertise

Assessment the vendor's experience and ability to provide the necessary services for current and anticipated needs.

- Identification of areas where the Green Bank would have to supplement the vendor's expertise to fully manage risk.
- Evaluation of the vendor's use of third parties that would be used to support the vendor's operations.

- Evaluation of the vendor’s experience in providing services in the anticipated operating environment.
- Evaluation of the vendor’s ability to respond to service disruptions.
- Evaluation of references and user group opinions for determining the vendor’s reputation and performance history.
- Evaluation of the vendor’s knowledge of the regulations that are relevant to the services the vendor is providing.
- Evaluation of key vendor personnel that would be assigned to support the Green Bank.

Operations and Controls

- Determination of the adequacy of a vendor’s standards, policies and procedures relating to internal controls, facilities management (access requirements, sharing of facilities, etc.), security (systems, data, equipment, etc.), privacy protections, maintenance of records, business resumption contingency planning, systems development and maintenance and employee background checks.

- When applicable, the determination of the adequacy of the vendor’s security precautions with respect to the Green Bank’s resources and the detection and response to intrusions.

- Evaluation of the Green Bank’s ability to have complete and timely access to the information maintained by the vendor.

- Performance of on-site visits, when necessary, to better understand how the vendor operates and supports its clients.

Financial condition

- Analysis of the vendor’s most recent audited or unaudited financial statements and annual report as well as other available documents (SEC filings, etc.).

- Consideration of factors such as how long the vendor has been in business and the vendor’s market share for a given service and how much it has fluctuated.

- Consideration of the significance of the Green Bank’s proposed contract on the vendor’s financial condition.

- Evaluation of resource expenditures to ensure that the vendor’s level of investment in its resources is consistent with supporting the Green Bank’s activities. The vendor should have the financial resources to invest in and support the required level of service.

- Existence of any significant complaints or litigation, or regulatory actions against the vendor.

Contract issues

A contract review provides an effective way to identify risk with a current or prospective vendor. Contracts with vendors should adhere to the same general guidelines as other contractual relationships in which the Green Bank is involved. The contract should include clear and concise language regarding the arrangement between the Green Bank and the vendor.

When entering a contract it is management's responsibility to ensure that the following issues are addressed within the vendor contract. However, management recognize that not all vendors will agree to the terms desired by the Green Bank and that under limited circumstances the Green Bank may not be able to address each item noted below. To the extent that all items are not adequately addressed, it is responsibility of the owner of the vendor relationship to inform the Vendor Management Committee, prior to execution of a contract, of any items omitted from the recommended contractual items listed below.

- **Scope of Service:** Contracts should clearly describe the rights and responsibilities of parties involved. Considerations should include:

    - Timeframes and activities for implementation and assignment of responsibilities. Services to be performed by the vendor, including support, maintenance, training and customer service.
    - Obligations of the Green Bank in the relationship.
    - The contracting parties' rights in modifying the existing services performed under the contract.
    - Guidelines for adding new or different services and for contract renegotiation.

- **Performance Standards:** Minimum service level requirements and remedies for failure to meet standards should be included in the contract.

- **Security and Confidentiality:** The contract should address the vendor's responsibility for security and confidentiality of the Green Bank's resources. The agreement should prohibit the vendor and its agents from using or disclosing the Green Bank's information, except as necessary to or consistent with providing the contracted services, to protect against unauthorized use. If the vendor receives nonpublic financial information regarding Green Bank customers, the Green Bank must notify the vendor to fully disclose breaches in security resulting in unauthorized intrusions into the vendor that may materially affect the Green Bank or its customers. The vendor should report any material intrusions, the effect on the Green Bank and the corrective action taken to respond to the intrusion. The owner of the vendor relationship should refer to the Green Bank's Information Security Program for further guidance.

- **Internal Controls:** Consideration should be given to contract provisions addressing control over operations such as:

    - Internal controls to be maintained by the vendor.
    - Compliance with applicable regulatory requirements.
    - Records to be maintained by vendor.
    - Access to the records by the Green Bank.
    - Notification by the vendor to the Green Bank and the Green Bank's approval rights regarding material changes to services, systems, controls, key project personnel allocated to the Green Bank, and new service locations.
    - Setting and monitoring of parameters relating to any financial functions, such as payments processing and any extensions of credit on behalf of the Green Bank.
    - Insurance coverage to be maintained by the vendor.

- **Audit:** The contract should include the types of audit reports the Green Bank is entitled to receive. The contract should specify audit frequency, cost to the Green Bank associated with the audits if any, as well as the rights of the Green Bank and its agencies to obtain the results of the audits in a timely manner. The contract should also specify rights to obtain documentation regarding the resolution of audit disclosed deficiencies and inspect the vendor's facilities and operating practices of the vendor. Management should consider, based on the risk assessment phase, the degree to which independent internal audits completed by the vendor audit staff can be used and the need for external audits and reviews (e.g., SSAE16 Type I and II reviews).

- **Reports:** Contractual terms should discuss the frequency and type of reports the Green Bank will receive. Guidelines and fees for obtaining custom reports should also be discussed.

- **Business Continuity Planning/Disaster Recovery Planning:** The contract should address the vendor's responsibility for backup and record protection, including equipment, program and data files, and the maintenance of disaster recovery and contingency plans. The plans must be tested periodically (at least annually) with results provided to the Green Bank. Interdependencies between vendors must be considered when determining business resumption testing requirements. The vendor should provide the Green Bank with operating procedures for the vendor and the Green Bank in the event business resumption contingency plans are implemented. Contracts should include specific provisions for business recovery timeframes that meet the Green Bank's business requirements. The contract must not contain any provisions that would excuse the vendor from implementing its contingency plans.

- **Sub-Contracting and Multiple Vendor Relationships:** Contracts with vendors should include a provision specifying that the contracting vendor is responsible for the service provided to the Green Bank regardless of which entity is actually conducting the operations and that the Green Bank must approve any changes regarding the status of sub-contractor relationships.

- **Use of Green Bank Resources:** All contracts with vendors must address ownership and allowable use by the vendor of the Green Bank's data, equipment/hardware, system documentation and other intellectual property rights including logo, trademarks, etc. The contract should not contain unnecessary limitations on the return of items owned by the Green Bank.

- **Duration:** The type of service being provided should be considered when negotiating the appropriate length of a vendor contract and its renewal periods. The length of time required for notification of intent not to renew a contract with a vendor should be specified and should be reasonable. Where possible, the "automatic renewable" clause should be removed so that both parties are responsible for the contract's extension.

- **Dispute Resolution:** Where possible and practical, vendor contracts should contain a provision for the resolution of disputes in a timely manner. The contract should also provide for the continuation of services during the dispute resolution period.

- **Indemnification:** Indemnification provisions should be reviewed to reduce the likelihood of potential situations in which the Green Bank may be liable for claims arising as a result of the negligence of the vendor. While the Green Bank seeks to mitigate risk through the use of indemnification, this practice alone does not insulate the Green Bank from its ultimate responsibility to conduct banking and related activities in a safe and sound manner and in compliance with law.

- **Limitation of Liability:** Some vendor standard contracts may contain clauses limiting the amount of liability that can be incurred by the vendor. Such contracts should be examined to ensure that the damage limitation bears an adequate relationship to the amount of loss the Green Bank might reasonably experience as a result of the vendor's failure to perform its obligations.

- **Termination:** The extent and flexibility of termination rights sought can vary depending on the vendor. Termination rights may be sought for a variety of conditions. All contracts with vendors should permit the Green Bank to terminate the contract in a timely manner and without prohibitive expense. Each contract should state termination and notification requirements with time frames to allow the orderly conversion to another vendor. Contracts must provide for timely return of any data and other intellectual and physical property owned by the Green Bank. Any costs associated with transition assistance should be clearly stated.

- **Assignment:** Any contract with a vendor should contain a provision that prohibits the assignment of the contract to a vendor without the consent of the Green Bank. This includes changes to any subcontractors.

OVERSIGHT

The Green Bank must maintain adequate oversight of vendor activities and adequate quality control over those products and services provided through vendor arrangements to minimize exposure to potential significant financial loss, reputation damage, and supervisory action. The Board should initially approve, oversee, and review at least annually significant vendor arrangements, and review these arrangements and written agreements whenever there is a material change to the program. Management must periodically review the vendor's operations in order to verify that they are consistent with the terms of the written agreement and that risks are being controlled. The Green Bank's compliance management system should ensure continuing compliance with applicable federal and state laws, rules, and regulations, as well as internal policies and procedures.

Management must allocate sufficient qualified staff to monitor significant vendor relationships and provide the necessary oversight. Management must consider designating a specific officer to coordinate the oversight activities with respect to significant relationships, and involve their compliance management function and, as necessary, involve other operational areas such as audit and information technology, in the monitoring process. The extent of oversight of a particular third-party relationship will depend upon the potential risks and the scope and magnitude of the arrangement.

An oversight program will generally include monitoring of the vendor's quality of service, risk management practices, financial condition, and applicable controls and reports. Results of oversight activities for material vendor arrangements must be periodically reported to the Green Bank's Board of Directors or designated committee. Identified weaknesses should be documented and promptly addressed.

Performance monitoring should include, as appropriate, the following:

- Evaluate the overall effectiveness of the vendor relationship and the consistency of the relationship with the Green Bank's strategic goals.
- Review any licensing or registrations to ensure the vendor can legally perform its services.
- Evaluate the vendor's financial condition at least annually. Financial review should be as comprehensive as the credit risk analysis performed on the Green Bank's borrowing relationships. Audited financial statements should be required for significant third-party relationships.
- Review the adequacy of the vendor's insurance coverage.
- Ensure that the vendor's financial obligations to others are being met.
- Review audit reports or other reports of the vendor, and follow up on any needed corrective actions.
- Review the adequacy and adherence to the vendor's policies relating to internal controls and security issues.
- Monitor for compliance with applicable laws, rules, and regulations.
- Review the vendor's business resumption contingency planning and testing.

- o Assess the effect of any changes in key vendor personnel involved in the relationship with the Green Bank.
- o Review reports relating to the vendor's performance in the context of contractual requirements and performance standards, with appropriate follow-up as needed.
- o Determine the adequacy of any training provided to employees of the Green Bank and the vendor.
- o Administer any testing programs for vendors with direct interaction with customers.
- o Review customer complaints about the products and services provided by the vendor and the resolution of the complaints.
- o Meet as needed with representatives of the vendor to discuss performance and operational issues.

Proper documentation will facilitate the monitoring and management of the risks associated with vendor relationships. Therefore, the Green Bank must maintain documents and records on all aspects of the vendor relationship, including valid contracts, business plans, risk analyses, due diligence, and oversight activities (including reports to the Board or delegated committees).

DOCUMENTING NEW VENDOR SELECTION

For a new vendor with the who meets the one of the following criteria:

- Vendor and vendor activity could have a material effect on the Green Bank's mission;
- Vendors will perform some form of "critical function;"
- The vendor will store, access, transmit or perform transactions on sensitive customer information;
- Vendor will represent the Green Bank and its products or services directly to potential customers;

the following documentation must be completed and submitted prior to any contract being signed:

- **Vendor Risk Assessment/Risk Rating Form** (see Appendix "A") which may include the following requirements:
    - o Financial Analysis (two years financial statements/tax returns)/Credit Report
    - o Proof of Business (Articles of Incorporation/Association)
    - o Professional References (Business references)
    - o Operational Analysis including SSAE16 and the Green Bank's response to the SSAE16 User Concerns (if applicable)
    - o Disaster Contingency Plans and/or testing results of DR plans (if applicable)
    - o Contract Review for compliance with GLBA
    - o Review of proposed Service Level Agreement
    - o Evaluate the existing risks that exist with this vendor in the areas listed below and indicate whether this risks are increasing/decreasing or stable:
        - Strategic Risk

- Reputation Risk
- Compliance Risk
- Transaction Risk
- Credit Risk
- Privacy / Info Security Risk
- Other Risks

- **Vendor CIP Form** (see Appendix "B")

The completed Vendor Risk Assessment/Rating and Vendor CIP Forms are to be submitted and approved by the IT Steering Committee. Any exception to these requirements must be approved by the Chief Legal Officer.

DUE DILIGENCE OF EXISTING VENDOR

On at least an annual basis, vendors must be re-assessed. The Vendor Assessment/Risk Rating Form must be completed. The Director of Operations or its equivalent will be responsible for compliance. Please refer to Appendix "A."" Included in the risk assessment, the relationship owner is asked to consider the following areas in managing the existing vendor:

1. Evaluate the existing risks that exist with this vendor in the areas listed below and indicate whether this risks are increasing/decreasing or stable:

   - Strategic Risk
   - Reputation Risk
   - Compliance Risk
   - Transaction Risk
   - Credit Risk
   - Privacy / Info Security Risk
   - Other Risk

     - Liquidity
     - Interest Rate
     - Price
     - Foreign Currency Translation
     - Country

- Evaluate the vendor's financial condition periodically.

- Review audit reports (e.g., SSAE16, etc.) as well as regulatory examination reports if available, and evaluate the adequacy of the vendor's systems and controls including resource availability, security, integrity and confidentiality. Follow up on any deficiencies noted in the audits and reviews of the vendor and respond to all issues addressed as "User Concerns."

- Perform on-site inspections in conjunction with some of the reviews performed above, where practicable and necessary.

- Review the vendor's business resumption contingency plans to ensure that any services considered mission critical for the Green Bank could be restored within an acceptable timeframe. Review the vendor's program for contingency plan testing. For mission critical services, the contingency plan must be tested at least annually.

- Periodically review the vendor's performance relative to service level agreements, determine whether other contractual terms and conditions are being met, and whether any revisions to service level expectations or other terms are needed given changes in the Green Bank's needs and technological developments.

- At meetings with vendor, ensure there are proper controls in place for protection of customer documents and information. Insure the vendors understanding of their responsibility to report intrusion or information leaks to the Green Bank on a timely basis.

- Maintain documents and records regarding contract compliance, revision and dispute resolution.

DOCUMENTING EXISTING VENDOR ANNUAL REVIEW

The Vendor Management Program for existing vendors is comprised of four key steps:

1. Identify and classify the Green Bank's vendors into tiers based on potential risk associated with the vendor:

- **Tier 1:** Major Vendors whose process is core to the Green Bank's daily operations (i.e. core data or item processing). These vendors can be potential operational risks for the Green Bank and the Green Bank's customers if they did not operate as expected. Tier 1 vendors include:

    - Vendor and vendor activity has a material effect on the Green Bank's revenues or expenses;
    - Vendors performs some form of "critical function;"
    - The vendor stores, accesses, transmits or performs transactions on sensitive customer information;
    - Vendor markets bank products or services;
    - Vendor poses risks that could significantly affect mission.

    - **Tier 2:** Vendors that maintain direct relationships with Green Bank customers through a referral by the Green Bank. Although these customers would not present an operational risk to the Green Bank if they did not continue since their relationship is directly with the customer, the Green Bank may still subject itself to reputation risk if the vendor ceased operation.

2. On an annual basis, the Green Bank will gather and systematically file all relative due diligence documentation for each vendor based on the tier to which they have been assigned. Although there is a coordinator of the Vendor Management program, the "owner" of the vendor relationship is responsible for gathering and reviewing the data required:

    - **Tier 1:** Major Vendors require the following documentation:

        i. Vendor Risk Assessment/Risk Rating Form (see Risk Assessment below)
        ii. Financial Analysis
        iii. Operational Analysis including SSAE16 and the Green Bank's response to the SSAE16 User Concerns
        iv. Disaster Contingency Plans and/or testing results of DR plans
        v. Contract Review for compliance with GLBA
        vi. Review of Service Level Agreements
        vii. Other information deemed appropriate based on the vendor and the associated level of risk.

    - **Tier 2:** Vendor Vendors require the following documentation:

i. Vendor Risk Assessment/Risk Rating Form
ii. Contract Review for compliance with GLBA
iii. Other information deemed appropriate based on the vendor and the associated level of risk.

2. The Director of Operations is to review all due diligence documentation provided by the owners of the vendors. Director of Operations will insure that all documents are completed by the owners and submitted for review. The IT Steering Committee will consult the Director of Operations to insure that the Green Bank does not continue with any vendors that are considered undue risk or risk that is beyond the Green Bank's tolerance. Alternate plans will be considered if the vendor has breached contractual terms.

3. After review by the the Director of Operations, the Board of Directors or an assigned Board committee will review management's summary findings. The Risk Assessments for the Tier 1 and Tier 2 vendors will all be submitted to the Board (or assigned committee) for review.

Appendix "A"

Vendor Assessment/Risk Rating Form

Vendor Management Policy

VENDOR ASSESSMENT/RISK RATING FORM

I. Project/Product/Service Information

VENDOR	
DATE PREPARED	
PREPARED	

II. Overview

IF THIS IS A NEW PRODUCT, COMPLETE PART A.
FOR AN ANNUAL REVIEW OF VENDOR COMPLETE PART B.

PART A – NEW VENDOR/NEW PRODUCT SUPPLIED BY VENDOR	
1. Briefly describe the purpose of this project.	
2. Describe what need will be addressed by this project, product or service. Include what the competition is doing.	
3. If this is the final vendor selected, please list the other vendors that were considered.	
4. Is this vendor an affiliate of the Green Bank? (refer to Master Affiliate List)	

PART B – EXISTING VENDOR/ANNUAL REVIEW	
1. What are the services currently supplied by the vendor?	
2. How long has the relationship with the vendor been in place?	
3. Is this vendor an affiliate of the Green Bank? (refer to Master Affiliate List)	
4. When does the current contract expire?	

III. Risk Management for Vendor Relationship - Summary

In evaluating risk, the following chart and definitions should be used in rating the risk of each of these categories. Risk levels are determined by a combination of likelihood of occurrence and impact severity.

RISK LEVEL						
Likelihood Of Occurrence	**IMPACT SEVERITY**					
	INSIGNIFICANT	**MINOR**	**SIGNIFICANT**	**DAMAGING**	**SERIOUS**	**CRITICAL**
Negligible	Low	Low	Low	Low	Low	Low
Very Low	Low	Low	Low	Low	Moderate	Moderate
Low	Low	Low	Moderate	Moderate	High	High
Medium	Low	Low	Moderate	High	High	High
High	Low	Moderate	High	High	High	High
Very High	Low	Moderate	High	High	High	High
Extreme	Low	Moderate	High	High	High	High

LIKELIHOOD OF OCCURRENCE	
Likelihood	**Description**
Negligible	Unlikely to occur
Very Low	Likely to occur two/three times every five years
Low	Likely to occur once every year or less
Medium	Likely to occur once every six months or less
High	Likely to occur once per month
Very High	Likely to occur multiple times per month
Extreme	Likely to occur multiple times per day

IMPACT SEVERITY LEVELS	
Impact Severity	**Description**
Insignificant	Almost no impact if the threat is realized and vulnerability is exploited
Minor	Minor effect that will require minimal effort to restore operation
Significant	Some negligible yet tangible harm that will require some expenditure of resources to restore operation
Damaging	Damage to the reputation of the Green Bank, and/or notable loss of confidence by Green Bank stakeholders. Will require expenditure of significant resources to repair.
Serious	Considerable business disruption and/or loss of customer/business partner confidence. May result in the compromise of services or a large amount of customer/Green Bank information.
Critical	Extended outage or permanent closure, causing operations to resume in a hot site environment. May result in complete compromise of services or confidential information.

Using the Risk Rating charts above, please rate the vendor in each of the following categories:

	New and Existing Vendors	Existing Vendors Only
	RATING (Low, Moderate, High, NA)	**DIRECTION OF RISK Increasing/Decreasing/Stable**
STRATEGIC RISK: Arises when the Green Bank does not perform an adequate risk assessment or possess sufficient knowledge about a new product, business line or activity or when an activity does not meet the Green Bank's goals or expected return on investment.		
REPUTATION RISK: Arises when the vendor's service or products don't meet the expectations of the Green Bank's customers or if the vendor or product is subject to public scrutiny or negative publicity.		
COMPLIANCE RISK: Arises when the vendor's operations are not in compliance with law or the Green Bank's internal policies and procedures and when audit and control features are weak or nonexistent.		
TRANSACTION RISK: Arises when the vendor is unable to deliver its product or provide service due to error, fraud or technology failure.		
CREDIT RISK: Vendor's failure to meet the terms of its contract or perform as agreed from a financial perspective.		

PRIVACY RISK: Risk that customer information will be compromised; confidence that vendor has installed controls and will report any intrusions to the Green Bank.		
OTHER RISKS: Vendor relationships may subject the Green Bank to LIQUIDITY, INTEREST RATE, PRICE, FOREIGN CURRENCY TRANSLATION OR COUNTRY RISK when dealing with a foreign-based vendor.		

IV. Risk Management for Vendor Relationship - Narrative

Please make comments in regards to the ratings above. Any risks that are considered "Moderate" or "High" should be explained. Describe the "likelihood of occurrence" and the "impact severity" using the definitions in Section III. Also, any risks that are considered increasing should be explained.

STRATEGIC RISK:	
REPUTATION RISK:	
COMPLIANCE RISK:	
TRANSACTION RISK:	
CREDIT RISK:	
PRIVACY/INFOSEC RISK:	
OTHER RISK:	

V. Vendor Evaluation Checklist

A. FINANCIAL INFORMATION	
AUDITED FINANCIALS	
Were audited financials on this vendor received and reviewed?	
If yes, were there any concerns about the vendor's financial situation?	
If yes, describe issues.	

CREDIT CHECK	
If no audited financials were available, did the Green Bank obtain a credit report?	
If a credit report was obtained, include	

Appendix "B"

Vendor CIP Form

Vendor Management Policy

Banking regulations require financial institutions to know their vendors. As such, Green Bank requires a complete background verification of all of our major vendors. Your cooperation and understanding is very appreciated

Company Information:

<table>
<tr><td>Business Legal Name</td><td>Address:</td><td>Phone & Fax Number:</td></tr>
<tr><td>Business Tax ID:</td><td>Contact Name / Title:</td><td>Phone Number / E-mail Address:</td></tr>
<tr><td>List Company Officers:</td><td>Title:</td><td>Type of Company:

Corporation: _____
Limited Liability Company: _____
Partnership: _____
Sole Proprietorship: _____

State Organized: _________________________</td></tr>
<tr><td>Years in Business?

Website Address:</td><td colspan="2">Are you registered with FinCEN, or are you required to be registered, as a Money Service Business (MSB) for purposes of the Bank Secrecy Act?

YES: ___________ NO __________ If Yes, attach documentation</td></tr>
<tr><td colspan="2">Has the Company, or has any related company, ever been under investigation or subject to any enforcement action by the FBI, SEC, FDIC, or other Federal Agency?

YES: ________ NO _________</td><td>Has the Company or any related company ever filed for protection under the bankruptcy laws?

YES: ___________ NO _________</td></tr>
<tr><td colspan="2">Have any of the officers in the Company ever worked in a company that was fined, penalized or banned from conducting business by a System Network (such as, Pulse, STAR, VISA, MasterCard, etc.)?

YES: ________ NO _________</td><td>Have any of the officers ever worked at a company that was under investigation, fined, penalized or banned from conducting business by a government agency?

YES: ________ NO _________</td></tr>
</table>

Ownership Information (Non-Public Companies):

First Name 1. 2. 3. 4.	**Last Name**	**% of Ownership**
Social Security Number 1. 2. 3. 4.	**Home Street Address**	**City/State/Zip**
Drivers License Number/State Issued 1. 2. 3. 4.	**Date of Birth**	**Home Telephone Number/ E-Mail Address**

Acknowledgement and Agreement:

The undersigned specifically represents to Green Bank, and its agents or assigns, and agrees and acknowledges that: (i) the information provided herein is true and correct as of the date set forth opposite my signature and that any intentional or negligent misrepresentation of the information contained herein may result in civil liability and/or criminal penalties; (ii) Green Bank may continuously rely on this information and I am obligated to amend or supplement the information if any of the material facts that I have represented herein have changed; (iii) I hereby give Green Bank permission to investigate my credit history and that of the Company, and question references, and conduct a civil litigation and criminal background check; and (iv) I have read and understand this acknowledgement and agreement and sign this release voluntarily, without coercion or duress from any individual or party.

For the **COMPANY**:

__________________________ __________________________ ____________________
Print Name / Title Signature Date

For each Owner **INDIVIDUALLY**:

__________________________ __________________________ ____________________
Print Name Signature Date

__________________________ __________________________ ____________________
Print Name Signature Date

__________________________ __________________________ ____________________
Print Name Signature Date

__________________________ __________________________ ____________________
Print Name Signature Date

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CONNECTICUT GREEN BANK

Memo

To: Connecticut Green Bank Board of Directors

From: Eric Shrago, Director of Operations

CC: Bryan Garcia, President and CEO

Date: April 28, 2017

Re: Q3 Progress to Targets

The following memo outlines Connecticut Green Bank (CGB) progress to combined Q1, Q2 and Q3 goals for fiscal year 2017 as of March 31, 2017, the end of the third quarter.

Infrastructure Sector
The Infrastructure sector is below its target so far this year due to slower growth than anticipated in the Residential Solar Investment Program (RSIP), primarily due to low energy prices. Additionally, we have seen cash-strapped installers withdraw their resources from Connecticut.

Further, the RSIP is running below its target because the largest installer in the state appears to be continuing to install systems in Connecticut but is doing so outside of the RSIP by registering systems in Massachusetts as Class I renewable resources to create Renewable Energy Credits (RECs) and then monetize this for the Massachusetts market. When these ~450 projects are considered, we can see solar PV installations are closer to the targeted levels for this fiscal year.

The Anaerobic Digester and Combined Heat and Power programs have 4 approved projects that staff is working with the developers to close.

Table 1. Statutory and Infrastructure Sector Q3 Progress to Targets

	Projects		Gross Investment		Capacity	
Product/Program	**Closed**	**Target**	**Closed**	**Target**	**Closed**	**Target**
Anaerobic Digesters	-	1	-	$18,000,000	-	1.6
CHP	1	-	$3,401,392	-	0.8	-
Residential Solar	3,684	6,000	$101,640,845	$173,165,071	28.5	47.4
Infrastructure Total	**3,685**	**6,001**	**$105,042,237**	**$191,165,071**	**29.3**	**49.0**

Residential Sector
Smart-E is on track to exceed targets for the year in terms of number of loans despite the overall drag on consumer demand for energy upgrades due to continued low fuel prices and more moderate temperatures on average for the past 2 years. However, the Gross Investment is tracking below target due to a lower average loan size in the portfolio, which is a result of more HVAC loans with a lower

ticket price in the portfolio than were projected. Strong performance in the HVAC Channel is due to hard work developing contractors in that space by CGB staff. The Capital for Change (C4C)/HES channel launched on December 1st after nearly a year delay and is now coming on strong with a robust pipeline – in fact C4C is now our top lender in terms of applications. This is a remarkable turnaround from just a few months ago. The following notable developments in this quarter should contribute to continued strong performance in the last fiscal quarter: all of our credit unions are now offering credit-challenged terms; 5 lenders, including our top 4, will consider 15 and 20 year terms; and we'll be reducing our special offer interest rates from 2.99% to 0.99% on May 8th through the end of the year.

The Low-to-Moderate-Income lease program offered through PosiGen is on target to exceed its targets, having essentially achieved the annual target by the end of the 3rd fiscal quarter. Of note, 70% of customers are low-to-moderate income and 99.9% of customers receive direct install measures through the Home Energy Solutions program. Year to date two-thirds of customers have taken advantage of the Energy Savings Agreement (ESA) offering which provides even further energy savings (this is a high percentage of customers going "deeper" relative to the experience in the Home Energy Solutions program, which averages ~30%).

The Multifamily programs expect to finance a smaller number of projects that are significantly larger in size than originally forecast – and due to 2 multi-million dollar deals, the Gross Investment Target for the year has now been exceeded by $6,000,000. One of these large deals was a $10.8 million new construction project in Bridgeport designed to house very low income and homeless families including homeless veterans, whereby a $75,000 Green Bank pre-development loan made in early 2016 financed the project's high performance energy standard design. The conversion of a portion of the pre-development loan into an interest rate buydown was critical to enabling C4C to participate in and aid a very tight and complex capital stack to close. Participants included Citi, the state, the City of Bridgeport, and the nonprofit developer (we were not a lender in the term financing). Alternately, there remain numerous C4C/LIME projects in pipeline development that had been expected to close by the end of the fiscal year but are now on hold indefinitely due to compliance issues with the project developer, who has been suspended from utilizing Green Bank programs until the issues are resolved. In terms of deal size and timing, "lumpiness" continues to define the Multifamily programs' pipeline due to the complexity of affordable housing capital stacks, the technical nature of the energy projects, the interplay with other capital improvements and parties involved, and the high degree of hand holding throughout a project cycle that can last up to 2-3 years. There is a robust pipeline of early stage projects that have not yet materialized into pre-development or term loans, including over 30 pre-development projects (these become loans at phase 3 of a 3-part process), which is starting to be characterized by repeat applications by customers. Benchmarking feeds the top of the pipeline and we currently have 1,098 buildings representing 19,500 units or about ~10% of all multifamily units in CT benchmarked.

Table 2. Residential Sector Q3 Progress to Targets

	Projects		Gross Investment		Capacity	
Product/Program	**Closed**	**Target**	**Closed**	**Target**	**Closed**	**Target**
Smart-E	200	254	$4,371,013	$5,873,447	0.7	1.1
Low Income Loans/Leases (PosiGen)	497	500	$14,004,180	$15,250,000	3.1	3.4
Multi-Family (Term Only)	10[1]	17	$18,075,109	$11,140,000	0.9	0.9
Resi Total	**707**	**771**	**$36,450,302**	**$32,263,447**	**4.8**	**5.4**

[1] Closed projects support 918 units of affordable rental housing.

Multi-Family (Pre-Dev)	3	-	$98,325	-	-	-

Table 3. Smart-E Channel Breakout

	Projects	
Channel	Closed	Target
Smart-E	200	254
CHIF/HES	17	20
EE/HVAC	102	126
Solar	72	108
Blank	9	-

Commercial, Industrial, & Institutional Sector

The Commercial, Industrial, & Institutional Sector is below its target for the year. Similar to other sectors, low energy prices and moderate temperatures have reduced demand for energy efficiency and renewable energy. The C-PACE channel that is furthest behind in its target is manufacturing projects through the Energy on the Line program. The original assumption was that the grant offered through this program would expedite the typically long C-PACE sales process, leading to closing in FY17. However, the grant has caused CGB to get involved earlier in the decision-making process, leading to longer sales times. Staff views this positively as it means projects are happening because of the program that wouldn't have happened otherwise. They will just close later than anticipated.

The Commercial Lease is behind targets mostly due to a set of idiosyncratic delays associated with documentation execution across a number of projects. As those outstanding issues are resolved, staff expects the program to approach or meet its targets by the end of Q4.

Table 4. Commercial and Industrial Q3 Progress to Targets

	Projects		Gross Investment		Capacity	
Product/Program	Closed	Target	Closed	Target	Closed	Target
CPACE	27	56	$9,861,020	$27,930,1000	1.9	7.3
Commercial Lease	10	28	$3,070,999	$21,000,000	0.9	7.0
Comprehensive Energy Strategy	1	-	$4,538,212	-	0.2	-
CEBS	1	-	$1,648,000	-	-	-
C&I Total	**36**	**74**	**$17,924,530**	**$41,430,000**	**2.8**	**11.8**

CGB Total

Table 5. CGB Q3 Progress to Targets

	Projects		Gross Investment		Capacity Installed (MW)	
Product/Program	Closed	Target	Closed	Target	Closed	Target
Commercial, Industrial and Institutional	**36**	**74**	**$17,924,530**	**$41,430,000**	**2.8**	**11.8**
Residential	**707**	**771**	**$36,450,302**	**$32,263,447**	**4.8**	**5.4**
Infrastructure	**3,685**	**6,001**	**$105,042,237**	**$191,165,071**	**29.3**	**49.0**

Total CGB*	**3,842**	**6,238**	**$142,389,009**	**$245,821,878**	**-**	**61.7**

* excludes duplicates for RSIP records using residential financing product, residential low income (Posigen) records from RSIP and commercial solar lease records using CPACE and multi-family commercial leases.

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CONNECTICUT GREEN BANK

Memo

To: Audit, Compliance and Governance Committee

From: George Bellas, VP Finance and Administration

Date: April 12, 2017

Re: Draft CT Solar Lease 2 LLC audited financial statements for the year ending December 31, 2016

CT Solar Lease 2 LLC engaged Marcum LLP to issue an audit report on its financial statements for the year ending December 31, 2016.

The audit is substantially complete. No material adjustment to the balance sheet, income statement or statement of cash flows is anticipated other than the allocation of the unrealized $314,162 gain on the interest rate swap, between other income and other comprehensive income on the face of the income statement to reflect the effective and ineffective components of the gain.

The notes to the financial statements are also substantially complete. The schedule in Note 4 which discloses future rental payments to be received by the company under operating leases with its customers remains to be completed.

Marcum has not reported to us any instances of material weaknesses or deficiencies in the internal accounting control system of CT SL2 discovered during their audit engagement.

I am requesting that the Audit, Compliance and Governance Committee approve the following resolution requesting that the Board of Directors approve the issuance of the audited financial statements as presented barring any subsequent material adjustments to such presentation:

Resolution #2

WHEREAS, Article V, Section 5.3.1(ii) of the Connecticut Green Bank ("Green Bank") Operating Procedures requires the Audit, Compliance, and the Governance Committee (the "Committee") to meet with the auditors to review the annual audit and formulation of an appropriate report and recommendations to the Board of Directors of the Green Bank (the "Board") with respect to the approval of the audit report;

NOW, therefore be it:

RESOLVED, that the Committee hereby recommends to the Board, and the Board approves the proposed draft CT Solar Lease 2 LLC audited financial statements the year ended December 31, 2016 contingent upon no further adjustments to the financial statements or additional required disclosures which would materially change the financial position of CT Solar Lease 2 LLC as presented.

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CONNECTICUT GREEN BANK

Memo

To: Audit, Compliance and Governance Committee

From: George Bellas, VP Finance and Administration

Date: April 12, 2017

Re: Auditors of Public Accounts – Audit Findings

The State Auditors of Public Accounts (the "APA") concluded their operational audit of the Green Bank for fiscal years 2014 and 2015 in March. The APA presented Bryan Garcia and I with their audit findings and requested a response for each. The three minor audit findings addressed the following areas:

1. Board approval of financing agreements
2. Professional Service Agreements with strategic partners
3. Untimely submission of statutory reports

I have included these findings along with our detailed responses in your Committee materials. We have discussed and acknowledged these findings with the APA, and have or are taking steps to correct these deficiencies. We will discuss each of these findings in further detail at the meeting.

The APA has not formally issued their report as of the date of this memo.

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CONNECTICUT
GREEN BANK

Memo

To: Connecticut Green Bank Board of Directors

From: Mike Yu, Assistant Director, Clean Energy Finance

CC: Bryan Garcia, President and CEO; Bert Hunter, EVP and CIO; Brian Farnen, General Counsel and CLO; Dale Hedman, Managing Director of Statutory & Infrastructure Programs; Ben Healey, Director of Clean Energy Finance

Date: April 21, 2017

Re: Purchase of Performance Based Incentive ("PBI") Obligations

---

In Q1 2017, the Board of Directors of the Connecticut Green Bank ("Green Bank") held a strategic retreat to discuss, amongst other things, opportunities whereby the Green Bank could deploy its resources to strengthen its balance sheet. One such opportunity was to "buy-out" some of the obligations of the performance based incentive program ("PBI") administered by the Green Bank under the Residential Solar Investment Program ("RSIP"). Following the strategic retreat, staff conducted calls with key third-party system owners ("TPOs") to gauge interest in a potential buy-out. At the March 28, 2017 Deployment Committee meeting, staff provided an update on a plan to buy-out the PBIs. Please see the memo attached as Appendix A for additional background on the PBIs and the RSIP. Since the Deployment Committee meeting, staff has continued discussions with TPOs and has formulated a buy-out framework to present to the Board of Directors.

Capital Allocation

After internal discussions, staff recommends allocating up to $5,000,000 for a PBI buy-out through June 30th, 2017. This figure represents approximately 25% of the total outstanding PBI obligations from systems activated before December 31st, 2015. Given that a $5,000,000 allocation of funds is less than the aggregate PBI payments, TPOs may need to select a subset of eligible systems to be bought out. The final composition of systems to be bought-out will be back-tested to ensure that they are performing to reasonable expectations. Should the buy-out be successful and there is continued interest by TPOs after June 30th, 2017, staff may recommend the allocation of additional funds for another round of buy-outs.

Top 5 Third Party Owners	PBI Systems	Estimated Total PBI	Estimated Remaining PBI	Percentage of Total Remaining PBI
SolarCity	3,073	$18,383,433	$13,016,541	64.3%
NRG Residental Solar Solutions LLC	629	$3,578,050	$2,704,483	13.4%
Sunrun Inc	443	$2,700,221	$1,952,990	9.6%
Sunnova	408	$1,630,111	$1,310,569	6.5%
Kilowatt Financial Inc	85	$721,079	$510,966	2.5%
Other	162	$1,273,865	$747,406	3.7%
Grand Total (all TPOs)	**4,800**	**$28,286,760**	**$20,242,955**	**100.0%**

Auction Format

Staff believes that a **Sealed-bid Blind Auction** will maximize the beneficial impact of a buy-out. In this type of auction, all bidders will submit sealed bids by a specified cutoff date (e.g., May 31st, 2017), so that no bidder knows the bid of any other participant. Each TPO's bid, in this instance, will be the rate at which the PBI payments for a specified portfolio of solar systems are discounted for a present value calculation ("Discount Rate"). All other variables, including expected generation methodology[1], buy-out date, etc., will be fixed. The TPO that bids the highest Discount Rate will be prioritized in terms of PBI buy-out and will be allocated the maximum amount possible. If there are funds remaining after such allocation, those funds will go to the TPO bidding the second highest Discount Rate. This waterfall will continue until buy-out funds are exhausted. Sealed-bid Blind Auctions are often used for the tendering of government contracts, mineral rights, artwork, and real estate.

Illustrative Auction - $5,000,000 Allocation

	PBI Amount (present value)	Bid	Ending Rate Sealed	Nominal PBI
Participant 1	$ 500,000	7%	7%	$ 609,314
Participant 2	$ 1,500,000	6%	6%	$ 1,779,435
Participant 3	$ 3,000,000	5%	5%	$ 3,462,930
Participant 4	$ 1,000,000	3%	Did not win	$ 5,851,679
Savings (sealed rat	$ 851,679			

Staff believes that a Sealed-bid Auction will maximize the blended Discount Rate and is appropriate given that TPOs may have different uses of proceeds (and hence a different willingness to pay). Staff does not intend to set a reserve/minimum Discount Rate, but recommends that the Green Bank reserve the right not to proceed with a bid in the event staff deems the Discount Rate too low. As PBI payments are based upon actual per kwh generation of a given system, the Green Bank, in settling the PBI payments today could be doing so at a rate that potentially over-compensates the TPOs should their systems underperform relative to the estimates that are the basis for the early termination payments. As such, the Discount Rate needs to be high enough to mitigate the risk of underperformance. For example, if all the bidders bid below 3%, staff would likely deem the buy-out not advantageous enough to proceed given the performance risk transference to the Green Bank as well as administrative and execution costs.

[1] The Deployment Committee memo discuss using P50 projections, however the Green Bank's uses PowerClerk, which utilizes a different methodology (TMY3). Given the cost associated with calculating P50 projections, staff recommends using internally calculated projections based upon available PowerClerk data

Before the start of the auction, the Green Bank may, in its discretion, make available to participants the Green Bank's good faith judgment of the range of likely clearing Discount Rates for the auction based on market and other information. This is typically referred to as "Price Talk" in securities auctions. Price Talk is not a guarantee, and participants are free to use it or ignore it.

Preliminary Timeline:

- May 5th: Communicate to TPOs the Green Bank's intent to conduct a sealed auction and the rules associated with the auction.
- May 5th – 19th: Answer TPO questions and agree upon nominal PBI cash flows for their proposed buy-out portfolio
- May 31st: Bid submission deadline
- June 5th: Notify winners and the amount of funding eligible to buy-out their obligations
- June 5th – June 28th: Documentation
- Prior to June 30th: Execute buy-out

Proposal

Staff proposes that the Board authorize the allocation and use of up to $5,000,000 of unrestricted Green Bank funds to buy-out PBI obligations. This amount represents approximately 25% of the total estimated outstanding PBI obligations[2], and staff believes its scarcity may result in higher bids in a competitive auction process. The $5,000,000 may not be fully utilized; if bids from TPOs are insufficient to make the buy-out worthwhile, staff will elect to deploy a smaller amount of capital to purchase PBI obligations (e.g., only those bids higher than a TBD minimum rate).

Staff also requests authorization to conduct a Sealed-bid Blind Auction in which the primary variable is the Discount Rate used to calculate the present value of the PBI cash flows associated with the eligible systems (or subset of eligible systems). The Green Bank will reserve the right not to proceed with any or all of the participants if it is deemed that the proposed buy-out discounts are insufficient to cover the administrative and transaction costs as well as the additional performance risk being assumed by the Green Bank. Staff will confirm any action between the Green Bank and TPOs with the Deployment Committee prior to committing the Green Bank.

[2] As of 1/1/2017 for systems generating by 12/31/2015

RESOLUTIONS

WHEREAS, the Green Bank designed and implemented a Residential Solar Photovoltaic Investment Program ("RSIP") in order to achieve a minimum of three hundred (300) megawatts of new residential PV installation in Connecticut before December 31, 2022;

WHEREAS, pursuant to Section 106 of the Act, the Green Bank offers direct financial incentives, in the form of performance-based incentives ("PBI") or expected performance-based buydowns ("EPBB"), for the purchase or lease of qualifying residential solar photovoltaic systems.; and

WHEREAS, the Green Bank seeks to opportunistically reduce some of its obligations under the PBI program by purchasing the obligations at a discount.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors ("Board") authorizes the allocation and use of up to $5,000,000 of unrestricted Green Bank funds to buy-out PBI obligations consistent with this memorandum dated April 21, 2017; and

RESOLVED, that the Board further authorizes Green Bank staff to conduct an auction whereby the Green Bank solicits bids from third-party owners to maximize the discount at which PBI obligations may be bought-out; and

RESOLVED, that subject to confirmation with the Deployment Committee, the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned auction.

Submitted by: Bryan Garcia, President and CEO; Bert Hunter, EVP and CIO; Dale Hedman, Managing Director, Statutory & Infrastructure Programs, Ben Healey, Director, Clean Energy Finance; and Michael Yu, Assistant Director, Clean Energy Finance

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CONNECTICUT GREEN BANK

Memo

To: Deployment Committee and Board of Directors of the Connecticut Green Bank

From: Bryan Garcia, Dale Hedman and Kerry O'Neill

Date: March 21, 2017 (Deployment Committee) and revised April 28, 2017 (Board of Directors)

Re: Residential Solar Investment Program – Steps 11 through 13 Recommendations

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Background

On March 2, 2012, the Connecticut Green Bank launched the Residential Solar Investment Program ("RSIP"). Per Section 106 of Public Act 11-80 (as amended and now codified at Connecticut General Statute Sec. 16-245ff), the RSIP requires that a minimum of 300 MW of new residential solar PV be installed in Connecticut on or before December 31, 2022, at a reasonable payback to the customer all the while developing a sustainable market for contractors. The RSIP provides to residential customers, via solar PV contractors, direct financial incentives in the form of a one-time expected performance-based buy-down ("EPBB") or a 6-year performance-based incentive ("PBI") for the purchase and/or lease of qualifying PV systems respectively. The success of the RSIP over its first three years resulted in an improvement to the policy in the 2015 legislative session – with subsequent technical fixes in the 2016 legislative session. As a result of the leadership of Governor Malloy, Public Act 15-194 "An Act Concerning the Encouragement of Local Economic Development and Access to Residential Renewable Energy" was passed with bipartisan support.

Deployment Progress for Incentives

To date, through the RSIP, we have approved and completed 161 megawatts of projects – approximately 54 percent of the public policy target – while reducing the level of subsidies by over 80 percent since 2012 through ten steps – see Table 1. About 28 percent (or 47 MW) of the installations are homeownership through the EPBB.

Table 1. Installed Capacity by Step for Approved, In Progress, and Completed Projects (as of March 31, 2017)

RSIP Incentive Step	**Approved** (kW)	**Completed** (kW)	**Total** (kW)	**Average Incentive** ($/W$_{STC}$)
1	0	1,381	1,381	$1.789
2	0	5,992	5,992	$1.629
3	34	13,130	13,164	$1.229
4	224	19,191	19,415	$1.033
5	324	13,189	13,513	$0.745
6	667	11,650	12,316	$0.513

7	779	18,483	19,261	$0.400
8	2,573	26,019	28,592	$0.356
9	7,116	21,877	28,994	$0.330
10	12,778	5,820	18,598	$0.324
Total	**24,494**	**136,731**	**161,225**	**$0.610**

About 54 MW of solar PV deployment were the results of Steps 1 through 5, while over 107 MW of solar PV deployment are the results of Steps 6 through Step 10 (current).[1] We have successfully petitioned PURA to approve the 54 MW of projects from Steps 1 through 5 enabling the Connecticut Green Bank to sell RECs on the spot and future market. PURA has recently approved the 15-year master purchase agreement for the Solar Home Renewable Energy Credits (SHRECS) – a contract between the utilities and the Connecticut Green Bank. The investment of over $670 million in residential solar PV in Connecticut through the RSIP to date has created 9,684 job-years (i.e., 3,756 direct, and 5,928 indirect and induced) and will reduce nearly 2.0 $MMTCO_2$ emissions over the 25-year life of the projects.

Deployment Progress by Area Median Income

Of the over 21,000 projects approved under the RSIP, in recent years, the Connecticut Green Bank has made progress with respect to installed capacity of residential solar PV by income – see Table 2 for a breakdown of census tracts by Area Median Income (AMI).

Table 2. Statewide Residential Solar PV Deployment by Income Level and Census Tract (as of February 28, 2017)

Income Level (AMI)	**# of Census Tracts**	**Total Households**	**# of Projects**	**Projects per 1,000 Households**	**Installed Capacity** (kW_{STC})	**Installed Capacity per Household** (W/Household)
<60%	171	240,062	1,572	6.5	9,694	40.4
60-80%	109	193,791	2,323	12.0	15,846	81.8
80-100%	153	269,711	4,011	14.9	29,456	109.2
100-120%	140	237,488	4,877	20.5	37,408	157.5
>120%	251	411,504	8,575	20.8	70,341	170.9
Total	**824**	**1,352,556**	**21,358**	**15.8**	**162,745**	**120.5**

Based on a study conducted by the University of Connecticut in December of 2014[2], the Green Bank identified a need to dramatically increase solar PV deployment in low-to-moderate income ("LMI") households (i.e., less than 100 percent of area median income[3]). Although not yet at parity with the non-low income market segment, we have made progress since we began tracking this metric in 2014: penetration of projects in <60% AMI census tracts is 6.5 per 1,000 households and would need to increase by 3.2 times to reach parity of >100% AMI tracts, versus a required increase of 10 times in 2014. Likewise, for 60-80% AMI tracts a 1.7x increase is needed to reach parity of >100% AMI tracts versus a 3x increase in 2014 and for 80-100% AMI tracts a 1.4x increase is needed versus a 2x increase in 2014.

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[1] Section 106 of PA 11-80 applies to Steps 1 through 5, while PA 15-194 applies to Steps 6 through 10 and beyond – or projects approved after January 1, 2015.

[2] Available here: http://www.ctcleanenergy.com/Portals/0/board-materials/7cii_Role%20of%20a%20Green%20Bank_Market%20Analysis_Low%20Income%20Solar%20and%20Housing_Memo_121214.pdf.

[3] The Green Bank defines low income as < 80% of Area Median Income and moderate income as 80-100% of Area Median Income.

Deployment Progress in Comparison to Regional States

The RSIP performance in Connecticut, in comparison to Massachusetts, New Jersey, and New York, demonstrates many favorable signs – see Table 3.[4]

Table 3. Comparison of Residential Solar PV Markets - CT, MA, NJ, and NY

Residential Solar PV Market Comparison, Q1 2017	CT	MA	NJ	NY
Electric Retail Rate ($/kWh) - EIA	$0.193	$0.196	$0.158	$0.173
Installed Cost of Homeowner Owned System ($/W)	$3.70	$4.00	$3.67	$3.98
State Incentives ($/W)	$0.40	$2.59	$2.10	$1.06
Federal ITC (30%)	$0.99	$0.42	$0.47	$0.88
Net Cost to Consumer after all Incentives	$2.31	$0.99	$1.10	$2.05
LCOE to Customer after all Incentives[5]	$0.125	$0.096	$0.088	$0.117
Net Cost to Consumer as % of Installed Cost	62%	25%	30%	51%
Installed Capacity in CY 2016 (MW)	59	165	165	206
Installed Capacity in CY 2016 per capita	16	24	18	10
Installed Capacity per State Incentives Invested (W/$)	3.0	0.4	0.5	0.9
Energy Efficiency (EE) Requirement	energy audit required for all projects	energy audit required if using Mass Solar Loan	none	none
% Third Party Owned (CY 2016)	81%	72%	85%	59%
Installed Cost of TPO System ($/W)	$3.49	$3.46	$3.65	$4.34
Net Metering Policy	yes	yes	yes	yes*

The favorable signs for Connecticut in comparison to the region, include:

- Lower overall state incentives, resulting in higher federal incentives;
- Comparable installed capacity per capita;
- Demonstrable leading installed capacity per state incentives invested – between 3 to 7 times lower state incentives;
- Lower end of installed cost range and competitive financing products will help market achieve sustained orderly development over the long-term as state and federal incentives are phased out; and
- Inclusion of energy efficiency audit requirement, supporting deployment of both solar PV and energy efficiency measures, furthering the goals of the CT Green Bank, the

[4] Installed costs calculated and estimated based on data from state program websites
MA and NJ have SRECs (10 and 15 year, respectively) while CT and NY have traditional state program incentives
MA has personal income tax credit, the lesser of 15% of system cost or $1,000
NY has property tax credit of 25% of system cost, capped at $5,000, which can be carried over for up to five years
* New York is beginning a multi-year transition process from retail rate net metering to a value of solar type of tariff, as of 3/9/2017.
Installed capacity from U.S. Solar Market Insight 2016 Year in Review by GTM/SEIA (CT numbers adjusted based on program data)

[5] Includes financing costs at 6.49% for 15-year loan

utility-administered energy efficiency programs, and the state's climate change and economic development goals

Estimate of RSIP Incentive vs. Actual for Steps 8 through 10
With respect to the estimated RSIP incentive at an equivalent 15-year price that we had estimated for Steps 8 through 10,[6] we were near the expected case scenarios – see Table 4.

Table 4. Estimated Case vs. Actual for RSIP Incentive at Equivalent 15-Year Price ($/REC)

RSIP Step	Best Case	Expected Case	Worst Case	Actual
Step 8	$22.30	$25.03	$33.03	$24.02[7]
Step 9	$18.90	$22.08	$31.51	$22.14[8]
Step 10	$16.10	$19.63	$30.09	$22.19[9]

Based on these tentative results, the Connecticut Green Bank staff believes that the RSIP incentive at an equivalent 15-year price from Steps 8 through 10 will be on average about $23, which in comparison to the spot market REC price for CT Class I resources for 2017 RECs of $25 and the ZREC price for commercial projects (i.e., between $60-$100), demonstrates that the Connecticut Green Bank is successfully transitioning the residential solar PV market reliance away from the RSIP incentive. In fact, the Connecticut Green Bank has learned that residential solar PV projects being developed in Connecticut outside of the RSIP, are now selling REC's into Massachusetts – exactly an impact the Connecticut Green Bank seeks to have occurred through the RSIP – local economic development, reducing household energy burden, while reducing the Class I RPS cost impact on CT ratepayers.

RSIP Proposed Schedule of Incentives for Steps 11 through 13
The staff proposes the following incentive for Steps 11 through 13 of the RSIP:

- **Race to the Solar Rooftop** – The total capacity target for Step 11 is 20.0 MW, Step 12 is 20.0 MW, and Step 13 is 20.0 MW. The FY 2017 Comprehensive Plan identifies a target of 49 MW through the RSIP.

- **Launch Date** – Step 11 will begin at the conclusion of Step 10.

- **Incentive Level** – we are proposing additional incentive levels by steps, including continuation of the LMI PBI (i.e., below 100% AMI), as well as a new pilot in collaboration with the utility administrators of the Conservation and Load Management Fund – see incentive descriptions below.

[6] For estimates, see "Residential Solar Investment Program – Steps 8 through 10 Recommendations" memo of July 10, 2015 – click here (p. 5)
[7] For Step 8, EPBB was 17%, PBI was 83%, and LMI PBI was 0%
[8] For Step 9, EPBB was 19%, PBI was 77%, and LMI PBI was 4%
[9] For Step 10, EPBB was 28%, PBI was 63%, and LMI PBI was 9% - this is 16 of 30 MW within Step 10

Non-LMI RSIP Incentives
In order to continue to differentiate the incentive levels for the EPBB and PBI (see Table 5) given the legislative guidance of comparable economic incentives as well as national best practice incentive levels,[10] we are proposing the following incentive levels:

- **EPBB** – for Step 11, the EPBB will be $487/kW. For Steps 12 and 13 the EPBB will decline by about 5% to $463/kW.

- **PBI** – for Step 11, the PBI will be $39/REC. For Steps 12 and 13 the PBI will decline by about 10% to $35/REC.

Table 5. Schedule of Incentives for Steps 11 through 13 for NON-LMI HOUSEHOLDS

RSIP Incentive Step	EPBB ($/W)			PBI ($/kWh)	
	≤5 kW	5 to 10 kW	>10kW	≤10 kW	>10 kW
1	$2.450	$1.250	$0.000	$0.300	$0.000
2	$2.275	$1.075	$0.000	$0.300	$0.000
3	$1.750	$0.550	$0.000	$0.225	$0.000
4	$1.250	$0.750	$0.000	$0.180	$0.000
5	$0.800		$0.400	$0.125	$0.060
6	$0.675		$0.400	$0.080	$0.060
7	$0.540		$0.400	$0.064	$0.060
8	$0.540		$0.400	$0.054	
9	$0.513		$0.400	$0.046	
10	$0.487		$0.400	$0.039	
11	$0.487		$0.400	$0.039	
12	$0.463		$0.400	$0.035	
13	$0.463		$0.400	$0.035	

The incentive level for the EPBB is roughly $0.01/kWh more than the PBI over a 15-year period – per the statute, making the incentive levels more economically comparable.

LMI RSIP Incentives
Given the continuing priority of expanding solar PV in Connecticut into the low to moderate income market segments (i.e., Solar for All), and to attempt to ensure that the 300 MW policy target provides an opportunity to reach all household income levels in the state, we are proposing the following schedule of incentives for the LMI-PBI to continue the progress we are making (see Table 6).

Table 6. Schedule of Incentives for Steps 11 through 13 for LMI Households

RSIP Incentive Step	LMI-PBI ($/kWh)	
	≤10 kW	>10 kW
8	$0.110	$0.055
9	$0.110	$0.055

[10] "A Survey of State and Local PV Program Response to Financial Innovation and Disparate Federal Tax Treatment in the Residential PV Sector" by Mark Bolinger and Edward Holt in LBNL-181290 (June 2015).

10	$0.110	$0.055
11	$0.110	$0.055
12	$0.100	$0.050
13	$0.090	$0.045

The LMI-PBI pilot incentive has been a success. We propose continuing the LMI-PBI incentive into Step 11, and then dropping by 10 percent in Steps 12 and 13. The LMI-PBI incentive levels are two to three times more than the non-LMI market incentives.

<u>Grid Modernization and Climate Change Pilot RSIP Incentives– In Partnership with the Utilities</u>

The residential solar PV market in Connecticut is nearly 4 GW, or 660,000 households.[11] The successful implementation of the 300 MW RSIP policy will deliver nearly 10 percent of the economic potential for solar PV in Connecticut. The long-term success of the residential solar PV market in Connecticut depends on the regulatory certainty of the state's net metering policy or equivalent (e.g., value of solar, "cost effective" distributed energy resources, etc.) and, also upon progress being made in the following areas:

1. Fostering the sustained orderly development of a state-based industry;
2. Successfully collaborating with the electric distribution companies administering the Conservation and Load Management Fund; and
3. Integrating "cost-effective" solar PV as a zero-emission stable fuel source for transportation, home heating and cooling, and distributed energy resources (e.g., battery storage).

The role of the Connecticut Green Bank in being a market catalyst is helping ensure the residential solar PV achieves its economic potential in Connecticut over the long-term.

Net Metering

In an effort to prepare for the policy uncertainty surrounding net metering, the RSIP grid mod pilot we are proposing (i.e., requiring smart inverters and better access to PV system data) will enable the future residential solar PV market to transition from households receiving retail credit for solar energy produced from their systems (i.e., through net metering policy) to an adjusted rate based on the true value their systems create for the transmission and distribution infrastructure. Given the value of net metering for households that invest in residential solar PV systems, achieving sustained orderly development of the industry requires assisting the market through the uncertainty of the net metering policy. Additionally, smart inverters and greater access to system data will better demonstrate the true value solar PV provides to the grid and will be useful in the policy discussion regarding net metering.

Sustained Orderly Development

The RSIP policy requires that the Connecticut Green Bank "provide incentives that decline over time and will foster the sustained, orderly development of a state-based solar industry". Sustained orderly development is a concept proposed in 1992[12] that describes a condition in which a growing and stable market is identified by orders that are replaced on a reliable schedule. The orders increase as previous deliveries and engineering and field experience

[11] FY 2017 and FY 2018 Comprehensive Plan of the Connecticut Green Bank (p. 41)

[12] *Sustained Orderly Development of the Solar Electric Technologies* by Donald W. Aitkin in Solar Today (May/June 1992)

lead to further reductions in costs. In addition, the reliability of these orders can be projected many years into the future, on the basis of long-term contracts, to minimize market risks and investor exposure.

Collaboration with the Utilities
The FY 2017 and FY 2018 Comprehensive Plan of the Connecticut Green Bank acknowledges the importance of working collaboratively with the utility administrators of the Conservation and Load Management Fund.[13] Whether it is the Home Energy Solutions (HES) program, or supporting more efficient space and water heating in our homes, driving comprehensive and deeper savings by reinforcing the connection between solar PV and energy efficiency presents a unique collaboration opportunity for the Connecticut Green Bank to work with the utility administrators of the Conservation and Load Management Fund. The goals of the Joint Committee would be supported through improved linkages between our programs.[14]

Transportation, Home Heating and Cooling, and Distributed Energy Resources
Through the Global Warming Solutions Act of 2008, the State of Connecticut has a goal of reducing greenhouse gas emissions by 80 percent from 2001 levels by 2050. The largest emitting sectors in Connecticut are the burning of fossil fuels for transportation and the thermal needs of our buildings (i.e., water and space heating and cooling).[15] The FY 2017 and FY 2018 Comprehensive Plan of the Connecticut Green Bank, and the strategic retreat held by the Board of Directors in January of 2017 acknowledged the importance of transportation, heating and cooling and distributed energy resources[16] and the important role that solar PV has in providing "cost-effective" access to distributed energy resources. By combining zero-emission solar PV as a fuel source for transportation, as well as the thermal needs of our homes, we can provide consumers with a "cleaner, cheaper, and more reliable source of energy".

The staff of the Connecticut Green Bank is proposing a Grid Modernization and Climate Change Pilot that would require the following, in order for households to receive solar PV incentives through the RSIP pilot:

1. **Home Energy Solutions** – a household undertakes HES first, before a solar PV system is designed or installed. Households will be provided incentives to pursue "deeper" energy efficiency measures based on the HES assessment through interest rate buydowns and the Smart-E Loan. They will also be provided a DOE Home Energy Score as a result of undertaking HES. This score is anticipated to be incorporated into real estate multiple listing services which will increase the value of energy efficiency in real estate transactions.
2. **Smart Inverters** – following energy efficiency, households then install solar PV systems that include smart inverters to enable households, utilities, and third-party owners to share information about the value of distributed energy resources, in preparation for changes in net metering policy having adverse economic impacts on future households installing solar PV.
3. **Data Release and System Access** – households will be required to sign a data release form for access to the production of solar PV and consumption of energy

[13] Ibid (p. 11, 38-39, 50-51)
[14] FY 2017 and FY 2018 Comprehensive Plan of the Connecticut Green Bank (p. 51)
[15] Connecticut Greenhouse Gas Emissions Inventory 2012
[16] FY 2017 and FY 2018 Comprehensive Plan of the Connecticut Green Bank (p. 6, 17, 38-40, and 75-80)

data from their homes for research purposes to better understand the value of distributed energy resources. Included on this form will be the allowance for the utility, when ready, to communicate to the solar PV system, if battery storage included, to access energy when the grid needs it so that households can share the benefits of storage with the utilities.

The pilot proposes the following incentive levels under the RSIP for the additional load required from the grid modernization and climate change pilot as well as battery storage (see Table 7):

Table 7. Schedule of Incentives for Steps 11 through 13 for Grid Modernization and Climate Change Pilot

RSIP Incentive Step	**EPBB** ($/W) or **PBI** ($/kWh) for **Grid Mod Pilot**	**LMI PBI** ($/kWh)	**Battery Storage Capacity** (14 kWh Max) **And Power Rating** (8 kW Max)	
			($/kWh)	($/kW)
11	$0.487 / $0.039	$0.110	$60.00	$50.00
12	$0.487 / $0.039	$0.110	$60.00	$50.00
13	$0.487 / $0.039	$0.110	$60.00	$50.00

In other words, the Step 11 incentive level for the RSIP will be maintained through Step 13 for the additional load caused from renewable heating and cooling equipment and electric vehicle load. For example, if an air source heat pump requires 3 kW of additional solar PV to cover the load, then the RSIP incentive for solar PV will stay at $0.487/W (or $0.039/kWh for PBI or $0.110/kWh for LMI PBI) versus dropping to $0.400/W for systems above 10 kW.

The RSIP incentive for battery storage, since storage is a part of the balance of plant for the solar PV system, is in addition to the existing incentives for solar PV. For example, if a 7-kW solar PV system is installed and a 14-kWh storage capacity/8-kW power rating battery storage is included, then the RSIP incentive will be $4,649, which includes $3,409 (at $0.487/W) for the solar PV system and an additional $840 (at $60/kWh storage capacity) and $400 (at $50/kW nominal power rating) for the battery storage. Given that a smart inverter must be installed as part of the solar PV system, the homeowner will also be required to go on their EDC's Time-Of-Day billing rate (Eversource's Rate 7 or United Illuminating's Rate RT) and discharge their battery during on-peak hours when utility power is available. Discharging the battery storage system during peak hours will reduce the generation cost of electricity to the homeowner during peak periods.

Resolution

WHEREAS, Public Act 15-194 "An Act Concerning the Encouragement of Local Economic Development and Access to Residential Renewable Energy" (the "Act") requires the Connecticut Green Bank ("Green Bank") to design and implement a Residential Solar Photovoltaic ("PV") Investment Program ("Program") that results in no more than three-hundred (300) megawatts of new residential PV installation in Connecticut before December 31, 2022 and creates a Solar Home Renewable Energy Credit ("SHREC") requiring the electric distribution companies to purchase through 15-year contracts the Renewable Energy Credits ("RECs");

WHEREAS, as of March 21, 2017, the Program has thus far resulted in nearly one-hundred and sixty megawatts of new residential PV installation application approvals and completions in Connecticut;

WHEREAS, pursuant to Conn. Gen Stat. 16-245a, a renewable portfolio standard was established that requires that Connecticut Electric Suppliers and Electric Distribution Company Wholesale Suppliers obtain a minimum percentage of their retail load by using renewable energy;

WHEREAS, real-time revenue quality meters are included as part of solar PV systems being installed through the Program that determine the amount of clean energy production from such systems as well as the associated RECs which, in accordance with Public Act 15-194 will be sold to the Electric Distribution Companies through a master purchase agreement entered into between the Green Bank, Eversource Energy, and United Illuminating, and approved by the Public Utility Regulatory Authority;

WHEREAS, pursuant to the Act, the Green Bank has prepared a declining incentive block schedule ("Schedule") that offers direct financial incentives, in the form of the expected performance based buy down ("EPBB") and performance-based incentives ("PBI"), for the purchase or lease of qualifying residential solar photovoltaic systems, respectively, fosters the sustained orderly development of a state-based solar industry, and sets program requirements for participants, including standards for deployment of energy efficient equipment as a condition for receiving incentive funding;

WHEREAS, pursuant to the Act, to address willingness to pay discrepancies between communities, the Green Bank will continue to provide additional incentive dollars to improve the deployment of residential solar PV in low to moderate income communities.

WHEREAS, pursuant to the Act, to address sustained orderly development of a state-based solar industry, the proposed grid modernization and climate change pilot will provide incentives for solar PV to offset the additional energy load from clean energy sources and storage needs.

WHEREAS, pursuant to Section 16-245(d)(2) of the Connecticut General Statutes, a Joint Committee of the Energy Conservation Management Board and the Connecticut Green Bank was established to "examine opportunities to coordinate the programs and activities" contained in their respective plans (i.e., Conservation and Load Management Plan and Comprehensive Plan);

WHEREAS, the Global Warming Solutions Act of 2008 requires Connecticut to reduce its greenhouse gas emissions by 80 percent from 2001 levels by 2050, all the while transportation and the thermal heating and cooling of buildings representing the largest emitting sectors;

WHEREAS, residential solar PV can provide cleaner, cheaper, and more reliable sources of energy for electric vehicles and renewable thermal technologies while creating jobs and supporting local economic development;

WHEREAS, the Deployment Committee has reviewed and recommends that the Board approves of the Schedule of Incentives as set forth in Tables 5, 6, and 7 of the memo dated April 28, 2017 20.0 MW from Step 11, 20.0 MW from Step 12, and 20.0 MW from Step 13.

NOW, therefore be it:

RESOLVED, that the Board, including the Commissioner of the Department of Energy and Environmental Protection, approves of the Schedule of Incentives as set forth in Tables 5, 6 and 7 of the memo dated April 28, 2017 20.0 MW from Step 11, 20.0 MW from Step 12, and 20.0 MW from Step 13.

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CONNECTICUT GREEN BANK

Memo

To: Connecticut Green Bank Board of Directors

From: Mariana C. Trief, Senior Manager, Clean Energy Finance

CC: Bryan Garcia, President and CEO; Bert Hunter, EVP and CIO; Brian Farnen, General Counsel and CLO; Ben Healey, Director, Clean Energy Finance

Date: April 21, 2017

Re: 193kW Hydroelectric Facility in Meriden, CT – Bond Issuance Update

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Background and Purpose

On February 26, 2016, staff brought forward to the Connecticut Green Bank ("Green Bank") Board of Directors (the "Board") a proposal for the Green Bank to provide both construction and term financing through the issuance of New Clean Renewable Energy Bonds ("CREBs") for a 193kW hydroelectric facility in Meriden, CT (the "Project"). The Board approved the original proposal, as subsequently modified at its April, June, July, October, and December 2016 meetings, including the authorization of:

- i) A guaranty to a third-party lender for construction financing in an amount not to exceed $3.9 million,
- ii) Funding from the Green Bank's balance sheet in an amount not to exceed $1,400,000,
- iii) A working capital guaranty in an amount not to exceed $600,000 for the benefit of New England Hydropower Company ("NEHC"), the project developer, with a 24-month maturity, under the Green Bank's existing working capital facility partnership with Webster Bank;
- iv) Term financing based on the following conditions precedent:
  - a. Proceeding with the issuance of CREBs in an amount not to exceed $3,000,000 within 405 days of the original date of authorization by the Board of Directors (that is, February 26, 2016);
  - b. Supporting the CREBs issuance utilizing the Special Capital Reserve Fund ("SCRF") subject to further Office of the Treasurer ("OTT") and Office of Policy and Management ("OPM") approval; and
  - c. Adoption of the Project's Findings of Self Sufficiency for the purposes of the SCRF;
- v) A $100,000 annual Project contribution;
- vi) A minimum debt service reserve fund required for the SCRF in an amount not to exceed $300,000; and,
- vii) The creation of a special purpose entity to be wholly owned by the Green Bank, to own, operate, and manage the Project, as required by CREBs regulations.

Staff has issued the CREBs and, in parallel, NEHC as Project developer is close to completing the Project's construction. The purpose of this memo is to share with the Board details about progress achieved to date on both fronts and request an increase in Green Bank balance sheet financing due primarily to unanticipated Project costs resulting from: i) additional compliance work and a three-month delay associated with the Federal Energy Regulatory Commission ("FERC") Dam Safety's office review of the project, which in turn affected the Project timeline leading to further costs due to winter conditions; and, ii) potential Connecticut sales tax applicable to the purchase of the Project (further color on this below).

Construction Update and Cost Increases

Construction Update: The Project has substantially completed construction: i) Eversource has issued its Notice of Approval to Energize; ii) the City of Meriden's Electrical and Building inspections have concluded successfully; iii) the ZREC meters are in the process of receiving validation from Eversource; and, iv) an engineer from Banc of America Public Capital Corp, LLC (the CREBs purchaser,) performed a site visit and signed off on the Project. Seeding, landscaping and fencing are the only remaining construction items, all of which are expected to finalize by mid-May once the site is fully graded.

Cost increases: The Project's costs have increased relative to the budget presented to the Board in July 2016. The two most significant increase to the budget are due to: i) potential Connecticut sales tax on Green Bank's entire purchase price of the project (again, see further color below); and, ii) FERC Dam Safety's additional compliance requirements and an associated three-month delay that shifted construction into the winter months. A full breakdown of the shifts in the Project budget is presented in Exhibit A.

With respect to the potential sales tax issue, there is some complexity around a variety of interconnected issues: principally, the Green Bank's use of a subsidiary company to own the Project and the use of the Green Bank's bonding authority to finance the Project. In consultation with external legal and accounting advisors, Green Bank staff have now engaged with the Department of Revenue Service ("DRS") to clarify the unresolved tax issues associated with the Project and hope to confirm that the Green Bank's use of its bonding authority will exempt the purchase of the Project from sales and use tax. A memo summarizing the key points for DRS' consideration is presented in Exhibit B.

Despite these cost increases (both confirmed with respect to construction and potential with respect to taxation), the Project is nonetheless benefitting from a lower "all-in" CREBs interest rate and a higher CREBs advance rate than staff originally anticipated, which means that the Project is nonetheless still anticipated to generate sufficient cash flow to not only cover all CREBs obligations but also provide the Green Bank with a modest return to its funding.

Sources and Uses (including potential sales tax)

REDACTED

Sources and Uses (excluding potential sales tax)

REDACTED

Net Present Value Analysis

REDACTED

Cash Flows

REDACTED

Updated cash flow / NPV analysis reflect the Green Bank's ability to recover the upsized $1.9MM balance sheet investment even under the most conservative scenario (that is, including a potential sales tax hit).

CREBs Update

The Green Bank formally issued $2.9 million in CREBs on February 4, 2017 to provide term financing for the Project. The transaction's importance to the Green Bank is considerable:

- It represented the Green Bank's first official issuance of a Green Bond. The Indenture of Trust and other template agreements could serve as a template for future bond issuances.
- It was also the first time the Green Bank took advantage of the CREBs structure, a federally supported bonding strategy that staff expects to replicate further in 2017 and beyond.
- It was the first use of the State's Special Capital Reserve Fund ("SCRF") for the Green Bank – a powerful credit enhancement tool used by quasi-public agencies in Connecticut to help secure affordable long term bond financing.
- It was the Green Bank's first use of the Banc of America interest rate buydown facility.
- The financing makes possible the first use of the Archimedes screw pump in the United States for power generation, using the flow of water from the Hanover Pond water impoundment to rotate the screw and turn a generator to produce electricity.
- Finally, by combining these elements, the Green Bank achieved a 0.56% net effective interest rate over the 20-year term.

Proceeds from the bonds are currently sitting in a construction fund and will be released for the Green Bank's purchase of the Project once the Connecticut sales tax issues are clarified with DRS.

Conclusion

The development of small hydro in Connecticut continues to face its challenges, but the upside potential associated with this Project and hydro in the state remain significant. Though the technology associated with the Project has been widely used in Europe, it is the first time this reliable and environmentally sound clean energy technology has been installed in North America and has complied with all applicable local, state, and federal building, electrical, and regulatory compliance requirements. It is also important to remember that this financing opportunity comes to the Green Bank as the result of a Connecticut Clean Energy Fund ("CCEF") approved Operational Demonstration ("Op Demo"), which intended to establish a faster and lower cost permitting process for small-hydro installations in Connecticut. NEHC has already demonstrated success on this front, as it received its FERC license in a record 2 years, well below the 3-5 years usually required for the permitting process, and in so doing it developed repeatable processes and established replicable standards. This success is important because NEHC has several other viable projects in the Northeast in its pipeline, and the learnings from this Project should accrue to the benefit of those subsequent planned developments, with positive implications for the Green Bank and ratepayers. Finally, it is worth keeping in mind that this project will generate nearly a million kWh of clean energy a year (equivalent to about 115 residential solar systems), and that given the Project's low cost of capital using CREBs, its 40-year NPV is still over $2 million based on reasonable revenue assumptions. With no further construction risks at this point, and subject to the Board's adoption of the attached resolutions, Green Bank staff looks forward to purchasing the Project and managing the asset well into the future.

Resolutions

WHEREAS, the Green Bank Board of Directors (the “Board”), at its February 26, April 22, June 22, July 6, July 22, October 21, and December 16, 2016 meetings (the “Prior Meetings”) authorized the following elements of the development of a small hydroelectric facility at the Hanover Pond Dam on the Quinnipiac River in Meriden (“Project”):

i) A guaranty to a third-party lender for construction financing in an amount not to exceed $3.9 million,

ii) Funding from the Green Bank’s balance sheet in an amount not to exceed $1,400,000,

iii) A working capital guaranty in an amount not to exceed $600,000 for the benefit of New England Hydropower Company (“NEHC”), the project developer, with a 24-month maturity under the Green Bank’s existing working capital facility partnership with Webster Bank;

iv) Term financing based on:

a. Proceeding with the conditions precedent to the issuance of New Clean Renewable Energy Bonds (“CREBs”) in an amount not to exceed $3,100,000 within 405 days of the original date of authorization by the Board of Directors (that is, February 26, 2016); and,

b. Securing the issuance utilizing the Special Capital Reserve Fund (“SCRF”) subject to further Board, Office of the Treasurer, and Office of Policy and Management approval;

v) A minimum debt service reserve fund required for the SCRF in an amount not to exceed $300,000;

vi) The creation of a Special Purpose Entity to be wholly owned by the Green Bank, to own, operate, and manage the Project, as required by CREBs regulations;

vii) The official intent that payment of Project construction and financing costs may be paid from temporary advances of other available funds and that such advances shall be reimbursed from the proceeds of the CREBs financing; and

viii) A loan to CGB Meriden Hydro LLC (the “Borrower”), a wholly-owned subsidiary of the Green Bank, for its purchase of the Project, as referred to and pursuant to a Loan Agreement, by and between the Green Bank and the Borrower (the “Loan Agreement”);

WHEREAS, staff has determined that the Project has and may incur additional costs and that the economics of the Project are still viable, notwithstanding these additional costs, as more fully explained in a memorandum to the Board dated April 21, 2017;

NOW, therefore be it:

RESOLVED, that the Green Bank is authorized to provide funding from the Green Bank's balance sheet to the Project in an amount not to exceed $1,900,000 (previously approved at the not to exceed amount of $1,400,000); and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned legal instruments.

Submitted by: Bryan Garcia, President and CEO; Bert Hunter, EVP and CIO; Ben Healey and Mariana C. Trief, Clean Energy Finance.

Exhibit A: Project Costs

(including potential sales tax)

REDACTED

(excluding potential sales tax)

REDACTED

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Green Bank Microgrid Financing Program

Program Outlook and Summary

April 21, 2017

Document Purpose: This document contains background information on, and expectations associated with, a proposed financing program for projects designated as microgrids within Connecticut. The information herein is provided to the Connecticut Green Bank Board of Directors for the purposes of reviewing and approving recommendations made by the staff of the Connecticut Green Bank.

In some cases, this package may contain, among other things, trade secrets and commercial or financial information given to the Connecticut Green Bank in confidence and should be excluded under C.G.S. §1-210(b) and §16-245n(D) from any public disclosure under the Connecticut Freedom of Information Act. If such information is included in this package, it will be noted as confidential.

Program Qualification Memo

To: Connecticut Green Bank Board of Directors

From: Anthony Clark, Senior Manager, CI&I; Chris Magalhaes, Assistant Director, Clean Energy Finance; Bert Hunter, EVP & CIO; Mackey Dykes, VP, CI&I

Cc: Bryan Garcia, President & CEO; Brian Farnen, General Counsel & CLO

Date: April 21, 2017

Re: Green Bank Microgrid Financing Program

Purpose

The purpose of this memo is to request approval from the Connecticut Green Bank ("Green Bank") Board of Directors (the "Board") for an allocation of $5,000,000 (the "Microgrid Program Funds") over FY2018 and FY2019 to finance microgrid projects as an expansion of the Green Bank's previous efforts to support microgrid development in the state.

Green Bank will work with the Connecticut Department of Energy & Environmental Protection ("DEEP") to identify eligible projects that conform to the requirements of the DEEP Microgrid Program via an application process whereby developers will submit project details to Green Bank for review, and portions of the Microgrid Program Funds will be advanced on a project-by-project basis after subsequent request to, and approval from, the Green Bank Board.

The Microgrid Program Funds will be supported by a Loan Loss Reserve provided by DEEP (the "DEEP LLR"), which will be sized according to each project's aggregate risk profile and will be used to mitigate Green Bank's overall risk exposure to the program, allowing Green Bank to provide flexible, supportive capital that benefits eligible microgrid projects through both the direct application of Green Bank funds to the capital stack and the potential to attract and leverage additional private capital into the mix. DEEP intends to release their revised Microgrid Program application in May 2017, prior to the Green Bank's budget review process for FY2018. Accordingly, staff presently seeks approval to set aside funds in FY2018 and FY2019 in order to support DEEP's Program.

Background

Public Act 12-148, Section 7, required DEEP to create a Microgrid Program to help support local distributed energy generation for critical facilities (defined in the Act as "any hospital, police station, fire station, water treatment plant, sewage treatment plant, public shelter or correctional facility, any commercial area of a municipality, a municipal center as identified by the chief elected official of any municipality, or any other facility or area identified by the Department of Energy and Environmental Protection as critical)." The DEEP Microgrid Program was developed in response to the recommendation of the Governor's Two Storm Panel to minimize the impacts to critical infrastructure associated with emergencies, natural disasters, and other events when these cause the larger electricity grid to lose power. The Act required DEEP to solicit applications to build microgrids to support critical facilities during times of electricity grid outages.

Since the beginning of the DEEP Microgrid Program in 2012, DEEP has awarded funding for approximately ten microgrid projects. Green Bank has previously offered to assist Microgrid Program applicants with accessing, arranging, and securing financing for microgrid projects using then-existing programs such as C-PACE, Lead by Example, and pilot Anaerobic Digestion and Combined Heat and Power programs. In 2016, Green Bank successfully placed $500,000 of subordinated debt from the

Combined Heat and Power program into the Bridgeport Microgrid, which was also funded through the DEEP Microgrid Program. Additionally, the Green Bank allocated $5 million in FY 15 for microgrid projects and $2 million for CI&I new product development (inclusive of microgrids and energy storage) in FY 17. Thus, there has been a history of Green Bank and DEEP working together to finance and develop eligible microgrid projects, but there has not been a single, unifying program that allowed for both organizations to approach microgrids together in an efficient and scalable way.

In November 2016, the State Bond Commission approved an additional $30 million in funding to expand DEEP's Microgrid Program. DEEP anticipates releasing in May 2017 revised their Microgrid Program guidelines and a new application that provides greater flexibility in how DEEP grant support can be applied to the costs associated with development and construction of a microgrid. These changes are expected to increase demand for funds from the program as well as the potential need for financing for successful applicants. Given the expanded, but still limited (relative to expected project costs) funding for the DEEP Microgrid Program, DEEP and Green Bank began discussion on developing a partnership to leverage a portion of DEEP's $30 million in new bond allocation with Green Bank's project financing capabilities and experience. Pursuant to Green Bank's and DEEP's shared desire to support microgrids in a programmatic, efficient, and scalable effort, Green Bank staff and DEEP staff have determined that Green Bank Microgrid Program Funds, supported by loan loss reserve funding from DEEP, have the potential to maximize the amount of private capital leveraged into microgrid projects per limited public dollars at risk, resulting in a greater ability to develop and finance eligible projects.

Microgrid Program Funds

Project Considerations

Microgrids projects are composed of a variety of asset and technology types (each with their own cost structure, performance risks profile, operating constraints, and benefits) developed to achieve a range of energy, economic, and operational objectives.

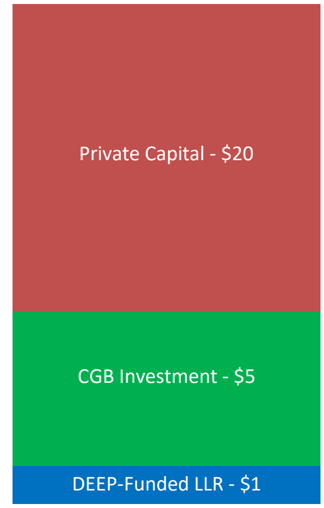
From a project finance perspective, this means that each microgrid project must be underwritten according to its own unique merits and risks, and that each layer of capital used to fund a project will be sized and structured according to:

a.) Project cash flows (as generated by project technologies and off-takers)
b.) The risks associated with project cash flows
c.) The value of the underlying project assets, collateral, and guarantees
d.) The risk tolerance and return expectations of investors
e.) All other conceivable risks and considerations associated with financial markets, legal and regulatory requirements, and miscellaneous project details

Given the complexity of assets, ownership, and operational parameters, microgrids are among the most difficult projects for which to develop a theoretical or abstract financing plan. Given Green Bank's expertise in financing a wide variety of clean energy projects in Connecticut however, Green Bank staff understands the types of financial structures and parameters that are more conducive to developing projects (even if the exact breakdown of financing details differs project-by-project). With that knowledge, staff believes that Microgrid Program Funds, supported by the DEEP LLR, provides the best opportunity for maximizing the impact that limited public funds can have on developing microgrid projects.

Loan Terms and LLR Requirements

The DEEP LLR provides the credit enhancement necessary for the Green Bank to participate in the programmatic financing of microgrid projects by acting as a first-loss cushion that protects Green Bank investments. The Green Bank will then lend out a multiple of the LLR funds in place for a given project; that multiple will depend on the inherent risk profile of that project, which is a function of all the unique factors associated with microgrids (technology risk, credit risk, legislative and regulatory risk, etc.).



Staff anticipates the DEEP LLR investment multiple will range from 2x to 5x, as determined by the Green Bank for each project (e.g. for a multiple of 5x, $1 of LLR from DEEP supports $5 of investment by the Green Bank). That said, it's worth emphasizing that the LLR will generate two levels of leverage for DEEP and the applicant: the direct leverage that the LLR generates with Green Bank funds, and the 2nd level leverage that the Green Bank generates with respect to private capital providers. For example, if the LLR investment multiple for a project is 5x, and the Green Bank participation in the overall capital stack of the project is 20%, then $1 of DEEP-funded LLR will generate $20 of total capital deployed ($5 of Green Bank investment plus $20 of 3rd party private capital investment).

Just as the DEEP LLR investment multiple will vary by project, so too will the terms associated with the individual Green Bank project loans vary according to project risk, scope and underlying DEEP LLR. Staff further anticipates project loans will carry rates between 3.00% - 7.00% (P.A.) generally across 15 – 20 year terms, and will vary in terms of seniority and security in conjunction with additional capital providers in the projects.

Project Identification, Development, and Financing Process

The Green Bank recommends that Microgrid Program applicants consult with the Green Bank while in the process of developing their application to DEEP. In terms of financial support, the applicant will have access to DEEP grants for non-generating assets as well as DEEP support for the generating assets of the proposed microgrid. The applicant will work with the Green Bank to identify what the trade-off is between taking DEEP grants for generation vs. low-cost Green Bank financing supported by a DEEP LLR to the Green Bank. The Green Bank may also make suggestions and/or introductions to 3rd party capital providers to the applicant, based on the underlying project economics and potential Green Bank participation.

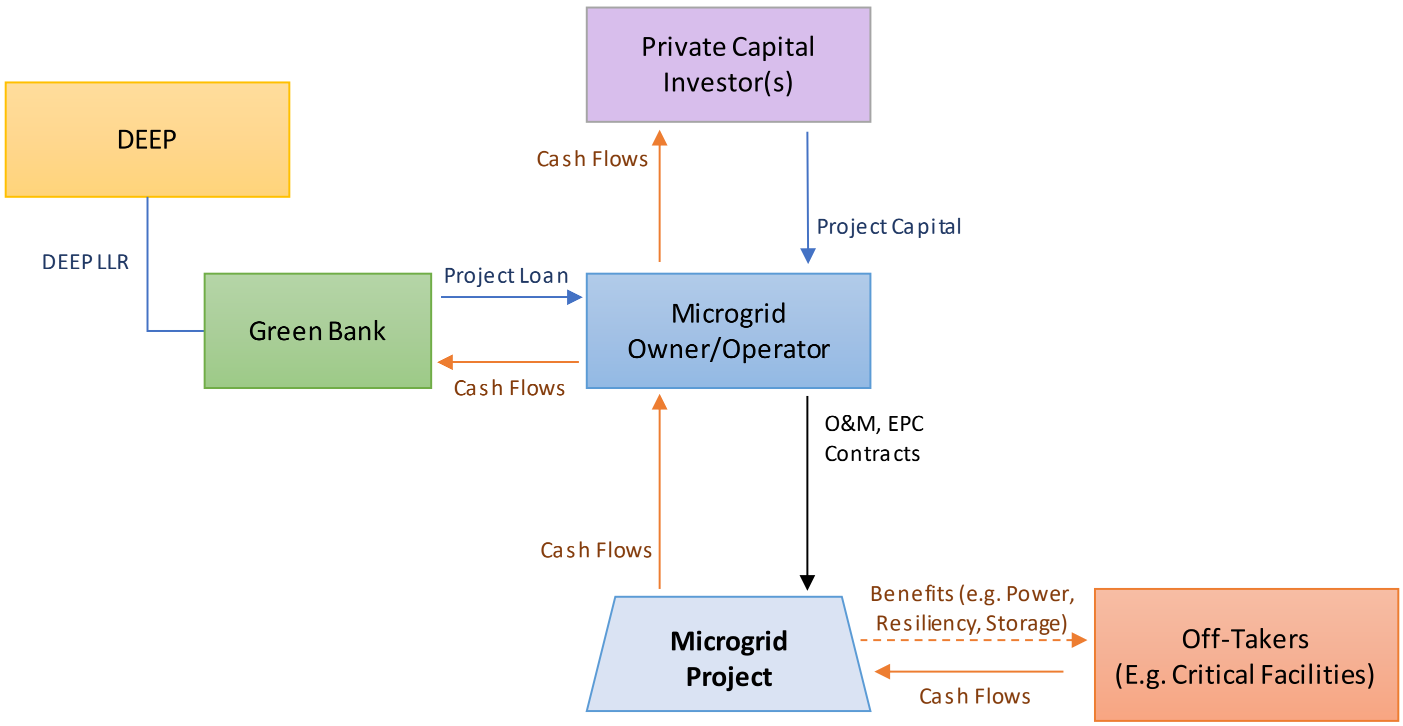
To be clear, the applicant will not be required to consult with the Green Bank for the RFP, but will be offered every opportunity to do so in order to explore all of the financing options available at the applicant's disposal. Furthermore, consultation with the Green Bank will not require the applicant to proceed with Green Bank funding – if the applicant is able to acquire financing on better terms with 3rd party capital providers and without Green Bank support, the applicant would be free to pursue such options and we would encourage that.

As part of the RFP process, together the Green Bank and applicant would identify:

- financing gap(s) related to the generator assets in the microgrid
- amount and general terms of Green Bank capital available for investment into the project
- availability of other quasi-public resources such as through CHEFA
- expected requirements for, and availability of, third-party private capital
- amount of DEEP LLR funding to be requested to support the optimum capital stack for the project (to be determined between Green Bank and DEEP – applicant will only be aware of the tradeoff between a DEEP grant vs. Green Bank financing, but will not participate in determining LLR amounts)

If the application is approved by DEEP as having submitted an eligible project, and if the applicant chooses to proceed with the Green Bank financing proposal, Green Bank would request from DEEP the approved amount of LLR funding to be placed into a to-be determined account, on behalf of the Green Bank, for the duration of the financing term.

Indicative Capital Flow Diagram



Strategic Plan

Is the program proposed, consistent with the Board approved Comprehensive Plan and Budget for the fiscal year?

The proposed Green Bank microgrid financing program aligns with the Grid 2.0 and infrastructure modernization goals outlined in the Emerging Markets for Clean Energy section of the Comprehensive Plan. Green Bank investment in microgrids can provide opportunities to deploy distributed and resilient energy systems that include clean generation technologies such as fuel cells and battery energy storage.

Ratepayer Payback

How much clean energy is being produced (i.e. kWh over the projects lifetime) from the program versus the dollars of ratepayer funds at risk?

Estimates for clean energy production versus ratepayer dollars at risk will be provided to the board as part of the transaction memo for each individual project investment to be made under this program.

Terms and Conditions

What are the terms and conditions of ratepayer payback, if any?

Average interest rates for investments made under this program are expected to be in the range of 3.00% - 7.00% with terms expected to range from 15 – 20 years.

Capital Expended

How much of the ratepayer and other capital that Green Bank manages is being expended on the project?

$5,000,000: up to $2,500,000 for FY2018 and up to $2,500,000 for FY2019.

Risk

What is the maximum risk exposure of ratepayer funds for the program?

Assuming approval of $5,000,000 in available Green Bank funding and applying the DEEP LLR investment multiple within the anticipated range that provides the least coverage for Green Bank funds to that approved amount, the maximum risk exposure associated with the microgrid financing program would be $4,000,000 ($5,000,000 in Green Bank funding less $1,000,000 in credit enhancement from the DEEP LLR, assuming a leverage ratio of 5:1 of Green Bank funds to DEEP LLR).

Financial Statements

How is the program investment accounted for on the balance sheet and profit and loss statements?

Each project loan advanced by the Green Bank would result in a reduction of unrestricted cash and an increase in “promissory notes (microgrid program)” in the amount of the loan. The DEEP LLR would result in an increase in “restricted cash (microgrid program)” and an increase in “reserves for loan losses (microgrid program)”.

Target Market

Who are the end-users of the engagement?

End-users are municipalities and other owners of critical facilities who are successful in their applications to the DEEP Microgrid Program for funding to support their microgrid projects.

Green Bank Role, Financial Assistance & Selection/Award Process

Lender to relevant microgrid projects supported by the DEEP LLRs. The actual award process is to be determined in cooperation with the DEEP microgrid team.

Program Partners

DEEP

Risks and Mitigation Strategies

Green Bank investments will be supported by loan loss reserve funds allocated by DEEP and placed into an account controlled by the Green Bank for the duration of the financing term.

Resolutions

WHEREAS, in accordance with (1) the statutory mandate of the Connecticut Green Bank ("Green Bank") to foster the growth, development, and deployment of clean energy sources that serve end-use customers in the State of Connecticut, (2) the State's Comprehensive Energy Strategy ("CES") and Integrated Resources Plan ("IRP"), and (3) Green Bank's Comprehensive Plan for Fiscal Years 2017 and 2018 (the "Comprehensive Plan") in reference to the CES and IRP, Green Bank continuously aims to develop financing tools to further drive private capital investment into clean energy projects;

WHEREAS, pursuant to Green Bank's and Department of Energy and Environmental Policy (DEEP's) shared desire to support microgrids in a programmatic, efficient, and scalable effort, Green Bank Microgrid Program Funds, supported by loan loss reserve funding from DEEP, have the potential to maximize the amount of private capital leveraged into microgrid projects per limited public dollars at risk, resulting in a greater ability to develop and finance eligible projects.

WHEREAS, staff recommends support for the Green Bank Microgrid Program in the form of term loans not to exceed $5,000,000 in aggregate and supported by DEEP Loan Loss Reserve funds;

WHEREAS, Green Bank staff recommends that the Green Bank Board of Directors ("Board") approve an allocation of $5,000,000 (over FY2018 and FY2019 to finance microgrid projects as an expansion of the Green Bank's previous efforts to support microgrid development in the state.

NOW, therefore be it:

RESOLVED, that the Green Bank Board of Directors hereby approves the allocation not to exceed $5,000,000 for the Microgrid Program as described in the memorandum to the Board dated April 21, 2017; and

RESOLVED, that the President of the Green Bank and any other duly authorized officer is authorized to take appropriate actions to make the term loan funding available to Microgrid Program applicants; and

RESOLVED, that the proper Green Bank officers are authorized and empowered to do all other acts and execute and deliver all other documents and instruments as they shall deem necessary and desirable to effect the above-mentioned Term Loans.

Submitted by: Bryan Garcia, President and CEO; Bert Hunter, EVP and CIO; Mackey Dykes, VP, CI&I; and Anthony Clark, Senior Manager, CI&I.

As part of our efforts to accelerate clean transportation alternatives in Connecticut, CT Green Bank is partnering with Nissan North America to offer eligible City of Hartford fleet managers and municipal employees a special rebate on the purchase of a new 2017 Nissan LEAF electric vehicle.

Simply show proof of employment with the City of Hartford and a copy of this flyer at your participating Nissan dealership to receive a ***$10,000 rebate*** (off MSRP[4]) on a new 2017 Nissan LEAF! This limited time offer ***expires 6/30/2017*** or while supplies last (whichever occurs first), and cannot be combined with any other Nissan special lease, APR or rebate.

BENEFITS:

- 100% all-electric Nissan LEAF
- Up to 107-mile range; 30 kWh battery[1]
- No gasoline, no oil changes
- Potential Federal tax incentive of up to $7,500[2]
- 8 yr. / 100K (whichever occurs first) limited battery warranty [3]

See your local participating LEAF Certified Nissan Dealer for complete details at:
www.nissanusa.com/nissandealers/location/

Fleetail Certification Code:

G65476

To learn more about Nissan LEAF, visit NissanUSA.com/leaf

[1] MY17 EPA range of 107 miles. Based on targeted 2017 EPA estimates. Actual range may vary based on driving conditions. Use for comparison only. [2] The incentive referenced is for informational purposes only. This information does not constitute tax or legal advice. All persons considering use of available incentives should consult with their own tax or legal professional to determine eligibility, specific amount of incentives available, if any, and further details. The incentive is not within Nissan's control and is subject to change without notice. Interested parties should confirm the accuracy of the information before relying on it to make a purchase. [3] For complete information concerning coverage, conditions and exclusions, see your Nissan dealer and read the actual New Vehicle Limited Warranty booklet. [4] MSRP excludes tax, title, license, options, and destination

March 10, 2017

Mr. Craig Connolly
Marketing Director
845 Brook Street
Rocky Hill, CT 06067-3444

RE: Sparking the Green Bank Movement

Dear Mr. Connolly,

Congratulations! I am pleased to inform you that Sparking the Green Bank Movement has been chosen as one of only 11 initiatives to advance in the Innovations in American Government Awards competition. These 11 programs represent the top 2% of the initial applicant pool.

In order to be named a finalist for the Innovations in American Government Awards and to be eligible to receive an Innovations grant to be directed toward program dissemination and replication activities, you must complete a successful site visit, to be conducted before April 14, 2017.

On May 17, the members of the National Selection Committee will meet in Cambridge to select one winner of the Innovations Award winner and one winner of the Roy and Lila Ash Innovation Award for Public Engagement in Government from among the 11 finalists. The Committee's decision will be based on your applications, on a report prepared by the Innovations site visitor, and on a presentation by your program representatives. Information regarding your presentation to the National Selection Committee will be sent to you in the coming weeks. Please hold May 16–17 on your calendars for finalist events.

This packet contains the information you need for the upcoming site visit. In addition to information on the awards competition, this packet contains information about the mission of the Innovations Program and its partners.

As a finalist, your program will be included in the list of the Top 25 programs from this year's applicant pool that will be released in April, when we will also announce your status as a finalist. ***To ensure the best coverage possible, it is imperative that you hold the release of any information about your status until after the press release date.*** We will be in touch regarding the release in the coming weeks.

Congratulations, once again, on reaching this level of accomplishment and my best wishes for your continued success. If you have any questions, please do not hesitate to contact me at the below e-mail.

Sincerely,

Kaitlin Burroughs

Kaitlin Burroughs
Program Coordinator
Innovations in American Government Program
kaitlin_burroughs@hks.harvard.edu

SOLARIZE YOUR COMMUNITY

An Evidence-Based Guide for Accelerating the Adoption of Residential Solar

Project Partners

U.S. Department of Energy Sunshot Initiative SEEDS grant Principal Investigators:
Kenneth Gillingham, Assistant Professor, Yale University, School of Forestry & Environmental Studies
Bryan Bollinger, Assistant Professor, Duke University, Fuqua School of Business

The U.S. Department of Energy SunShot Initiative is a national effort to drive down the cost of solar electricity and support solar adoption. SunShot aims to make solar energy a low cost electricity source for all Americans through research and development efforts in collaboration with public and private partners. Learn more at energy.gov/sunshot.

The Connecticut Green Bank was established by the Governor and Connecticut's General Assembly on July 1, 2011 through Public Act 11-80 as a quasi-public agency that supersedes the former Connecticut Clean Energy Fund. As the nation's first state "Green Bank", the Connecticut Green Bank leverages public and private funds to accelerate the growth of green energy in Connecticut.

SmartPower is the nation's leading non-profit marketing firm dedicated to promoting energy efficiency and renewable energy and has extensive experience with hundreds of community-based energy campaigns and Solarize projects across the country. SmartPower provides participating communities with technical assistance, campaign strategizing and outreach, and media planning.

The Yale Center for Business and the Environment joins two world-renowned graduate schools—the Yale School of Management and the Yale School of Forestry & Environmental Studies—with a network of internal and external leaders working at the interface of business and the environment. We catalyze research and cultivate partnerships that advance business solutions to global environmental problems.

+ 20 Solarize installation companies and 58 towns

About the Partnership

What motivates people to install rooftop solar panels? Which incentives can rapidly boost the adoption of this technology? Which programs are persistently effective, and which are most easily scaled?

Supported by a grant from the U.S. Department of Energy a multidisciplinary set of partners came together to test these questions by examining the uptake of solar through the Solarize CT program. Out of this collaboration, we have produced a guidebook for community and business leaders, active citizens and policymakers detailing the most effective strategies for accelerating the adoption of residential solar.

The Yale School of Forestry and Environmental Studies and **Duke University**, in collaboration with the **CT Green Bank** and **SmartPower**, conducted a series of rigorous controlled field trials to better understand the adoption of residential solar.

The Yale Center for Business and the Environment coordinated the partnership and worked with a team of students to facilitate the research, assist with the data analysis and create this guidebook.

The Connecticut Green Bank, a state-level institution devoted to expanding the region's clean energy sources, accelerated consumer financing options by developing risk-reduction mechanisms in partnership with local lending and capital partners.

SmartPower, a social marketing firm, provided insight and support for Solarize CT, creating high impact on-the-ground community campaigns.

About Solarize

Solarize is a community based program that leverages social interaction to promote the adoption of solar through a group pricing scheme. Solarize campaigns are designed to leverage peers and social networks to spur solar adoption.

Yale Center for Business and the Environment

Yale School of Forestry & Environmental Studies

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SmartPower Let's Get Energy Smart.

Connecticut Green Bank

Duke The Fuqua School of Business

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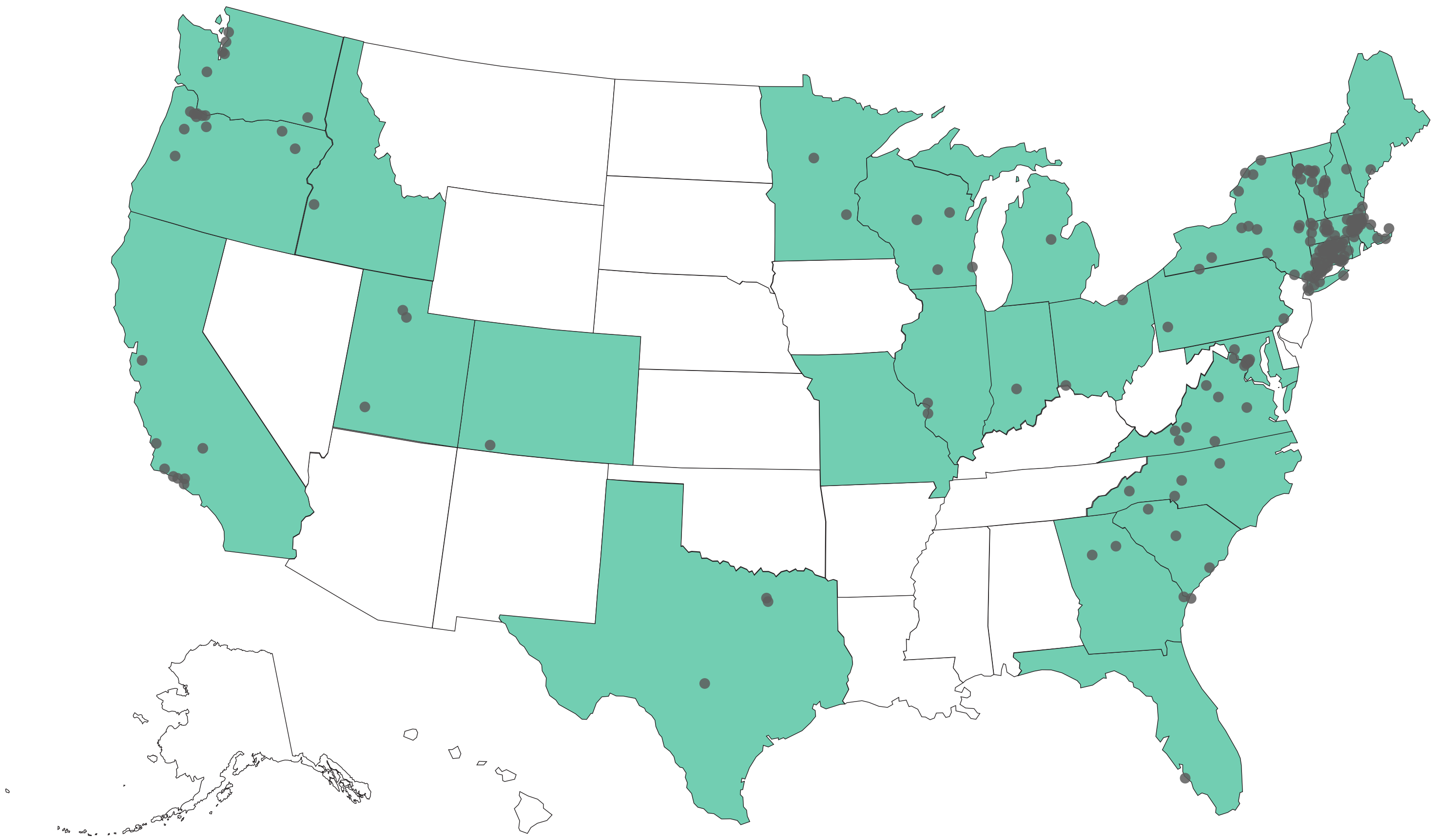
Solarize: A National Movement, Rigorously Tested in Connecticut



This map illustrates the communities that organized Solarize campaigns across the U.S from 2009–2016.[1]

1 Ryan Cook, Meister Consultants Group

Foreword

The national energy economy is undergoing a massive transition. Solar recently became the cheapest source of new electricity generation while other renewable technologies are quickly becoming cost-competitive with traditional fossil-fuel sources; energy infrastructure from the twentieth century is in need of replacement; and states are considering capital-intensive infrastructure projects with an eye to the future—both of regulation and competitiveness.

Distributed, residential solar installations will no doubt be integral to this future.

The following guidebook is based on the promising outcome of a research project focusing on a set of campaigns called Solarize CT, launched across the state of Connecticut from Fall 2013 to Spring 2016. The Solarize campaign, which was designed to increase the adoption of solar energy, ran in 58 towns statewide. The results were striking: **in just three years, the number of homes with solar grew from about 800 to over 12,500**. Solarize played a central role in this expansion.

Solarize CT was rolled out in five distinct phases, allowing for research on different variants of the campaign, with small tweaks to the campaign in each phase. These variants allowed researchers from Yale and Duke Universities to determine the factors that most directly influenced household solar adoption—from the best messaging to ideal campaign lengths to optimized use of social networks. The researchers also examined the behavioral underpinnings of consumer decision-making: why do people decide to install solar panels? What hinders this decision, and what can make the decision more likely? Though Solarize is a national effort with a demonstrated record of success in the town's where it is implemented—the idea was first launched in Portland, OR in 2009—**Solarize CT represents the first large-scale experiment of its kind to rigorously examine specific catalysts of solar adoption.**

For those looking to foster a local solar market, the pages that follow offer explicit guidance that is firmly rooted in research findings. The lessons learned in Connecticut can be applied to streamline policy, design compelling business strategies, and galvanize community-led programs for organic solar growth. This guide offers insight into ***what* to do when fostering a local solar market and *why* to do it**. It is organized into four main sections:

1. Capitalizing on social networks to drive adoption
2. The business case for a solar campaign
3. How a campaign like this benefits communities and local governments
4. The essential components of a successful campaign

Also included is a two-page "how-to" for designing and implementing a campaign with links to templates and resources. For any person or institution interested in how to increase rates of solar adoption, this guidebook will help set and achieve those goals.

Executive Summary

SolarizeCT, which began in 2009, is designed to increase the installation of residential solar systems through local campaigns. The results have been stunning. In a three-year Connecticut campaign (2012–2015), the number of homes with solar grew from about 800 to over 12,500. Research findings based on the campaign—the first of their kind—indicate that the success of Solarize rests on a few key components.

The diffusion of awareness, or spreading of knowledge, about solar through social networks is a surprisingly powerful lever for boosting adoption. For instance, over a six-month period, the presence of one solar rooftop project increased the average number of installations within a half-mile radius by nearly 50 percent.[2] This peer influence effect is even stronger if the panels are visible from the street.[3] Thus, increasing the visibility of solar is clearly an important facet of any solar marketing campaign.

Recognizing that—social networks have a strong influence on decisions to install solar—Solarize campaigns are specifically designed to focus and amplify this peer effect: Solarize makes installations visible; it convenes events where people talk about solar (and watch it being installed); and it supports an energetic, local, and organic marketing campaign.

The findings on the research from Solarize CT also made evident the importance of recruiting the right volunteers ("solar ambassadors") and involving a range of stakeholders. Effective solar ambassadors—people who are respected in the community and passionate about not just the environment, but Solarize specifically—are critical to a successful campaign; towns with strong volunteer leadership demonstrate consistently higher adoption rates.[4]

Beyond these ambassadors, a coalition of support that includes local and state officials, and vetted installers, legitimizes a Solarize campaign in the eyes of customers. Especially because Solarize is a grassroots approach to increasing solar adoption, having trusted sources in positions of leadership who not only support the program, but actually take part in it, makes a difference.[5]

But why should leadership—why should anyone—take part in a Solarize campaign? Besides the environmental benefit, these campaigns generate tremendous benefits for businesses and local economies. On the business side, Solarize CT resulted in a statewide "20–20 rule." Most campaigns ran for roughly 20 weeks and reduced the average cost of solar by 20 percent. This resulted in **more than three times**[6] the number of rooftop installations in participating communities.

2 Graziano and Gillingham (2015), https://academic.oup.com/joeg/article/15/4/815/2412599/Spatial-patterns-of-solar-photovoltaic-system
3 Bollinger and Gillingham (2012), http://pubsonline.informs.org/doi/pdf/10.1287/mksc.1120.0727
4 Kraft-Todd, Gordon, David Rand, Bryan Bollinger, Kenneth Gillingham – "Environmental Actions Speak Louder than Words" Yale University Working Paper
5 Bollinger and Gillingham (2017) Social Learning and Solar Photovoltaic Adoption: Evidence from a Field Experiment. Yale University Working Paper
6 Ibid.

Solarize CT led to a "tipping point" within a few months of launching the campaign. Residential solar adoption significantly increased while prices significantly decreased during the campaign.

Bollinger, Gillingham, and Lamp (2017) "Tipping Points and Solar Photovoltaic Adoption," Yale University Working Paper

For local economies, Solarize creates jobs, bolsters the local solar industry, and streamlines permitting processes by establishing a pipeline of installations with similar characteristics. More broadly, Solarize campaigns overseen by a cross-sectoral coalition create a strong foundation for a robust clean energy market that no single actor could achieve in isolation. **In other words, Solarize has the potential to be a launching point for a much larger investment in the transition to a renewable energy infrastructure.**

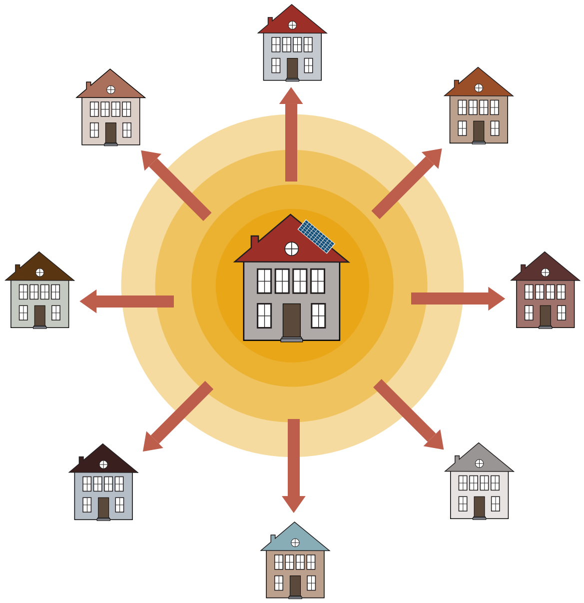
Given these benefits, it's fortunate that designing and implementing a campaign is straightforward and built around three fundamentals:

1. Educate the consumer
2. Find points of motivation
3. Convert interest into a decision to install solar.

This guidebook clearly maps the process for any town, or individual, interested in solarizing their community.

Solar is Contagious. Capitalize on This.

Community social networks are a powerful force for driving solar adoption. Recognizing and using these ‘peer effects’ accelerates individual decisions to go solar.



SHINE A SPOTLIGHT ON SOLAR: THE DIFFUSION EFFECT

One of the central factors determining whether a given house installed solar was the actions and influence of peers. **Over a six-month period, the presence of one solar rooftop project increased the average number of installations within a half-mile radius by nearly 50 percent.**[7] This peer influence effect is stronger if the panels are visible from the street. This is why installers often attempt to raise the visibility of installations with signs that call out the panels.[8]

Recognizing that social networks have a strong influence on decisions to install solar, Solarize campaigns are specifically designed to amplify social interactions about solar. Under normal circumstances, social interaction on issues of solar energy would occur passively and randomly. Solarize campaigns work in part because they create a forum that concentrates conversation and interaction.

RECRUIT SOLAR ENTHUSIASTS TO SPREAD THE WORD

Community-led marketing leverages a small group of passionate volunteers—Solarize CT dubbed them “solar ambassadors”—to spearhead outreach activities and to organize other volunteers who can canvass and host events. Recruiting the right solar ambassadors is critical to the success of a campaign; towns in Connecticut with strong volunteer leadership demonstrated consistently higher adoption rates.

One of the most powerful predictors of an effective ambassador is that he or she takes part in the Solarize campaign by signing up for an installation. This action proved far more telling of successful ambassadorship than other environmental behaviors like composting, owning a hybrid vehicle, or having double-paned windows. (This is consistent with the well-known notion that “actions speak louder than words.”) Surveys and interviews also found that ambassadors who conceptualized

7 Graziano and Gillingham (2015), https://academic.oup.com/joeg/article/15/4/815/2412599/Spatial-patterns-of-solar-photovoltaic-system

8 Bollinger, B, Gillingham, K, Kirkpatrick J, and Sexton, S.—“Visibility and Social Influence” Duke University Working Paper

WHAT DO SOLAR AMBASSADORS DO?

As locally trusted sources, solar ambassadors advance word-of-mouth recommendations for solar PV on three fronts:

- **EDUCATE:** They raise awareness and answer questions about the benefits of solar PV.
- **MARKET:** They organize community events, canvass neighbors and friends to sign up for solar, and publicize the Solarize program through various media.
- **CONNECT:** They act as a liaison between the homeowner and installer.

their role as part of a job rather than as ancillary volunteer work were more persuasive.[9]

Solar tours and live installations serve two ends at once: they facilitate exposure to solar installations among peers, and they offer basic information about the process and benefits of going solar.

Solar tours allow people to meet current owners, see the panels and inverters, and hear first-hand about the owner's experience. In Solarize CT, current owners often showed visitors years of extremely low electric bills along with monitoring systems demonstrating historic and live production numbers. These events feed the curiosity of potential customers, help build trust in solar technology, and make the prospect of renewable electricity visible. They also allow prospective customers to absorb the experiences of others before taking the leap personally.

Live installation events are exactly what they sound like: a chance to watch the installation of solar panels. These require a homeowner who has signed up for panels, lives in a visible location, and is willing to host an event such as a barbeque on his or her lawn. The event gives interested residents an opportunity to watch the raising and attachment of solar panels to the roof. Installation events also provide a great opportunity for press, especially in areas where there is not a lot of solar. Installers on roofs with a party down on the ground makes a great photo op for newspapers and TV. Both the homeowners *and* installer are then on-hand to answer questions about solar and the installation process.

GET CREATIVE WHEN CONNECTING WITH THE COMMUNITY

The more visible a campaign is, the more successful it will likely be. As one town leader in Connecticut put it, "be everywhere in the community." Every town event and town meeting is an opportunity to promote solar—at the Lions Club, farmers' markets, and the library, to name just a few.

In West Hartford, Connecticut, besides posting flyers and tabling at various events, solar ambassadors brought solar to life with distinctive outreach efforts. The first event was a float in a neighborhood parade escorted by

WHAT DOES A LIVE INSTALLATION EVENT LOOK LIKE?

In short, whatever you want it to look like.

For a live installation in the shoreline community of East Lyme, Encon Solar had a full-scale clambake. People were able to watch the panels go up and enjoy fresh clams and corn.

In West Hartford, C-TEC Solar had a barbeque with balloons drawing people to the event. Homeowner Mickey Toro (who is the president of C-TEC) even gave people rides in his Tesla. The corner location of his house attracted a lot of people simply out for a stroll; a number of folks signed up for site visits on the spot.

9 Kraft-Todd, Gordon, David Rand, Bryan Bollinger, Kenneth Gillingham—"Environmental Actions Speak Louder than Words" Yale University Working Paper

marching ambassadors wearing sun hats and carrying signs. Runners also participated in a winter “mitten run” wearing Solarize t-shirts. PTA members got the schools involved with a video of students singing “Here Comes the Sun” interspersed with a rooftop tour of the school’s solar installation. West Hartford has many neighborhood associations; members of these associations conducted outreach through blogs and email groups. Toward the end of the campaign, ambassadors got together to make phone calls reminding people about the approaching deadline and asking them if they had any questions concerning solar.

COMBINING THESE APPROACHES FOR SUCCESS: DEFINING A SOLARIZE CAMPAIGN

Solarize campaigns are locally organized community outreach efforts aimed at getting a critical mass of homes to “go solar” together in a limited amount of time, typically a few months.

The campaigns leverage group-purchasing power: customers can purchase solar systems in bulk for significantly less money than the typical market rate through the creation of a steady stream of purchases and installations.

A classic Solarize model combines four key strategies—town-supported outreach and education, pre-selected solar installers from competitive bidding, discount pricing, and a limited time period—and typically unfolds in four basic stages:

STAGE 1

Well in advance of the campaign launch, Campaign organizers reach out to several local solar installation companies and invite them to participate in an RFP process to be the solar installer(s) for the campaign. The Campaign organizers and three selected volunteers from the community conduct a thorough review and interview process based on selection criteria. These criteria can include quality, experience, and locally specific requirements, such as ‘Made in America’ hardware. The Campaign organizers and the three-person community volunteers choose the designated installer for the Solarize CT campaign.

STAGE 2

Interested community members are recruited to volunteer their time telling friends and neighbors about the program. Prior to the campaign launch they plan the outreach and media strategy to get the word out about the Solarize campaign. Over the course of the campaign, these solar ambassadors spearhead outreach activities and organize other volunteers to canvass and host events.

STAGE 3

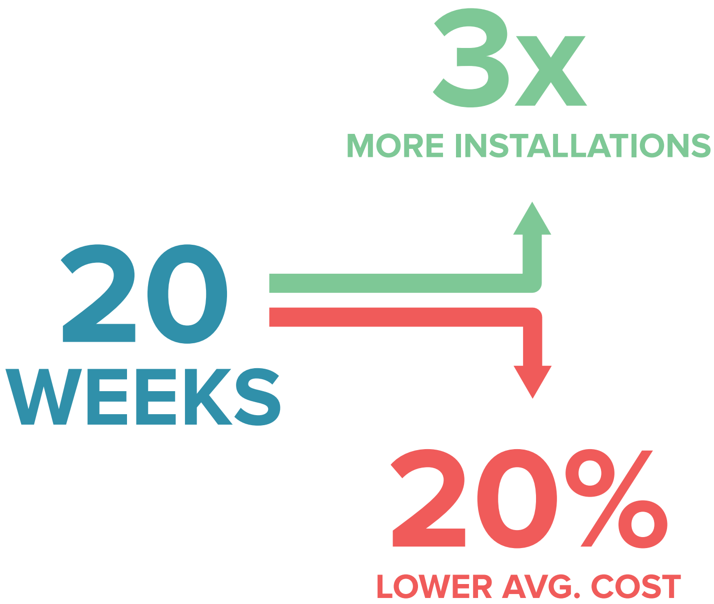
Town champions, distinct from solar ambassadors and typically from the First Selectman’s/Mayor’s office and/or a Clean Energy Task Force, come together with local or state-level partners, as well as with the chosen installer and solar ambassadors, to launch an intensive community outreach campaign.

STAGE 4

With the support of solar ambassadors, the designated installer follows up with members of the community who express an interest in solar, offering a tiered discount pricing structure whereby the more customers that sign up to install solar during the 20 weeks of the campaign, the cheaper the price per watt for everyone.

A Striking Business Case

Using a tight timeline and bulk discounts can result in dramatic outcomes.



THE 20–20 RULE

Most Solarize CT campaigns ran for roughly 20 weeks. Over this period, they reduced the average cost of residential solar by 20–30 percent. The campaigns **more than tripled** the number of installations in each community and significantly expanded the size of the market (one out of five households that signed a contract through Solarize had never before considered installing panels[10]).

Thus, the 20–20 rule—a 20 week campaign, a 20 percent cost reduction for customers resulting in more than three times the number of installations. This is a compelling benchmark for the solar installation business.

WIDE-RANGING BENEFITS FOR SOLAR INSTALLERS

Beyond the increase in sales and market-size—20–100 new contracts over the course of the campaign— installers saw a number of benefits from Solarize. For instance, Solarize programs introduced benefits of scale and reputation to smaller firms that are typically reserved for larger, name-brand companies.

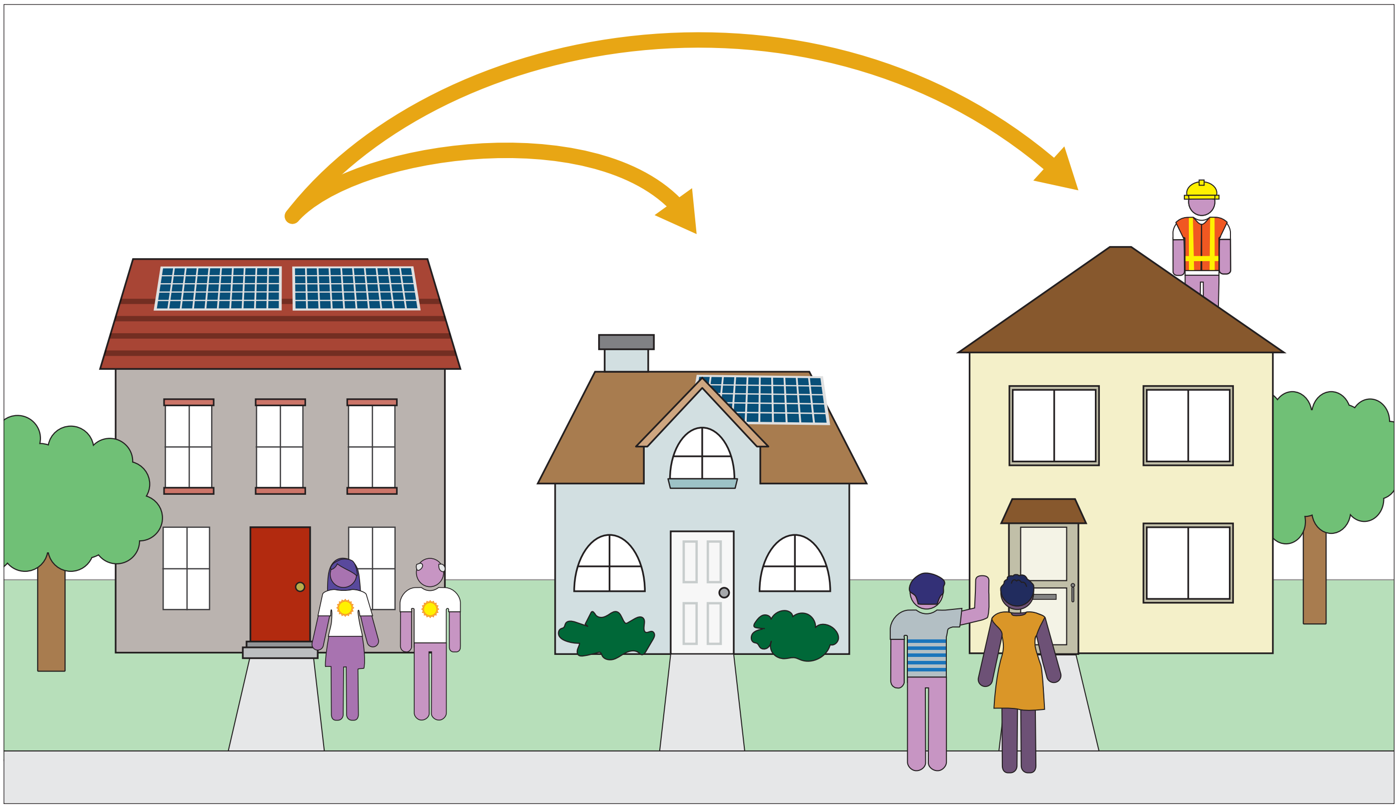
Participating solar installers also reported that Solarize CT significantly lowered customer acquisition costs through:

- Greater awareness of solar among customers
- Increased brand recognition of Solarize
- Reduced marketing spend
- Geographic concentration of customers (reducing travel time)
- Higher lead volumes
- Higher close rates
- Shorter time to sale

These are valuable benefits, considering that costs unrelated to solar hardware made up 55 percent of a system's price tag in the U.S. in 2015.

As a result of the volume of signed contracts, all installers reported growth in their business. To meet demand, many hired additional employees. After the Solarize CT campaigns ended, several installers continued offering discounted pricing to customers who signed-up after

10 Bollinger and Gillingham (2017) Social Learning and Solar Photovoltaic Adoption: Evidence from a Field Experiment. Yale University Working Paper



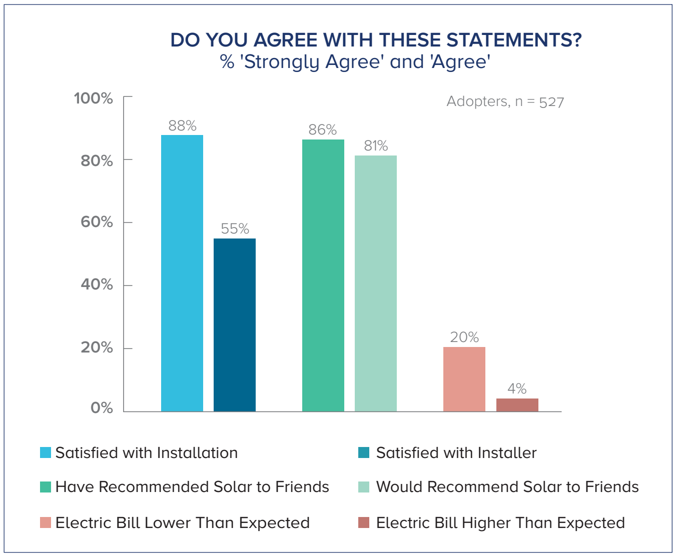
the deadline. The majority of installers reported that there were persistent benefits of participating in Solarize as customers contacted them even after the campaign was over.

In some instances, such rapid growth also created challenges. Where solar adopters reported reasons for being unsatisfied, they felt that problems stemmed from the installation company having insufficient bandwidth to handle the spike in demand. But as the section below describes, customer satisfaction generally remained high.

CUSTOMERS ARE OVERWHELMINGLY HAPPY WITH THE RESULTS

Customers in the research survey data from the Solarize CT program provided mostly positive feedback. Almost 90 percent were very satisfied with their installations, and more than 80 percent would recommend (or have already recommended) solar to others. Overall, the program provided accurate information about costs: only 2 percent of households said that their electricity bill was higher than expected after the installation. Reasons that solar adopters reported being unsatisfied included lack of responsiveness, missed deadlines, and inadequate training for technicians.

Of course, it goes almost without saying that the selection of a reliable installer, who is prepared for a large increase in business, is of fundamental importance to campaign success and future adoptions.



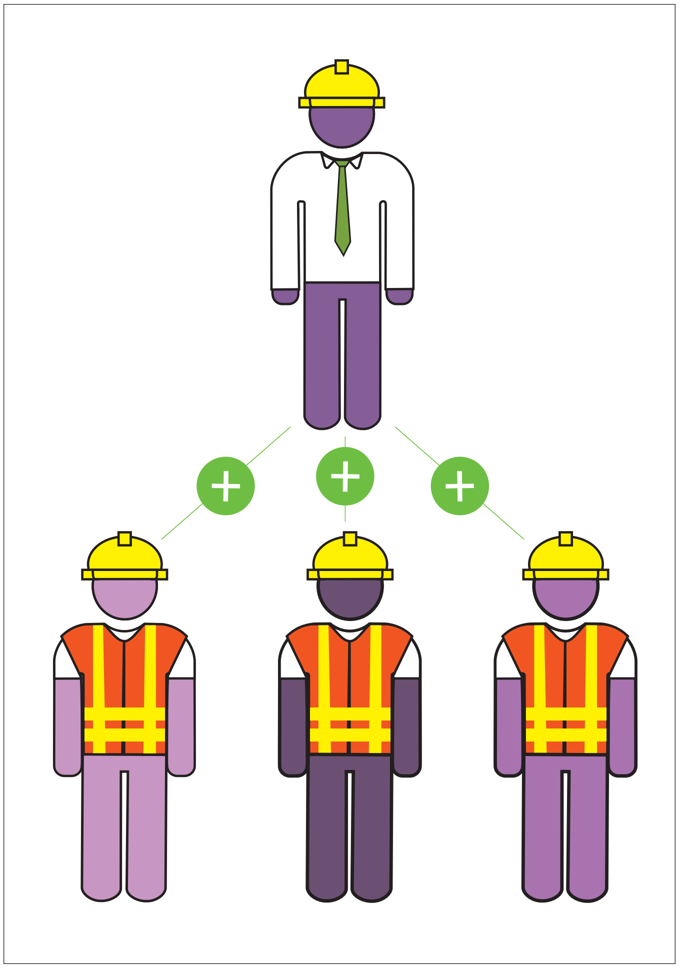
The Tremendous Benefit to Local Communities

From a stronger local economy to streamlined policy, running a Solarize campaign offers communities an array of social benefits beyond simply more solar panels.

SUPPORTING JOB GROWTH AND WORKFORCE INVESTMENT

Solarize campaigns strengthen consumer demand and spur job growth within the solar industry. Nearly every installer that took part in Solarize CT hired new employees for a variety of positions, like electricians and sales representatives. One solar installer even created a standing Community Solar division in its company, dedicating resources to develop and participate in community solar programs.

Given the difficulty of filling so many new positions so quickly—a relative dearth of qualified employees existed in Connecticut—the state created jobs training programs and recruitment fairs.



A PATH TO EFFICIENT MARKETS AND STREAMLINED POLICY

Solarize CT convened groups from across sectors to support the campaign. This broad coalition of organizations and community leaders—from a quasi-public financing agency to a nonprofit clean energy marketing firm—created a foundation for a sustainable clean energy market that no single actor could have achieved in isolation.

A SHARED SENSE OF COMMUNITY PURPOSE

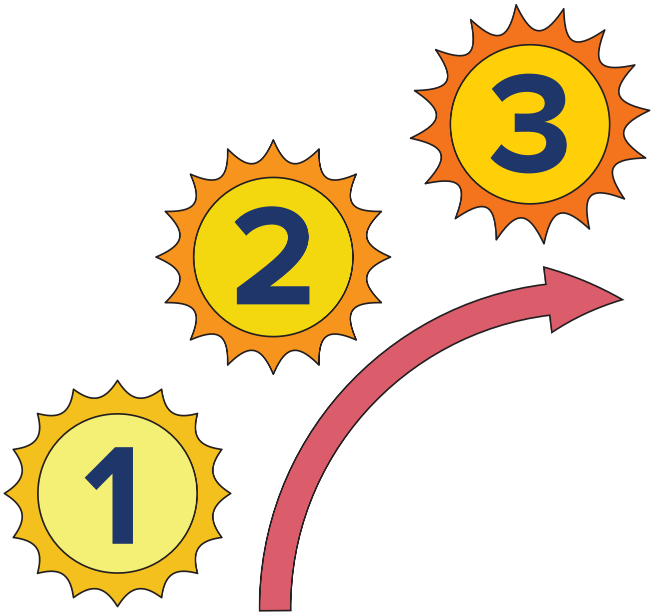
Having the support of town leadership on community-based campaigns is paramount in building legitimacy for the campaigns, and serves to bring leadership and citizens together toward a shared sense of purpose. The Town of Portland was lucky to have First Selectwoman Susan Bransfield as one of its solar ambassadors. Bransfield was very involved in the installer review and selection process and very supportive of the Clean Energy Task Force's efforts. She even opened up her own home for a solar open house, where she talked about her personal experience going solar. Having her to lead by example increased social proof, one of the strongest motivations for human behavior. Especially since Solarize is a grassroots approach to increasing solar adoption, having trusted sources in positions of leadership who not only support the program, but actually take the recommended action, makes a difference.

Solarize campaigns, through the quick deployment of a large amount of solar, also help to establish uniform processes and build trust among communities. Creating a pipeline of installations with similar characteristics streamlines permitting, economic development, and job growth for governments.

In short, this combined policy and market mechanism to promote solar deployment not only benefits suppliers and customers, but it also can accelerate the growth and maturity of a statewide renewables market.

Three Critical Elements of a Successful Campaign

A well-designed campaign comprises three basic steps: first, raise awareness. Second, understand and tap into customer motivation. Third, convert motivation to action.



EDUCATION: GETTING THE CUSTOMER GOOD INFORMATION

The first step is getting the word out—educating town residents about both the campaign underway and the value of solar. In Solarize CT, local print newspapers were the single most important source for learning about the campaign. Other effective avenues were workshops, town events, and town websites; interestingly, social media was the least effective method for spreading the word.

Prominent visual displays like banners and yard signs also kept the campaign front-of-mind among residents. In towns where local regulations restricted public signage the lack of a constant visual reminder damaged the success of the campaign.

Outside of specific channels for marketing, four basic principles appear to drive household awareness of solar:

1. **Community networks** are the backbone of success, not just because they help to spread the word but also because they increase trust in the technology. Parent-teacher organizations (PTOs), clubs, civic groups, libraries, and churches are all great convening points to build community connections. Hosting events like those described above—solar tours and live installations—serves the same end.

2. Campaigns are most effective if **tailored** to the specific characteristics of the community. For instance, analysis of the Solarize CT campaign found that younger groups were most sensitive to price, which meant that the discount offered through Solarize attracted them to installations. Pricing mattered less and less moving up age brackets; older segments of the population were, instead, more persuaded by the trustworthiness provided by town sponsorship and vetted installers. (While solar ambassadors from the Connecticut campaign stressed that a "perfect pitch" should be tailored to the specific audience, they said that every communication should highlight the urgency of the campaign and the credibility earned through official support.)

3. Helping homeowners get their **technical questions** answered is as important as initially gaining their attention. Solarize workshops, usually held

at the launch of a campaign, and then periodically throughout the campaign, are simple ways to answer residents' technical questions.

4. Coalition towns i.e towns that partner on Solarize campaigns to increase capacity and potential adopters perform well, suggesting that a **friendly competition between towns can motivate** customers and/or campaign organizers.

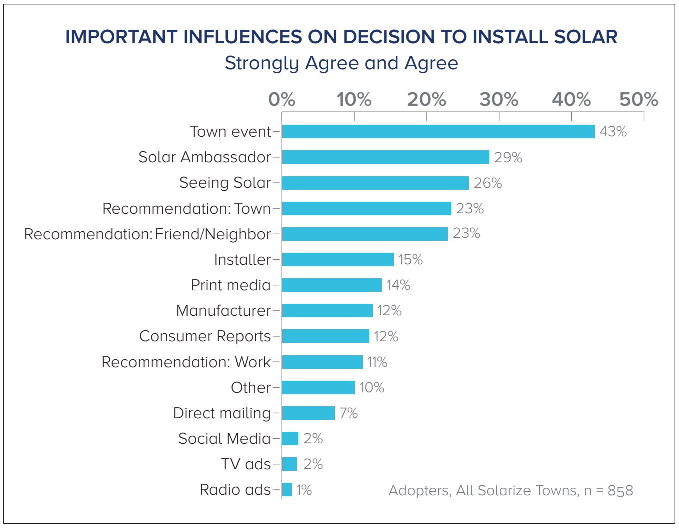
MOTIVATION: MOVING NEW CUSTOMERS TOWARD SOLAR ADOPTION

Customer education is a necessary first step, but some information is more motivating than other information in a campaign.

Start with the economics of going solar. Communicating the discount provided through Solarize—a tiered pricing model in which more money is saved when more people sign up—plus the prospect of saving money on energy bills. From there, once you have a better feel for the customer, introduce complementary reasons for going solar. Solar ambassadors—the locals spearheading a campaign—should think creatively about this facet of communication; it's better to avoid leaning exclusively on arguments like "it saves you money" or "it's good for the environment."

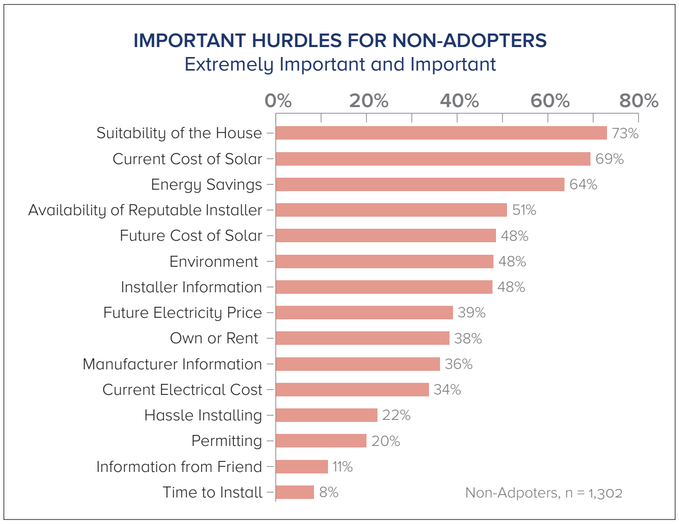
For example, in Simsbury, Connecticut, ambassadors found customers who were not simply motivated by the return on investment of solar. Some saw solar as a way to give back to the rising generation of their grandchildren. Others, frustrated with the local electric utility in the wake of power outages cause by Hurricane Sandy, were persuaded by ambassadors who framed solar as a way of gaining independence from the utility. A diversity of messages around the value of solar serves a campaign well.

Support from trusted actors, like local government and high-profile citizens or elected officials, also helps motivate people to install solar. Municipal leaders who



dedicate themselves to the success of local campaigns (through sponsorship of promotional materials, town-led events, personal outreach, etc.) legitimize the campaign as a program that residents can have faith in. Solar installers were especially appreciative of this third-party credibility.

In thinking about what motivates people to adopt solar, it's important to also consider specific hurdles to adoption. In the Solarize CT campaign, 75 percent of non-adopters mentioned unsuitability of their house as a reason for not going solar, and nearly 70 percent highlighted the current cost of solar as a barrier. While siting issues are difficult to overcome, innovative financing options, such as power purchase agreements, play a



critical role in unlocking solar for households. Leaders of a Solarize campaign should map these hurdles in planning and preempt them in execution.

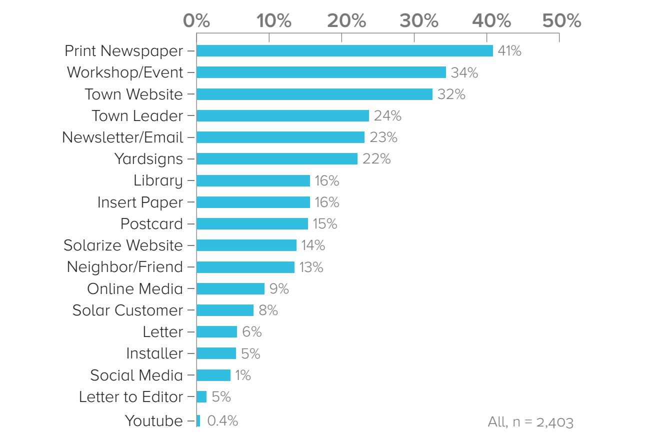
ACTION: CONVERTING INTEREST INTO INSTALLATIONS

Finally, two components of a campaign are especially useful for turning prospective buyers into paying customers.

First, the urgency of the campaign, with its strict (generally 20 week) deadline, is a particularly powerful force for motivating action. The majority of sign-ups in Connecticut occurred in the last several weeks of the campaign. In fact, knowing that the campaign end-date motivated customers to take action, installers were able to time their investment of resources at this stage of the campaign. (Notably, campaigns with end-dates close to the winter holidays and poor weather faced challenges with converting community outreach activities into customer sign-ups.)

Second, social diffusion—the combined influence of peers talking about and installing solar—has a marked effect on citizens' final decision to install solar. Create as many opportunities as possible for people to meet and talk about solar; highlight installations as they go up.

HOW DID YOU HEAR ABOUT SOLARIZE



STARTING THE SOLARIZE CAMPAIGN RIGHT

How a town or city introduces its community to Solarize helps set the campaign tone. Solarize CT was careful to schedule launch events that matched the sponsor community, asking towns to find a venue that would attract people and seat at least 100.

Every launch had elements in common: introductions by the Energy Committee Chair, a welcome by the Chief Elected Official, a presentation by SmartPower and CT Green Bank, and a presentation by the solar installer, who detailed a number of practicalities, from "how solar works" to "how to pay for a system." But each event also had its own charm and culture; they took place in historic buildings, school cafeterias, grange halls, town halls, and libraries. Easton/Redding/Trumbull held their launch on Sunday afternoon—full brunch included—because commuters came home from work too late to attend evening meetings. Westport launched its campaign at a local environmental center with wine and cheese.

MARKETING AND COMMUNICATION

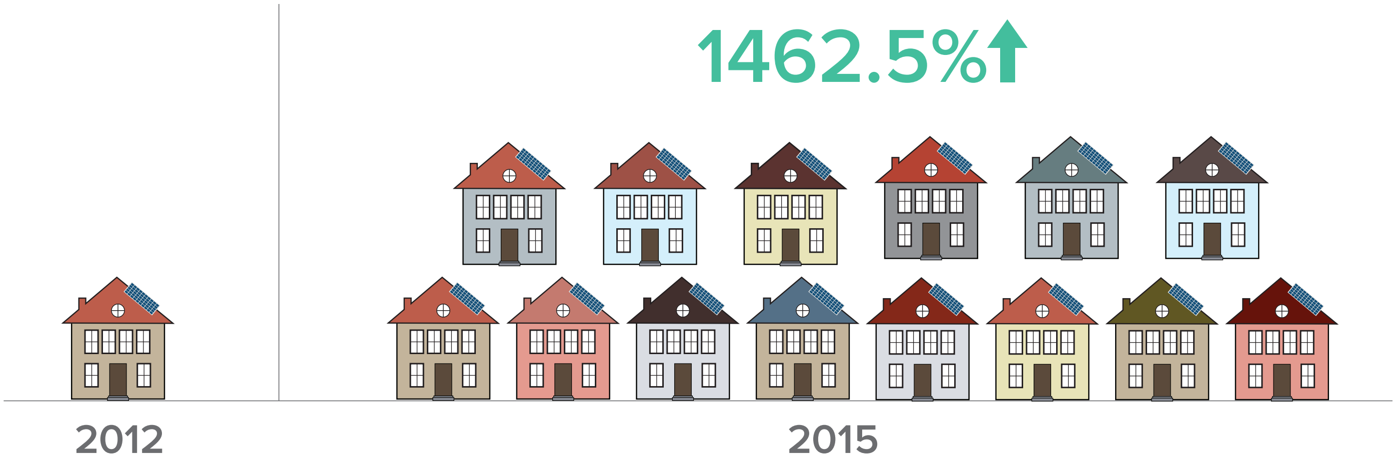
Constant communication is key, and marketing strategies should integrate both local media and live events. A few examples of outlets for advertising the campaign: town newsletters, the town website, local newspapers, workshops, town events, and local meeting groups. Prominent visual displays, such as banners and yard signs, are especially helpful to keep the campaign front-of-mind. In the Solarize Connecticut campaign, the six most effective methods for reaching community members, in order, were: print newspapers, workshops/events, the town website, the town leader, a newsletter/email, and yard signs.

BUILD A COALITION OF STAKEHOLDERS

For the Solarize CT campaign, organizations from the public, private, and nonprofit sectors were all involved. These broad partnering efforts created a rich ecosystem around a renewable energy market. Presented below are the core stakeholders for the campaigns in Connecticut, with a short summary of their roles.

- State agency: lends support and legitimacy to a campaign; accelerates consumer-financing options alongside local lending partners.
- Town leadership: provides legitimacy and raises awareness
- Solar ambassadors: locally trusted sources who advanced word-of-mouth recommendations, recruit volunteers, and organize/host informational events
- Installer: connects with consumers, follow-up on leads, installs solar systems
- Marketing firm: if budgeting permits, a marketing firm can help spread the word

The Path Forward



In Connecticut, solar installations increased dramatically from 2012–2015

Solarize campaigns have the potential to dramatically increase the adoption rate of rooftop solar photovoltaic systems. Connecticut's experience demonstrates a radical effect: in just three years, the number of homes with solar grew from about 800 to over 12,500, with Solarize responsible for about 20 percent of this growth. Campaigns leverage existing social networks and provide a wide range of benefits:

- Reduced energy bills for consumers
- Streamlined permitting, economic development, and job growth for governments
- Cohesion around a single campaign for communities
- New customers, increased sales, and business expansion for solar installers
- A reduction in greenhouse gas emissions through the replacement of fossil fuel energy sources with renewables

More broadly, the coalition of organizations supporting a Solarize campaign create a strong foundation for a robust clean energy market that no single actor could achieve in isolation.

As such, these campaigns are more than a simple behavioral or marketing innovation for capitalizing on the power of social networks. Rather, Solarize serves as an innovation with the potential to induce widespread progress around renewable energy. As the price of renewables continues to drop, and the profile of renewables continues to rise, consumers will be more predisposed to consider solar as a valuable energy option.

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Appendix A – Experimental Design of Solarize CT

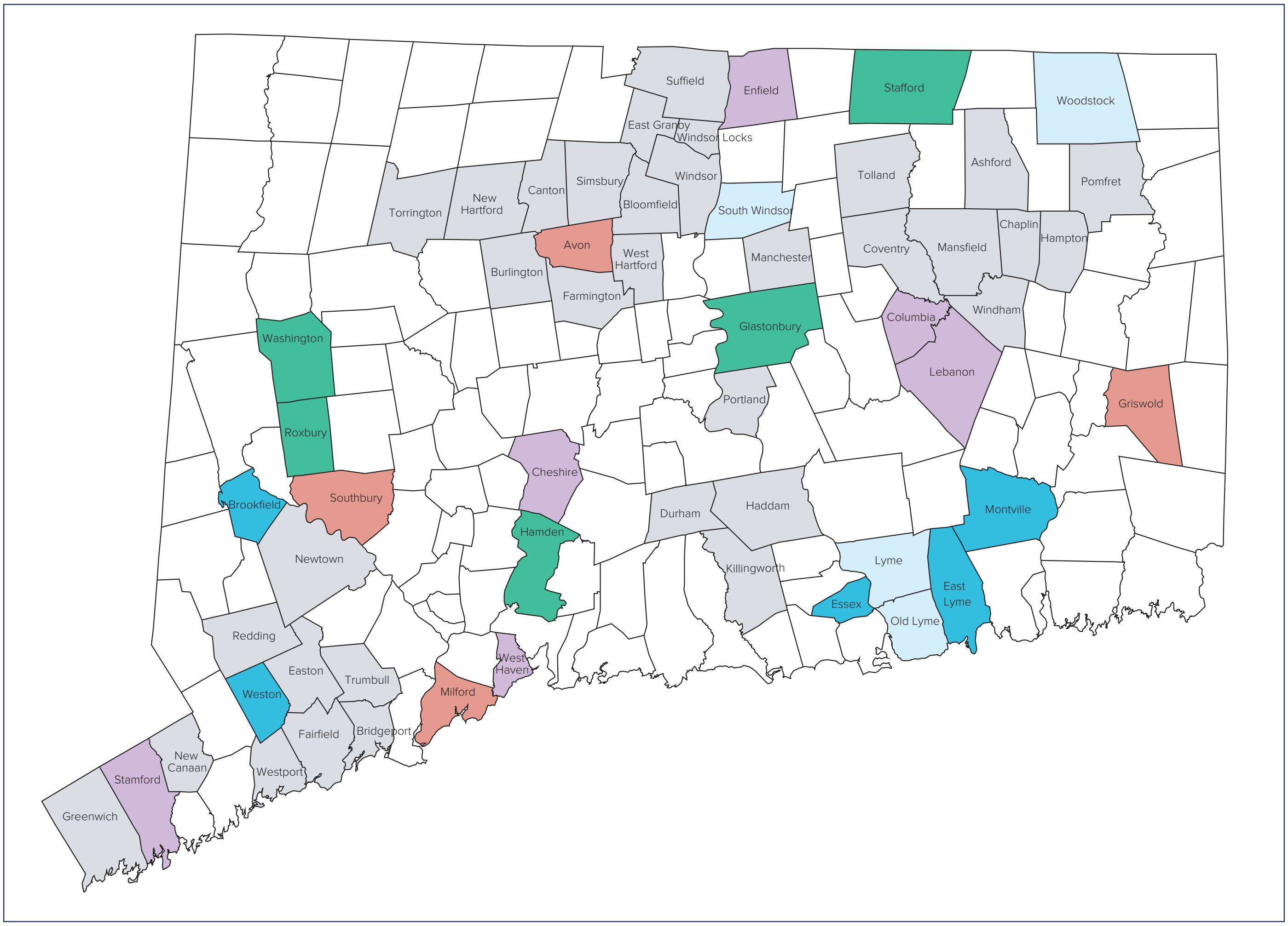
Solarize campaigns share central tenets of community-based outreach, a clear end-date, discount pricing, and some number of pre-determined installer(s) or price options. Our research tested five variations on the "Classic" model, which is described below. By adjusting a single campaign variable at a time, researchers from Yale and Duke Universities were able to capture the direct value of single aspects of the campaign. How important, for instance, is the 20-week campaign length? Might that be shortened without sacrificing effectiveness?

The table and figure across offer, respectively, a snapshot of each model and where it was implemented across the state.

The table on page 22, for each variation, offers a thorough summary, its benefits and potential considerations if implementing.

VARIATIONS OF SOLARIZE CT

MODEL	TOWN MOTIVATION	LENGTH OF CAMPAIGN	PRICING OFFER	# INSTALLERS	QUOTE COMPARISON
Classic	Competitive Application	20 Weeks	Tiered	1	N/A
Select	Selected At Random	20 Weeks	Tiered	1	N/A
Express	Competitive Application	10-12 Weeks	Tiered	1	N/A
Prime	Competitive Application	20 Weeks	One Low Price	1	N/A
Choice	Competitive Application	20 Weeks	Tiered	2-3	In-Person
Online	Competitive Application	20 Weeks	N/A	5+	Online Platform



MODEL	HOW IT WORKS	BENEFITS	CONSIDERATIONS
Classic[11]	• 20 Weeks • Tiered Pricing • One Installer	• 20 weeks allowed communities time to plan and execute their campaigns • Single installer simplified choice for customers and simplified coordination for campaign organizers • Tiered pricing encouraged a peer-to-peer effect with customers striving to reach the highest tier • Proven model nationwide	• With a single selected Solarize installer, residents did not have a choice of installation company if they wanted to take advantage of the Solarize discount • Smaller installers needed to expand capacity quickly to meet higher demand
Express[12]	• 12 Weeks • Tiered Pricing • One Installer	• Suggestive evidence that Express was more effective per week, but less effective in aggregate (neither difference is statistically significant). Theoretically, Express campaigns could save implementation costs. (This was not the result of Solarize CT) • Word of mouth played a much smaller role in leading people to adopt	• Express did not deliver the expected cost savings: SmartPower and CT Green Bank had to increase their administrative support and increase their investment in coordination efforts to meet the earlier deadline • Towns needed to invest in up-front planning to make marketing effective during the short campaign • All installers who participated in an Express program reported that the timeframe was too short
Choice[13]	• Multiple Installers • One Low Price	• Compared to Classic, Choice towns were more successful in terms of the percentage increase in total number of installations. Several installers competing for business appeared to play a key role in this uptake dynamic • Solarize Choice towns had the lowest prices – the average system price in Choice towns was 2.65$/W compared to 2.72$/W in Round 3 Classic towns • Choice experienced sustained price discounts post-campaign • Customers felt confident that they were getting a good price with participation of multiple installers • Strong growth rates were observed post-campaign, suggesting that the campaign brought installers in touch with more residents	• Installers and Solar Ambassadors reported that choice created confusion for some customers • More coordination effort was required • Installers highlighted the need for strong guidelines to execute effectively. A number of installers reported poor customer experience, lost leads due to overwhelming or conflicting information, and increased cost of customer acquisition

MODEL	HOW IT WORKS	BENEFITS	CONSIDERATIONS
Select[14]	• Towns Selected At Random To Join	• Allowed residents to experience the benefits of a Solarize campaign even if their towns did not have the time or resources to commit to the application process • For some towns, the “you’ve been chosen” message was motivating as a special opportunity • Results show that Solarize can still be effective in randomly selected municipalities	• Whilst still effective, results show a lower effect when municipalities do not opt-in on their own; level of interest/ resources may be lower
Prime[15]	• One Low Price • Single Installer	• Simplified the decision-making process for residents: one installer and one price • Word-of-mouth from community members declined in effectiveness but was offset by other word-of-mouth channels (friends, coworkers, etc.)	• Limited homeowners’ choice to a single installer • Without the pressure of tiered pricing, with discounts contingent on numbers signed up, residents may have been less inclined to encourage others in their towns to install with them
Online[16]	• Compare Quotes Online, • Multiple Installers	• Gave residents more choice and provided them with easily accessible information to make decisions • Customers were able to easily compare quotes with apples-to-apples assumptions • Residents were able to utilize the assistance of an online solar coach to help guide them in their decision • Competition among installers reduced prices—a reduction that persisted even after the campaign ended	• In CT, the Solarize Online campaigns generally did not perform as strongly • Limited installer visibility and engagement • With many participating installers, it was reported that some customers felt an overload of information; onus on customer to compare installer quotes • Potential technical barriers associated with user access of online platform

11 Gillingham and Bollinger (2017) “Social Learning and Solar Photovoltaic Adoption: Evidence from a Field Experiment,” Yale University Working Paper
12 Bollinger, Gillingham, and Tsvetanov (2016) http://environment.yale.edu/gillingham/BollingerGillinghamTsvetanov_SalesDurationGroupBuys.pdf
13 Bollinger, Gillingham, and Lamp (2017) “Long Run Effects of Competition on Solar Photovoltaic Demand and Pricing,” Yale University Working Paper
14 Gillingham and Bollinger (2017) “Social Learning and Solar Photovoltaic Adoption: Evidence from a Field Experiment,” Yale University Working Paper
15 Bollinger, Gillingham, and Tsvetanov (2016) - http://environment.yale.edu/gillingham/BollingerGillinghamTsvetanov_SalesDurationGroupBuys.pdf
16 Bollinger, Gillingham, and Lamp (2017) “Long Run Effects of Competition on Solar Photovoltaic Demand and Pricing,” Yale University Working Paper

Appendix B – Financing Residential Solar Installations

Though the mix of reasons for participating in Solarize varied across demographics, the discount pricing consistently proved to be the predominant motivation. In fact, nearly 70 percent of respondents highlighted the current cost of solar as a barrier to adoption.

Innovative financing options, such as power purchase agreements, therefore have a critical role to play in unlocking solar for households.

In Connecticut, the CT Green Bank, a state-level institution devoted to expanding the region's clean energy sources, lent its support to the Solarize program in three basic ways:

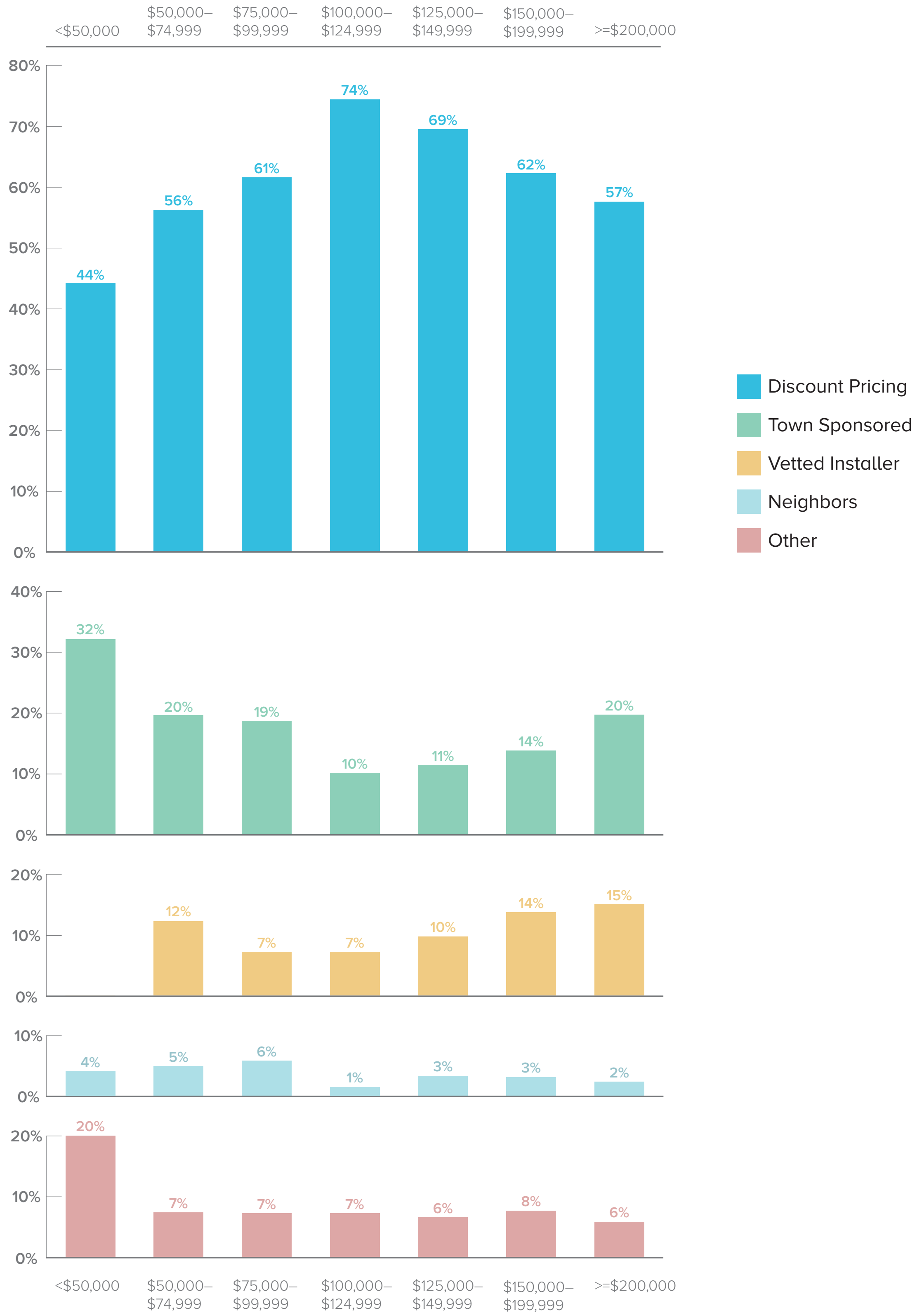
1. The Bank oversaw the Request for Proposal process among solar installers, vetting all of the applicants and establishing quality controls. This formal "stamp of approval" gave homeowners confidence in local suppliers.

2. The Bank contracted with the clean energy marketing organization SmartPower to raise the profile of solar across the state.

3. Most importantly, the Bank accelerated consumer financing options by developing risk-reduction mechanisms in partnership with local lending and capital partners.

The existence of the CT Green Bank has prompted private-sector investment in clean energy infrastructure at a scale that may otherwise have been impossible. States pursuing Solarize should consider in what capacity they can help homeowners overcome the barrier of cost.

MOST IMPORTANT REASON FOR PARTICIPATING BY INCOME



Feasibility of Renewable Thermal Technologies in Connecticut

MARKET POTENTIAL

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March 2017

Yale Center for Business and the Environment

energize CONNECTICUT

CONNECTICUT GREEN BANK

EVERSOURCE ENERGY

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In preparing this report, the Yale team benefitted particularly from the extensive collaboration, insights, and experience of key players pursuing the deployment of renewable and efficient energy solutions in the Connecticut market. Without the thorough debate around assumptions, and the reality check of results along the way, the conclusions would not be as well founded. We would like to thank the following individuals for substantive contributions to the study:

- Bryan Garcia, Connecticut Green Bank
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In addition, we would like to thank Natural Resources Canada for making RETScreen Expert available for the team and patiently responding to our questions. We are furthermore indebted to numerous regional program administrators for providing portfolios of technical and economic data for renewable thermal projects supported through their programs. Namely, the Massachusetts Clean Energy Center, Northern Forest Center, New Hampshire Public Utilities Commission, Vermont Clean Energy Development Fund, and Connecticut Green Bank.

The Yale team remains solely responsible for any errors or omissions in this report.

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LIST OF ACRONYMS

AEO	Annual Energy Outlook
ACS	American Community Survey
ASHP	Air Source Heat Pump
CBECS	Commercial Buildings Energy Consumption Study
CDD	Cooling Degree Days
CES	Comprehensive Energy Strategy
CO_2e	Carbon Dioxide Equivalent
CT	Connecticut
DEEP	Department of Energy and Environmental Protection
EIA	Energy Information Agency
EPC	Energy Performance Contract
ESCO	Energy Service Company
EUI	Energy Use Intensity (BTU/Square feet)
GC3	CT Governor's Council on Climate Change
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
HDD	Heating Degree Days
NPV	Net Present Value
PACE	Property Assessed Clean Energy
PSD	Program Savings Document
PV	Photo Voltaic
RECS	Residential Energy Consumption Study
RTT	Renewable Thermal Technologies
SCC	Social Costs of Carbon
SEDS	State Energy Data System
SHW	Solar Hot Water
TPO	Third Party Ownership
TRECs	Thermal Renewable Thermal Credits

Executive Summary

Renewable thermal technologies (RTTs) harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking.[1,2]

In 2014, a total of 344 trillion British thermal units (BTUs) were delivered for stationary energy purposes in residential, commercial, and industrial sectors in Connecticut (CT).[3] Over 60 percent of the energy used in residential and commercial buildings was for space heating and cooling in 2012.[4] Changing from fossil fuels to RTTs in heating and cooling buildings, as well as in heating industrial processes, has the potential to provide a valuable contribution to meeting Connecticut's statutory target of reducing greenhouse gas emissions 80 percent below 2001 levels by 2050.

The purpose of the "Feasibility of renewable thermal technologies in Connecticut" research project is twofold: to assess a realistic contribution from RTTs in achieving Connecticut's transition to a less carbon-intensive economy, and to establish the knowledge necessary for effective policies and strategies to advance RTTs in Connecticut. In addition to this market potential study, the project included a field study on RTT market barriers and drivers.[5]

Although application of RTTs in the industrial sector is promising, both because of the sector's large thermal demand and because it produces waste energy that can be utilized, it has not been included in this study due to its heterogeneity and complexity.

Our analysis estimates a thermal demand in Connecticut buildings of 126 trillion BTUs in 2050, with a sensitivity range of 103–142 trillion BTUs. The lower end of the sensitivity range assumes higher annual rates of deep retrofits and stricter building codes; the upper end of the range assumes that outdoor temperatures will remain at current levels for the next several decades. In fact, however, significantly

1 Cooking is not part of this study.

2 This definition has been adapted by the Renewable Thermal Alliance, a private-public partnership established to develop the infrastructure for large-scale deployment of renewable thermal technologies in Northeast America: http://cbey.yale.edu/programs-research/renewable-thermal-alliance

3 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

4 2013 Connecticut comprehensive energy strategy: http://www.ct.gov/deep/lib/deep/energy/cep/2013_ces_final.pdf

5 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

higher temperatures during both heating and cooling seasons are expected as the region's climate changes,[6] and our analysis indicates that this results in a net reduction in the overall thermal demand of buildings.

Today, approximately 83 percent of the thermal demand of residential and commercial buildings is supplied directly by fossil fuels. Heating and cooling buildings and domestic hot water represent around 12.6 million metric tons CO_2e emissions per year, which corresponds to 30 percent of Connecticut's GHG emissions in 2013.[7] RTTs can play an important role in realizing a low carbon future. However, current market prices, existing installations and infrastructures represent considerable economic challenges to RTTs.

The competition analysis—examining how RTTs compete with traditional thermal technologies—includes seven archetypal categories of existing buildings. The RTTs include three alternative cases for air source heat pumps (ASHPs) representing different end-uses and physical limitations of the existing heating system. The RTT analysis also includes ground source heat pumps (GSHPs), solar hot water (SHW), and biomass. (Biomass pellets are used as a proxy for solid biomass in this study.) To supplement the RTT analysis, the study also examined highly efficient natural gas boilers as an alternative to traditional thermal technologies. Incumbent technologies include fuel oil, natural gas (standard efficiency), and conventional electric technologies (e.g., electric resistance heating). Financial viability has been evaluated on the basis of net present value and simple payback.

The base case assumes that RTTs deliver the end-user's entire annual thermal demand. Generally, heat pumps are assumed to deliver the user's space cooling and heating, and biomass and highly efficient natural gas are assumed to deliver the user's space and water heating. Solar hot water and ASHP water heaters are assumed to deliver the water heating. No financial incentives are included in the base case. No infrastructure costs have been included, with the exception of some heat pump alternatives in which the level of incremental installation costs has been varied to take into account existing building's physical limitations have to some extent been handled by varying the level of incremental installation costs.

Our competition analysis shows that 19 percent of today's thermal demand in Connecticut buildings can be met competitively by RTTs, representing an unrealized potential for reduced annual GHG emissions of 1.4 million metric tons CO_2e.[8] Of particular interest are air source heat pumps to replace conventional electric technologies for space heating and cooling and biomass pellets to replace fuel oil in some commercial settings.

6 U.S. Global Change Research Program, "National Climate Assessment," http://nca2014.globalchange.gov/.

7 See http://www.ct.gov/deep/lib/deep/climatechange/2012_ghg_inventory_2015/ct_2013_ghg_inventory.pdf

8 The GHG emission calculations are based on the RETScreen Expert inventory and rely on its modeling concept.

Fuel prices have a large impact on how competitive RTTs are compared to conventional thermal technologies. Currently at $16.63 per MMBTU,[9] natural gas prices are low, and natural gas boilers out-compete conventional and renewable thermal technologies in most settings.

To reduce GHG emissions by 80 percent in the thermal demand of buildings by 2050 (relative to 2001 levels), the GHG emissions related to thermal end-uses would have to be reduced from 12.6 million metric tons CO_{2e} to approximately 3 million tons CO_{2e}. This would require a considerable reduction in thermal demand in combination with deployment of RTTs and de-carbonized electricity generation. In today's market conditions, an array of interventions is necessary to realize Connecticut mandatory emission reduction targets using renewable thermal alternatives that currently present both favorable and unfavorable economics.

Although replacement of standard gas and fuel oil boilers with highly efficient gas boilers represents one of the cheapest means to reduce GHG emissions today, doing so extensively is not sufficient to reach the target and would lock in fossil fuel technologies that could prevent Connecticut from achieving an 80 percent reduction in GHG emissions by 2050. The high share of natural gas boilers in the commercial sector already represent a barrier to RTTs and thus inhibits Connecticut's ability to achieve needed reductions in GHG emissions. Nevertheless, replacing standard natural gas boilers with highly efficient gas boilers and decarbonizing the gas grid by, for example, injecting biogas from anaerobic digestion could supplement market strategies to promote RTTs.

Projections in this report are illustrations of what may happen given certain assumptions and methodologies. The team has performed several sensitivity analyses to evaluate the impact of potential market changes and policy instruments. Unless otherwise indicated, the practice has been to change only a single parameter at a time.

9 EIA SEDS as of October 2016.

PARAMETER FOR SENSITIVITY ANALYSIS	DESCRIPTION	MAIN IMPACT ON NET PRESENT VALUE COMPARED TO BASE CASE
Base case	See Appendix A for key assumptions	Heat pumps are competitive with conventional electric technologies in most customer categories. Additional costs related to physical limitations such as ductwork are a challenge, particularly in commercial sector settings. Solar water heating as an alternative to conventional electric technologies is competitive in the residential sector and for commercial customers with a considerable demand for hot water. Biomass is competitive as an alternative to fuel oil in many commercial settings. Highly efficient natural gas boilers are generally competitive with conventional electric technologies and fuel oil boilers.
Fuel costs	50 percent increase for incumbent case	All heat pump alternatives and solar water heating are competitive with conventional electric technologies across all customer categories. Biomass is competitive with fuel oil, and highly efficient natural gas boilers are competitive with standard efficient gas boilers.
	100 percent increase for incumbent case	Heat pumps and solar water heating are competitive with fuel oil in several customer categories, particularly in commercial settings. Biomass pellets are competitive with natural gas. Highly efficient natural gas boilers are competitive with standard gas boilers.
	25 percent reduction for proposed case	Only ASHPs for space heating and cooling, and ASHP water heaters remain competitive with conventional electric heating. Solar water heating remains competitive with conventional electric heating in residential sector. Biomass is competitive with fuel oil in all customer groups.
	Solar PV delivers drive energy of proposed case	Solar PV at an installation cost of $2.5 per Watt improves the competitiveness of heat pumps and solar water heating. Although GSHPs still have a negative, net present value due to high incremental installation costs, their operational costs are competitive with those of natural gas boilers.

PARAMETER FOR SENSITIVITY ANALYSIS	DESCRIPTION	MAIN IMPACT ON NET PRESENT VALUE COMPARED TO BASE CASE
Incremental initial costs	25 percent reduction	RTTs are generally competitive with conventional electric technologies. Biomass is competitive with fuel oil in residential sector, and highly efficient natural gas boilers are competitive with standard natural gas boilers in most customer categories.
	RTT for partial load (60 percent of capacity and ~80 percent of load)	In general, renewable technologies become more competitive with traditional thermal technologies.
Carbon price	Carbon price of $41 per tCO_2	A few additional heat pump alternatives are competitive with conventional electric technologies. Biomass is generally competitive with fuel oil.
Thermal Renewable Energy Certificates (TRECs)	TRECs corresponding to a market price of $25 per MWh	Impact similar to the carbon price alternative.
Financial terms	25 percent reduction of debt interest rate	Minor impact on NPV.
	25 percent increase of debt term, with economic life of asset as maximum debt term	Minor impact on NPV.
Sets of simultaneous changes	25 percent reduction of • incremental initial costs • electricity prices for the proposed case due to use of solar PV • pellet prices A carbon price of $120 per tCO_2	Heat pumps and solar water heating are competitive with conventional electric technologies for all customer categories. ASHPs, biomass, and highly efficient natural gas boilers are competitive with fuel oil. Biomass and highly efficient natural gas are competitive with standard natural gas boilers.
	25 percent reduction of • incremental initial costs • electricity prices for the proposed case via use of solar PV 50 percent increase of incumbent case fuel costs	As in previous case but additional heat pump alternatives become competitive. Fuel prices are less predictable than a carbon price.

Table 1 | Overview of sensitivity analysis

With the current market situation, combinations of marketing strategies, financing products, and policy instruments—such as a stricter building code combined with TRECs, soft cost strategies and financing products—are required to make RTTs competitive.

This report concludes with the following recommended market strategies to improve the competitiveness of RTTs, which are supplementing the recommendations of the field study on barriers and drivers: [10]

1. Reduce upfront costs. Initial installation costs have large impacts on how competitive the RTT is and how much capital the customer has to raise upfront. Available strategies:
   - Cost reduction campaigns à la Solarize.[11]
   - Partial-load strategies: using RTTs to displace most of the thermal demand for space heating but not requiring them to cover 100 percent of the capacity needed for peak demand.
   - New business and financing models to eliminate upfront costs and secure 100 percent financing via loans, leases, and property assessed clean energy financing.

2. Implement market interventions to improve the operational cash flow. Available strategies:
   - Packaging RTTs with solar PV and deep renovation.
   - Favorable interest rates and debt terms to reduce risk for private lenders, lend credibility to the technology, and qualify it as environmentally friendly.
   - Carbon pricing.
   - Thermal Renewable Energy Certificates.
   - Explore rate mechanisms that recognize the value of RTTs in reducing demand for natural gas and electricity.

3. Enhance awareness and trust in RTTs through marketing efforts, trusted messengers, and proven installations. Available strategies:
   - Performance verification to show that the technologies deliver as promised and to facilitate new financial models and attract investors.
   - Green Bank involvement in projects and technologies to enhance credibility.
   - Declining block grants.

4. Use the building code and standards to reduce thermal demand and establish a predictable minimum market for RTTs.

This market potential study has not evaluated the feasibility of district energy. District energy and thermal grids may represent opportunities for cheap and clean thermal energy, exploiting waste energy from electricity generation and industrial processes.

10 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

11 Solarize CT is a community-based program that leverages social interaction to promote the adoption of solar through a group-pricing scheme intended to reduce soft costs. See http://solarizect.com/

CHAPTER 1
Introduction

Background

In 2014 a total of 344 trillion BTUs were delivered for stationary energy purposes in residential, commercial, and industrial sectors in Connecticut.[12] Over 60 percent of the energy used in residential and commercial buildings is for space heating and cooling.[13] Changing from fossil fuels to renewable thermal technologies (RTTs) in heating and cooling buildings, as well as in heating industrial processes, has the potential to provide a valuable contribution to meeting Connecticut's statutory target of reducing greenhouse gas emissions to 80 percent below 2001 levels by 2050.

The purpose of the "Feasibility of renewable thermal technologies in Connecticut" research project is twofold: to assess a realistic contribution from RTTs in achieving Connecticut's transition to a less carbon-intensive economy, and to establish the knowledge necessary for effective policies and strategies to advance RTTs in Connecticut.

The goal of reducing Connecticut's greenhouse gas (GHG) emissions by 80 percent below 2001 levels by 2050 was adopted in the 2008 Global Warming Solutions Act.[14] The Governor's Council on Climate Change (GC3), established in April 2015, is charged with examining the opportunities and challenges as the state pursues to achieve this target.

Analysis by the GC3 to date, has demonstrated that meeting the 2050 target will require a combination of measures across the entire state economy.[15]

The business context for RTTs will be different in 2050 and will be influenced by actions taken today. This can be illustrated by Figure 1, which spans four futures along two axes: thermal electrification versus gas expansion, and individual versus community solutions.

12 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

13 2013 Connecticut Comprehensive Energy Strategy: http://www.ct.gov/deep/lib/deep/energy/cep/2013_ces_final.pdf

14 See https://www.cga.ct.gov/2008/ACT/PA/2008PA-00098-R00HB-05600-PA.htm

15 Analysis presented to the GC3 on July 26th: http://www.ct.gov/deep/cwp/view.asp?a=4423&Q=568878&deepNav_GID=2121

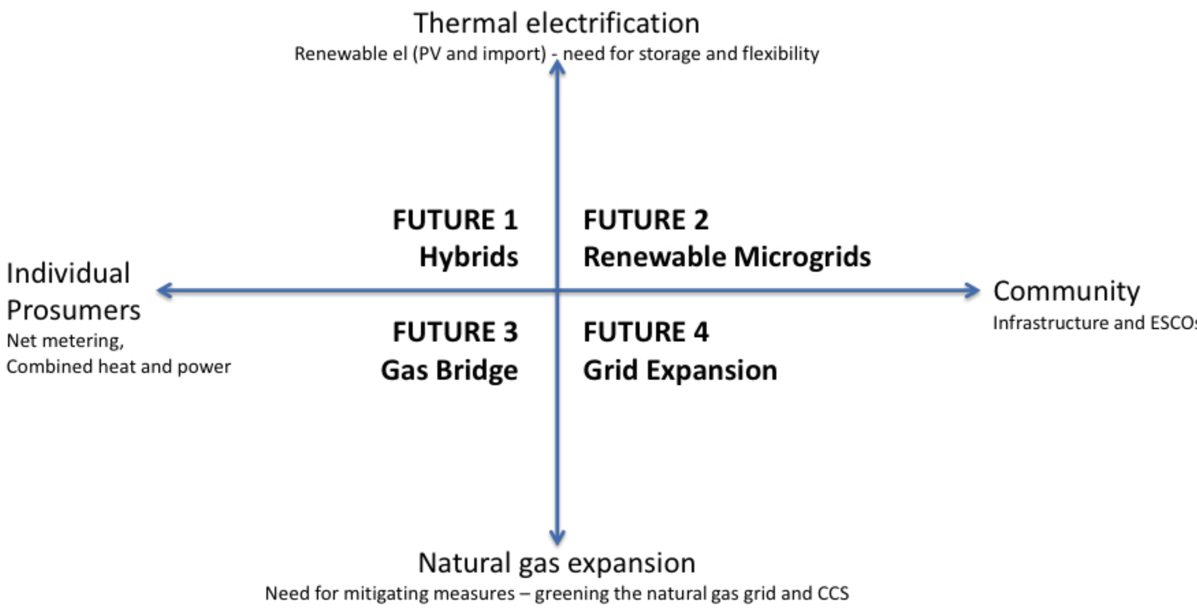


Figure 1 | Possible future competition fields for RTTs. Intended for illustration only.

The market for RTTs in future 1 would be different from that of future 4, with regard to both physical infrastructure and relative prices.

This study has not evaluated the feasibility of district energy. District energy and thermal grids represent opportunities for cheap and clean thermal energy, for instance by exploiting waste energy from electricity generation and industrial processes. These processes have not been included due their heterogeneity and complexity. District energy, community thermal grids and industrial thermal processes can offer important opportunities for RTT.

Framework for the Study

The framework for the project incorporates Connecticut's desire to move toward a cheaper, cleaner, and more reliable energy future while creating economic growth. The study has been guided by the definitions in Table 2.

CHEAPER A fuel source is considered cheaper for the customer when the net lifetime costs represented by the net present value of the technology are lower than that of the alternative that would otherwise have been preferred.	**CLEANER** A technology is considered cleaner when it has lower operating emissions of greenhouse gases (GHG) than the alternative technology that would otherwise have been preferred by the customer.
MORE RELIABLE A reliable energy system: • has enough energy to cover basic end-uses at a reasonable cost at all times • is robust in the face of short- and long-term changes in any individual energy source • is based on several energy sources that interact and complement each other	**ECONOMIC GROWTH**[16] Investment in and deployment of RTTs creates direct, indirect, and induced jobs. Direct economic benefits come from effects created by an investment in clean energy resources.[17] Indirect economic benefits result from changing demands that help produce clean energy technologies.[18]

Table 2 | Key terms for this study. Note: The above definitions present non-binding evaluation criteria and have been formulated to guide the research process.

16 See http://www.ctgreenbank.com/wp-content/uploads/2017/02/CTGReenBank-Memo-CT-Dept-Economic-Community-Development-October142016.pdf

17 e.g., income of local contractor, sales of equipment.

18 e.g., income of supplier companies, sales of materials for the equipment.

Definitions of Technologies

Renewable thermal technologies harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking.

RTTs utilize a broad range of renewable energy sources that otherwise could be lost. RTTs include:

- Heat pumps, such as air source heat pumps, ground source heat pumps, and heat pump water heaters
- Solid biomass, such as wood chips, pellets, and wood
- Liquid and gaseous biofuels
- Solar thermal technologies
- Waste heat technologies, including district heating and cooling

Different RTTs deliver heating and cooling at different temperature levels. Temperature levels are important to define the suitability of different technologies for meeting specific heat requirements in various end-use sectors. RTTs can range from small domestic applications to large-scale applications used in industrial processes and district heating and cooling networks. As RTTs often utilize locally available energy resources to meet on-site heating and cooling demand, customized solutions are often required.

We have applied the following definition of renewable energy resources:

"**Renewable energy resources** represent the annual energy flows available through sustainable harvesting on an indefinite basis. While their annual flows far exceed global energy needs, the challenge lies in developing adequate technologies to manage the often low or varying energy densities and supply intermittencies, and to convert them into usable fuels. Except for biomass, technologies harvesting renewable energy flows convert resource flows directly into electricity or heat. Their technical potentials are limited by factors such as geographical orientation, terrain, or proximity of water, while the economic potentials are a direct function of the performance characteristics of their conversion technologies within a specific local market setting."[19]

19 Grubler A, Nakicenovic N, Pachauri S, Rogner H-H, Smith KR, et. al. (2014): Energy Primer. International Institute for Applied Systems Analysis, Laxenburg, Austria, p. 40.

Market Definitions

This study analyzes the market potentials of various thermal technologies according to the framework shown in Figure 2.[20]

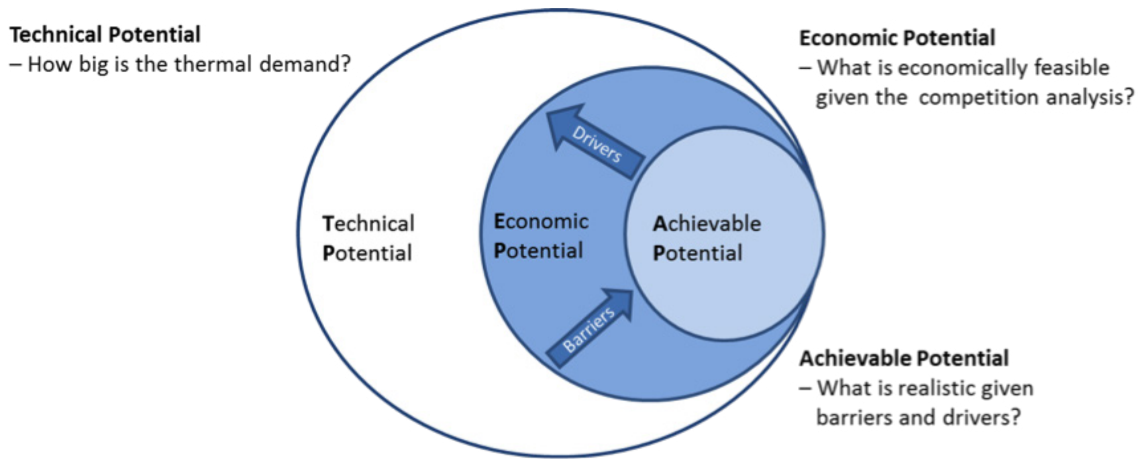


Figure 2 | Framework for market potentials.

TECHNICAL POTENTIAL

Technical Potential, also known as Total Addressable Market, is the theoretical maximum amount of thermal energy use that could be served by renewable thermal technologies, disregarding all non-engineering constraints such as cost-effectiveness and the willingness of end-users to adopt the technologies. It is often estimated as a “snapshot” in time assuming immediate implementation of renewable thermal technologies.

The technical potential for RTTs in Connecticut has been estimated and analyzed in Chapter 4: Technical Potential—Demand Analysis.

20 The market definitions are based on the framework offered by the National Action Plan for Energy Efficiency (2007). Guide for conducting energy efficiency potential studies. Prepared by Philip Mosenthal and Jeffrey Loiter, Optimal Energy, Inc. www.epa.gov/eeactionplan

ECONOMIC POTENTIAL

Economic Potential, also known as Serviceable Available Market, refers to the subset of the technical potential that can be cost-effectively served by renewable thermal technologies as compared to conventional thermal technologies. Both technical and economic potential are theoretical numbers that assume immediate implementation of renewable thermal technologies, with no regard for the gradual "ramping up" process typically in deployment of new technologies. In addition, they ignore market barriers to ensuring actual implementation of renewable thermal technologies. Finally, they consider only the costs of renewable thermal technologies themselves, ignoring any programmatic costs (e.g., marketing, analysis, administration) that would be necessary to deploy them widely.

The economic potential for RTTs in Connecticut has been estimated and analyzed in Chapter 5: Economic Potential—Competition Analysis.

ACHIEVABLE POTENTIAL

Achievable Potential, also known as Serviceable Obtainable Market or maximum achievable potential, is the amount of thermal energy use that RTTs can realistically be expected to serve assuming the most aggressive program scenario possible (e.g., providing end-users with payments for the entire incremental cost of the RTT).

The achievable potential takes into account real-world barriers to convincing end-users to adopt renewable thermal technologies, the non-measure costs of delivering programs (for administration, marketing, tracking systems, monitoring, and evaluation, etc.), and the capability of programs and administrators to ramp up program activity over time.

This report analyzes current technical and economic potential associated with RTT deployment in Connecticut. Barriers and drivers have been mapped through a field study documented in a separate report.[21]

21 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

CHAPTER 2
State of the Market

The residential sector is the largest user of energy, with a net consumption of 171 trillion BTUs in 2014; this is followed by the commercial sector, (112 trillion BTUs) and then the industrial sector (62 trillion BTUs).[22]

The mix of energy sources for thermal purposes, estimated at 200 trillion BTUs, varies across the sectors as shown by Figure 3.[23]

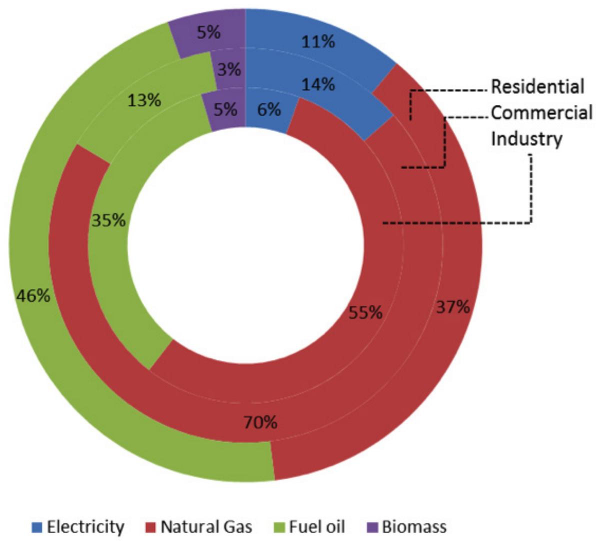


Figure 3 | Estimated current mix of energy sources for thermal purposes. Sources: EIA SEDS, AEO 2015 and own analysis in chapter 4.

As can be seen from Figure 3, the residential and industrial sectors have a high share of fuel oil, while natural gas dominates the commercial sector. The share of thermal demand supplied by electricity may comprise electrically driven heat pumps. However, the share of heat pumps in Connecticut appears to be low.

The number of RTT installations can be estimated based on feedback from the industry and sample surveys: the Connecticut Geothermal Association[24] indicates that the number of residential and commercial GSHPs installed in Connecticut per year is approaching 700. New construction seems to

22 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

23 The current mix of energy sources for thermal purposes has been estimated based on the technical potential from Chapter 4, the consumption by energy sources from EIA SEDS 2014 and the energy by end-use from AEO 2015.

24 Email correspondence August 28th, 2016

dominate the installations. Residential wood use was 339 thousand cords-equivalent of wood in 2014 and 3.9 trillion BTUs for commercial and industrial wood and biomass waste use that same year.[25] The Biomass Thermal Energy Council indicates that cumulative installations of biomass in Connecticut are fairly low and slow-building, explained by a higher rate of natural gas connections in CT than in other New England states.[26] Solar assisted thermal systems were supported through The Connecticut Clean Energy Fund (CCEF), the predecessor to the Connecticut Green Bank, from 2009 through 2013. Two different programs together funded 278 residential and 86 commercial solar thermal installations, and industry representatives indicate that the market has slowed down since then.[27]

In 2014, NMR Group concluded a sample survey among 180 single-family homes that also registered thermal systems.[28] The number of respondents to the study secured a confidence interval of 90 percent. Based on this study and the number of single-family homes in Connecticut in 2013, the total number of RTT installations for space heating in Connecticut has been estimated according to Table 3.

RTT	SINGLE-FAMILY HOMES	SHARE OF HOMES IN EACH PRIMARY FUEL CATEGORY	ESTIMATED TOTAL INSTALLATIONS (AS OF 2013)
ASHP	Primary source	1.7 percent	14,740
	Secondary source	2.8 percent	24,560
GSHP		0.6 percent	4,910
Solar assisted system		1.1 percent	9,820
Biomass[29]	Pellets	1 percent	8,841
	Wood	1 percent	8,841

Table 3 | Estimated total number of renewable thermal installations for space heating in Connecticut in 2013. Sources NMR Group and DCED.[30,31]

25 See http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_ww.html

26 Email correspondence September 21st, 2016

27 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

28 NMR Group Inc (2014): Single-Family Weatherization Baseline Assessment.

29 Due to rounding of percentages in Table 6-1 of the NMR study, the number of homes with wood and pellet installations is reported here as identical.

30 See http://www.ct.gov/ecd/cwp/view.asp?a=1106&q=250640

31 See 2000 Census of Population and Housing: http://www.ct.gov/ecd/LIB/ecd/20/14/2000censushousingandhousing.pdf

The number of detached and attached single-family homes was 884,120 in 2013. Based on this, the NMR study indicates that approximately 565,840 households used fuel oil as the primary energy source for space heating. 9 percent of the homes of the NMR study had installed ASHP for space cooling, and GSHP provided cooling to 1 percent of the homes.

A separate field study conducted by Yale University[32] shows that the RTT market is thin, with only a few installers providing RTTs and most of these focusing on specific technologies. With the exception of ductless ASHPs, the supply side of RTTs is characterized by low demand, low rates of cooperation across technologies, and a general discontent with the level of financial support, particularly compared to solar PV. An inadequate supply chain for pellets is perceived as another challenge. There have been issues related to the quality of installations of some RTTs, and there is a general difficulty finding qualified employees for this sector.

The demand side, on the other hand, experiences difficulties finding installers. This creates concerns related to future maintenance and replacement of RTTs. However, even more prevalent seems to be the customer awareness of RTTs, including their basic use and their distinction from solar PV. Financing options are generally unknown to the customers, who often are highly cost conscious and price sensitive at the time of the investment decision.

32 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

CHAPTER 3
Methodology

Overall Framework

The role of RTTs in achieving Connecticut's GHG reductions was studied with a bottom-up approach that analyzes the cost effectiveness of competing thermal technologies. The analysis was first done on a project level; then results were aggregated on the state level.

The technical potential represents the estimated maximum size of the state's market for thermal energy at different points in time, including the end-uses of space heating, space cooling, and water heating. The competitiveness of RTTs compared to conventional thermal technologies was analyzed for different customer categories using a commercially available tool, RETScreen Expert developed by CanmetENERGY Research Center at Natural Resources Canada.[33] (Appendix D).

The most competitive technology was chosen as the preferred technology for each customer segment and its particular thermal end-use. The economic evaluations on project levels were aggregated and calibrated to correspond to the technical potential.

Figure 4 presents the steps of this approach graphically.

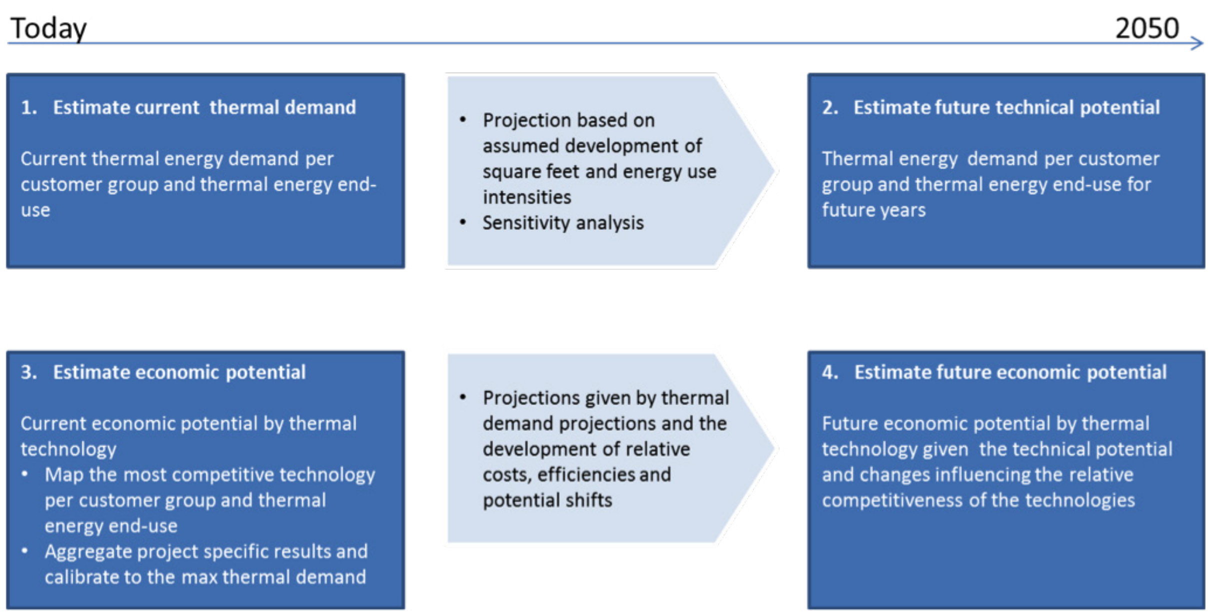


Figure 4 | The overall methodological framework for estimating technical and economic potential for RTTs.

33 http://www.nrcan.gc.ca/energy/software-tools/7465

The study has attempted to use data at a state or regional level where available. The EIA Annual Energy Outlook (2015) has also been an important reference for several assumptions in the analysis.

STEP 1—ESTIMATE THE CURRENT THERMAL DEMAND

First, the current demand for thermal energy end-uses per customer group was estimated. The aggregate demand for space heating, space cooling, and water heating was calculated by multiplying the total square footage of the existing building stock, differentiated by customer category, with the respective Energy Use Intensity (EUIs).

STEP 2—ESTIMATE FUTURE THERMAL DEMAND

The technical potential was estimated till 2050. For space heating, space cooling, and water heating, the technical potential was estimated by multiplying the square footage of existing building stock, projected new buildings, and projected demolitions by the respective EUIs, known and projected. The projected EUIs for the future periods were established using the current EUIs adjusted for an annual energy efficiency rate in the year in question.

Sensitivity analyses were established to highlight the uncertainty related to future projections. The sensitivity analyses highlight the impacts of applying different references for current average EUIs, energy efficiency rate, outdoor temperature levels, and required building standards of new buildings.

The technical potential was used to calibrate the estimated economic potential per customer group and end-use for the different years being studied.

STEP 3—ESTIMATE THE CURRENT ECONOMIC POTENTIAL

The modeling on a project level seeks to evaluate the cost-competitiveness and cleanness of RTTs against incumbent technologies. The simulations let decision-makers understand how different technologies perform, and how different assumptions and incentive structures affect competitiveness.

Running scenarios, we can provide a quantitative understanding of how much each RTT affects the use of fossil fuels, and thus reduces GHG emissions in Connecticut.

The simulation results for each archetypal customer were scaled to the state level using respective thermal load data and growth rates for representative customer groups. Lifecycle costs and benefits are considered using simple cash-flow and NPV models. In addition, the performance of the RTTs in terms of delivered thermal related end-use services is used to calculate the impact on GHG reductions relative to the state-level goals.

The conceptual steps for estimating the economic potential based on project evaluation are illustrated in Figure 5.

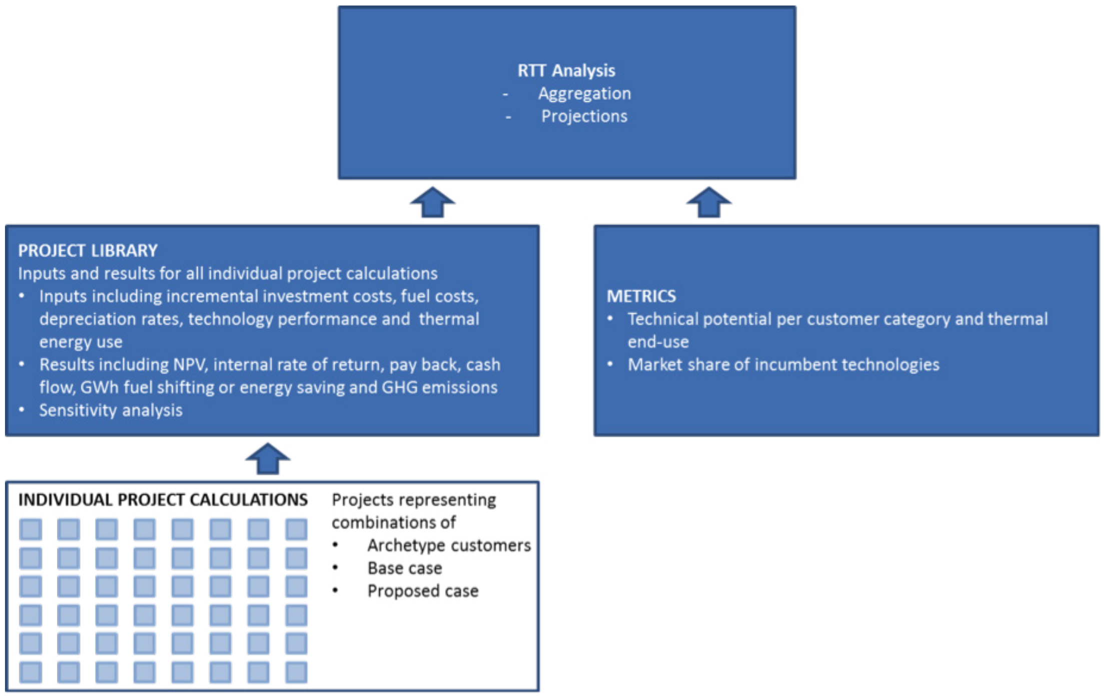


Figure 5 | Concept for estimating the economic potential for RTTs.

In order to analyze the cost effectiveness of RTTs, the research team applied RETScreen Expert due to its flexibility, inclusion of a broad range of technologies, ability to generate energy and emission changes, as well as its complex financial analysis capabilities. The model allows for comparing base cases representing incumbent or conventional technologies to the proposed cases of different RTTs. In addition to RTTs, highly efficient natural gas boilers were included to the analysis.

The model calculations of this study include:

- 7 archetypal customers
- 3 incumbent thermal technologies
- 7 proposed renewable or highly efficient thermal technology alternatives

The combinations of incumbent thermal technologies and proposed RTTs for all archetypal customers represent individual projects that constitute a "project library" of input and output data.

The "RTT analysis" aggregates individual results to a state level using input and results from the project library as well as metrics from the technical potential analysis.

STEP 4—ESTIMATE FUTURE ECONOMIC POTENTIAL

The economic potential was projected to 2050 by linear extrapolation of the individual project calculations within the scope of the technical potential.

The economic potential is influenced by the relative competitiveness of the technologies, given by investment costs, fuel prices, financial incentives and policies, performance of thermal technologies, and type of thermal end-uses served by each technology. The projected technical potential defines the maximum market that the different technologies compete within.

Sensitivity analyses were established to highlight the uncertainty of the competition analysis. The sensitivity analyses highlight the impacts of applying different relative costs and prices of the technologies as well as financial incentives and instruments.

Future Projections and Shifts

The projections assume linearity between today and 2050. There may be several shifts that can cause a break in this linearity, such as new superior technological solutions, new policies, economic shifts, or changes in other parts of the energy system.

Shifts, to some extent, will be interrelated, e.g. a new technology solution can be facilitated through policy choices and experiences of climate change. We have studied implications of a set of policy alternatives through the sensitivity analysis, but have only to a limited extent accounted for shifts due to innovations or future policies.

The market diffusion of novel and energy-efficient technologies is often prevented by high initial costs. Economies of scale and improvements of technologies can drive down costs and improve the competitiveness of the technologies. The cost-benefit performance of technologies can be improved through technological learning, which can be mapped through so-called learning rates. The technological learning rate quantifies the rate at which the costs decline with each doubling of cumulative production.

The learning rates of RTTs have been studied to a lesser extent than those of technologies for electricity generation, such as solar PV. Weiss et al (2010)[34] have reviewed some RTTs as part of their study of energy demand technologies. They find learning rates of energy demand technologies of 18 percent +/- 9 percentage points. Residential heat pumps are found to be in the upper end of this range, and conventional residential heating technologies in the lower end. Learning rates for heat pumps will, however, depend on the degree of site specificity.

34 Weiss, Martin; Martin Junginger; Martin K. Patel and Kornelius Blok (2010): A review of experience curve analyses for energy demand technologies. Journal of Technology Forecasting and Social Change 77 (2010), 411–428

Learning rates for different technologies, from heat pumps to conventional boilers, show time dependency and variability depending on the system boundaries chosen for analysis. Quality of data, choice of period, costs included in the analysis etc. influence the results, which limits the applicability of the learning curve approach for modeling technology change in energy and emission scenarios.

Most RTTs included in this analysis are globally mature technologies experiencing incremental improvements over time. The market for RTTs in Connecticut, however, appears to be immature. An immature market influences cost levels through lack of volume both in acquisition and installation.

Learning rates will impact the analysis only to the extent that they differ across technologies. We assume that the relative competitiveness of technologies remains the same. However, reduced incremental costs of RTTs compared to conventional alternatives is highlighted through the sensitivity analysis.

Addressing GHG Emissions

The analysis has shown which technology would be a customer's "first choice" from a purely economic point of view. These "first choices" are then used to estimate the change in GHG emissions that would result from replacing one thermal technology with another. The GHG emission calculations are based on the RETScreen Expert inventory and rely on its modeling concept. The GHGs included are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The GHG emission factors are fixed for the entire lifetime of the project. The following emission factors have been applied in this study:

- Electricity: 0.281 $kgCO_{2e}$ per kWh (0.302 $kgCO_{2e}$ per kWh including transmission losses), which corresponds to the average mix of energy sources delivered to the New England ISO grid
- Biomass pellets (refuse-derived pellets): 0.036 $kgCO_{2e}$ per kWh
- Fuel oil: 0.252 $kgCO_{2e}$ per kWh
- Natural gas: 0.179 $kgCO_{2e}$ per kWh

GHG emission factors depend on the carbon accounting method and data that is applied. The RETScreen Expert GHG emission factors are based on the IPCC Guidelines for National GHG Inventories.[35] This inventory represents average values for direct GHG emitted relative to a defined amount of activity such as energy demand.

The RETScreen inventory was chosen to make sure that the GHG emission factors are calculated according to a uniform methodology across energy sources. This implies applying average GHG

35 The RETScreen GHG emission factors take into account emerging rules for carbon finance. The emission analysis section of RETScreen Expert was developed in collaboration with the United Nations Environment Programme and the Prototype Carbon Fund at the World Bank. More information on GHG emissions factors in RETScreen Expert can be found in the model's user manual.

emission factors for the energy sources, which may not capture the variability of emissions by the origination of the energy sources. The IPCC framework furthermore focuses on direct emissions rather than emissions over the entire lifecycle of the energy source. GHG emissions in extraction, transportation, transformation into usable fuels and combustion may vary both across and within categories of energy sources.

It was outside of the scope of this study to map local GHG emission factors based on the origin of the energy sources.

As shown by the Oil-Climate Index of the Carnegie Endowment for International Peace,[36] total GHG emissions from the highest-emitting oil are about 60 percent higher than for the lowest-emitting oil. The Oil-Climate Index addresses both the issue of averages not capturing the full range of observed variability in emissions and the issue of including emissions throughout the lifetime of the fuel. Due to the wide range of emissions from global oils, it matters which oil is burned. Natural gas faces similar issues, where extraction and transformation potentially can cause large variability in emissions depending on the origin of the natural gas.

Unlike CO_2 emissions factors for fossil fuels, factors for biomass[37] combustion are not directly included in energy sector accounting. This accounting convention is based on the rationale that CO_2 of biogenic origin is part of the natural carbon cycle: carbon stored in biomass fuel has been sequestered from the atmosphere relatively recently, and it is assumed that when the fuel is burned the carbon released will be offset by carbon taken up when new biomass is grown. The assumption is made without regard for the specific forest husbandry policies and practices prevailing in the region where the biomass was harvested, even though these policies and practices strongly influence the rate of carbon uptake. A lifecycle carbon accounting framework based on New England biophysical characteristics and forest management practices has been applied in some studies comparing biomass to fossil fuels.[38]

36 See http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index-pub-59285

37 Biomass is defined as any organic matter derived from plants or animals available on a renewable basis. Biomass used for energy includes wood and agricultural crops, herbaceous and woody energy crops, municipal organic wastes as well as animal manure. Biomass feedstock can be provided as a solid, gaseous or liquid fuel, and can be used for generating electricity and transport fuels, as well as heat at different temperature levels for use in the building sector, in industry and in transport. Source: International Energy Agency (IEA)(2014): Heating without global warming. Market developments and policy considerations for renewable heat.

38 Manomet Center for Conservation Sciences (2010): Massachusetts biomass sustainability and carbon policy study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Buchholz, Thomas, and John Gunn (2016): Northern Forest wood pellet heat greenhouse gas emissions analysis methods summary.

The biogenic emissions framework of the IPCC Guidelines for National Greenhouse Gas Inventories represents the most widely accepted framework for national reporting of biogenic GHG emissions, although application of this framework in the European Union and elsewhere is subject to criticism.[39]

Emissions inventories, such as those compiled by the US EPA, also address emissions from land use, land-use change, and forestry. To the degree that bioenergy production affects the amount of carbon stored on land, it will impact the emissions or absorption of carbon reflected in the national greenhouse gas inventory. However, by convention, these emissions are not attributed to the energy sector, even when they stem from use of combustion technologies.[40]

Scientists have explored various ways to estimate the potential climate impact of biogenic CO_2 emissions. Such estimates invariably focus on hypothetical scenarios involving the terrestrial carbon cycle. They range from analyses based on individual stands of trees or crop plantations[41] to integrated land use models also incorporating agricultural and forestry economics.[42] In general, such assessments find that policies that enhance terrestrial carbon storage are beneficial and can be reconciled with bioenergy use. Notably, however, aggressive use of bioenergy in the absence of policies designed to enhance terrestrial carbon storage can be counterproductive, at least in the short and medium term.

In short, both the type of biomass used and local land-use management influence land use-related GHG emissions from biomass. The adequacy of biomass stock in New England and the adequacy of the region's forest husbandry policies and practices were not taken into account in this study.[43] Neither was the origin of fuel oil or natural gas applied in the region.

39 See, e.g.: Warren Cornwall (2017): Biomass under fire: Is wood a green source of energy? Scientists are divided. Science Magazine. http://www.sciencemag.org/news/2017/01/wood-green-source-energy-scientists-are-divided. John Upton (2015): Pulp fiction: The European accounting error that's warming the planet. Climate Central. http://reports.climatecentral.org/pulp-fiction/1/.

40 US EPA (2016): Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014. EPA 430-R-16-002. See in particular footnote (a) to the summary table and Section 3.10.

41 Cherubini, F., G. P. Peters, T. Berntsen, A. H. Strømman, and E. Hertwich (2011): CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy 3(5): 413–426.

42 Klein, D., F. Humpenöder, N. Bauer, J. P. Dietrich, A. Popp, B. Leon Bodirsky, M. Bonsch, and H. Lotze-Campen (2014): The global economic long-term potential of modern biomass in a climate-constrained world. Environmental Research Letters 9(7).

43 For several reasons, CT DEEP does not agree with the methodology this study adopted for biomass: (a) the emissions factor adopted for biomass combustion does not account for the region's existing forestry practices, even though forestry practices strongly influence the lifecycle GHG emissions associated with using the region's woody biomass as fuel; (b) the analysis of biomass's potential contribution to meeting the state's thermal demand does not account for the extent of the commercial biomass pellet market that can be maintained with biomass feedstock's sustainably harvested in New England; (c) extensive development of biomass as a thermal fuel in Connecticut likely would conflict with the state's statutory goals for complying with National Ambient Air Quality Standards for criteria pollutants; and (d) claims about the market potential of biomass combustion in Connecticut and the GHG benefits associated with this potential should be considered in the context of other air pollutants.

A further caveat is that in this study the GHG calculations use “biomass pellets” as a proxy for solid woody biomass. The RETScreen Expert inventory provides factors for two solid biomass fuels: “biomass” (meaning woody biomass) and “refuse-derived pellets.” The latter—selected for this study—has a substantially higher GHG value and therefore represents a conservative alternative within the IPCC framework. Gaseous or liquid fuels produced with biomass feedstock were not analyzed.

This study focuses on GHG emissions only. Air-pollutants such as particulate matters are not considered.

Limitations and Boundaries

Though this bottom-up approach facilitates detailed analysis of specific technologies, thermal demand categories, and financial models, it has its limitations.

Analyses have been done for a set of archetypal customers for the residential and commercial sectors using a variety of RTTs. The RTT choice for each setting is nuanced, as capital for investments, surface area, orientation of exterior surfaces, incumbent fuel type, and end-uses can vary greatly. Given the complexity and potential permutations, we have addressed some of the most common customer categories, technologies, and end-uses. We recognize this assumption as a limitation, albeit a necessary one, to this project. The building categories that have been analyzed cover buildings of different sizes and with varying thermal energy needs, as can be seen from Table 4.

RESIDENTIAL	COMMERCIAL		
• Single-Family home • Apartment building	• Hotel • Medium office	• Education • Food Services	• Hospital inpatient

Table 4 | Archetype customers established for economic evaluation.

The economic and environmental evaluations are defined by the boundaries of the analysis. The boundaries have implications as to which costs and benefits are included, and the level and differentiation of prices and GHG emission factors. This is illustrated by Figure 6.

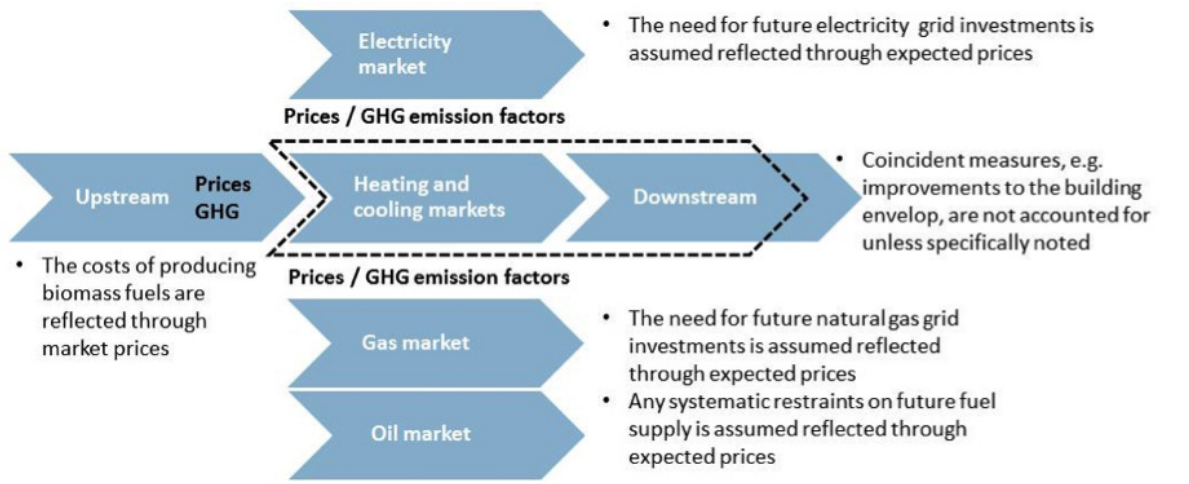


Figure 6 | Boundaries to the analysis.

The dotted arrow represents the boundaries of the economic analysis, and the interaction with the energy system at large. The upstream parts of the value chain, such as the production of processed biofuels, are represented through market prices delivered to the facility. Any future changes in the overall energy system are expected to be accounted for through price projections, where applicable.

The price projections of this study are based on the growth rates applied in the AEO 2015. The average electricity rates and natural gas rates of Connecticut are the base of the projections. Recent decisions[44] to cancel plans for added natural gas pipeline capacity were not known at the time of publishing AEO 2015.

Although RTTs can effectively help alleviate peaks in the energy demand of Connecticut by diversifying the pool of energy supply and delivering services balanced throughout the day and night, it is necessary to be aware of the features of the different RTTs compared to conventional alternatives. RTTs have different impacts on the electricity and gas loads depending on their drive energy, efficiency over the year, and which energy source they replace. This has not been subject to analysis in this study.

RTTs often utilize locally available energy resources to meet the specific on-site heating and cooling demand of one or several buildings, thus customized solutions are often required. Though the bottom-up approach allows for some representation of specific conditions, the need for simplicity and conciseness limits modeling of the full range of combinations of existing technologies and resources. The following assumptions have been made regarding the investment choices of the customers:

44 October 25th, 2015: DEEP press release on canceling the natural gas RFP.

INCUMBENT ENERGY SOURCES	RENEWABLE THERMAL TECHNOLOGIES AND THERMAL END-USES
• Space cooling is based on electricity • Space heating and hot water is based on the same energy source: electricity, fuel oil, or natural gas • Space heating based on electricity is provided by electric baseboard	• ASHP delivers space heating and cooling • GSHP delivers space heating and cooling • SHW delivers hot water • Bio delivers space heating and hot water • Efficient natural gas boilers deliver space heating and hot water • ASHP water heaters deliver hot water

Table 5 | Assumptions for technology choices.

To avoid additional complexity in the analysis, the RTTs have been modeled to deliver the whole thermal demand of a building over the year, that being for space cooling, heating or hot water. Even if the incremental installation costs are given per installed capacity, this may exclude some financially favorable solutions. Oversizing RTTs should be avoided both to restrict installation costs and secure efficient operations; and keeping the incumbent energy source for peak load operations may be desirable. See chapter 6.2.2 for an analysis of some partial load alternatives.

ASHPs and SHW are considered a supplementary technology to the incumbent. Even if these technologies are applied as primary energy source, the incumbent technology often has to be kept as a backup. The implication of this classification for the analysis is related to assumptions on avoided costs. See Appendix A.

CHAPTER 4
Technical Potential—Demand Analysis

The demand for hot water, space heating, and cooling in the state of Connecticut represents the total technical potential for thermal technologies.[45]

The time frame of the analysis extends to 2050, with 2014 as the basis for the projections and EUIs established for residential and commercial customers.

The technical potential for buildings is driven by the expected development of square footage of different building categories and the EUIs for thermal purposes. Expected energy efficiency rates for different customer categories have been applied. The projections have been informed by the AOE and CT residential housing and population data.

Assumptions for Demand Projections

The assumptions cover the methodology of estimating floor space, EUIs, as well as the base case for the relevant customer segment.

The total number of housing units is assumed to grow at a net rate corresponding to the expected population growth as estimated by Connecticut State Data Center.[46]

The projections for commercial thermal demand through 2050 have considered AEO New England growth factors for different categories of commercial customers and AEO projections of square feet by distribution of the New England workforce by category.

Temperature change impacts on space heating and cooling have been considered to affect heating and cooling days as follows, based on AEO for New England:

- Annual rate for heating degree days -0.5 percent
- Annual rate for cooling degree days 0.9 percent

Cooled space relative to heated space has been considered to remain unchanged in the base case.

45 Thermal energy demand for cooking, clothes drying, and other thermal uses is not included in this study.

46 2015–2025 Population projections for Connecticut. November 1, 2012 edition

CUSTOMER SEGMENT	BASE CASE ASSUMPTIONS
Residential	• Renovation affects 1 percent of the floor space per year. These renovations reduce the need for space heating by 25 percent, on average • Technical systems for space and water heating representing 3 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain for space and water heating is 15 percent, on average
Commercial	• Renovation affects 0.4 percent of the floor space per year. These renovations reduce the need for space heating by 20 percent and space cooling by 20 percent, on average • Technical systems for space heating representing 2 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 15 percent, on average • Technical systems for water heating representing 2 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 20 percent, on average. • Technical systems for space cooling representing 3 percent of the floor space are replaced with more efficient equipment each year. Efficiency gain is 30 percent, on average.

Table 6 | Base case assumptions on technical demand potential.

Residential Sector

The population of Connecticut is 3.597 million[47] and lives predominantly in single-family homes.[48] According to the 2000 Census, 64 percent of residential units were single-family homes. The rest of the residential building base consists predominantly of multi-family buildings.

The aggregated residential technical potential is estimated to be 88.6 trillion BTUs by 2050 in the base case, with a sensitivity range between 73.1 and 100.4 trillion BTUs.

- Building age, performance, and size are all important drivers of thermal demand in the residential sector.
- Older houses predominate, and they also have higher EUIs, thus presenting a viable retrofit opportunity in the future.
- Cooled space is negligible in comparison to space and water heating, but climate impacts and increased CDD could drive demand for cooling in the future.
- Through 2050, residential thermal demand declines, at different rates depending on factors such as regulations on energy efficiency (building codes), and retrofit rates and depths.
- The reference case of an 80 percent reduction in residential thermal energy demand implies a technical potential of 24 trillion BTUs in 2050.[49] To achieve this, a more-than 5.5 percent annual rate of deep retrofit would be required until 2050, *ceteris paribus*.

47 See http://www.census.gov/quickfacts/table/PST045215/09

48 EIA defines a Single Family Home as follows: "A housing unit, detached or attached, that provides living space for one household or family. Attached houses are considered single-family houses as long as they are not divided into more than one housing unit and they have independent outside entrance." http://www.eia.gov/consumption/residential/terminology.cfm#m

49 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from residential thermal energy demand envisioned here is hypothetical.

ENERGY USE INTENSITIES

The EUIs applied in the analysis are differentiated by thermal purpose and type of residential building, as can be seen in Figure 7.

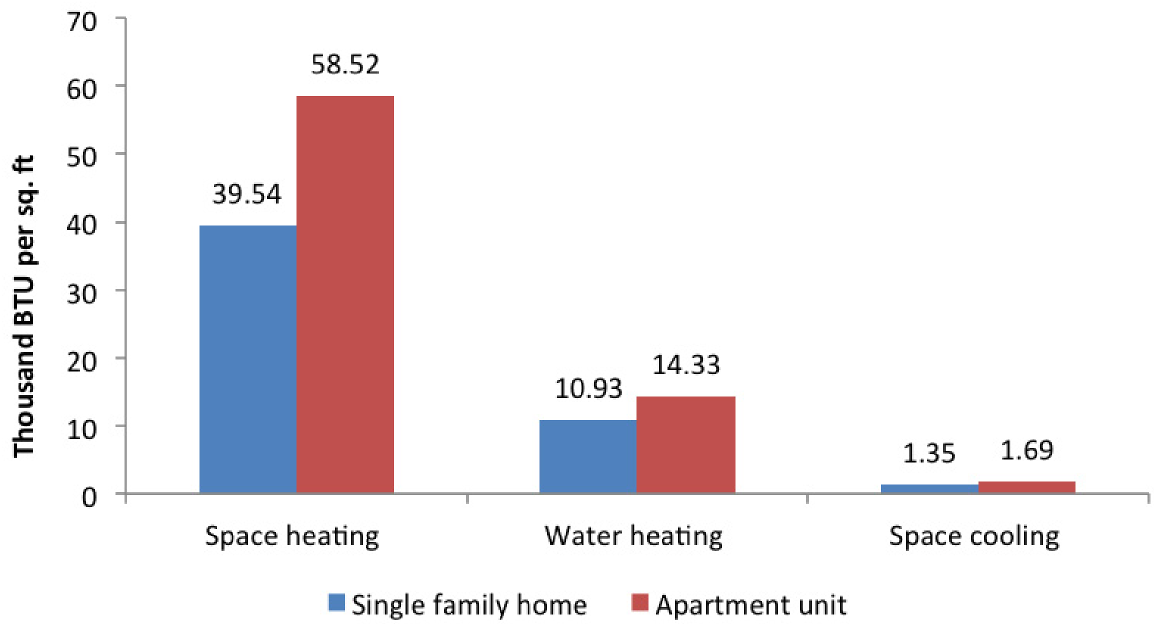


Figure 7 | Residential energy use intensity per square feet (2014 mean values), Source: RECS 2009 and PSD 2016.

Space heating per square foot is significantly higher in apartment units than in single-family homes. This can be explained by a higher share of conditioned space of the total square feet of the housing unit.

The EUIs for cooling are low, mainly due to a low share of central cooling in residential buildings in Connecticut.

The EUIs for space heating of buildings undergoing demolition has been estimated based on the weighted average age of the buildings built before 1960 and their EUIs for space heating (see Figure 9). The EUIs for newly constructed single-family homes are based on the 2016 PSD.

Assumptions for the cooling EUIs in new buildings are the same as for existing; thus cooling values in new buildings may be underestimated. Buildings undergoing demolition are assumed to not have space cooling.

ESTIMATED THERMAL ENERGY DEMAND

The size of the building is an important driver for thermal energy demand of residential buildings. The square footage has been established for CT through the number of homes in different categories, the average square feet, and growth rates of population and demolitions.

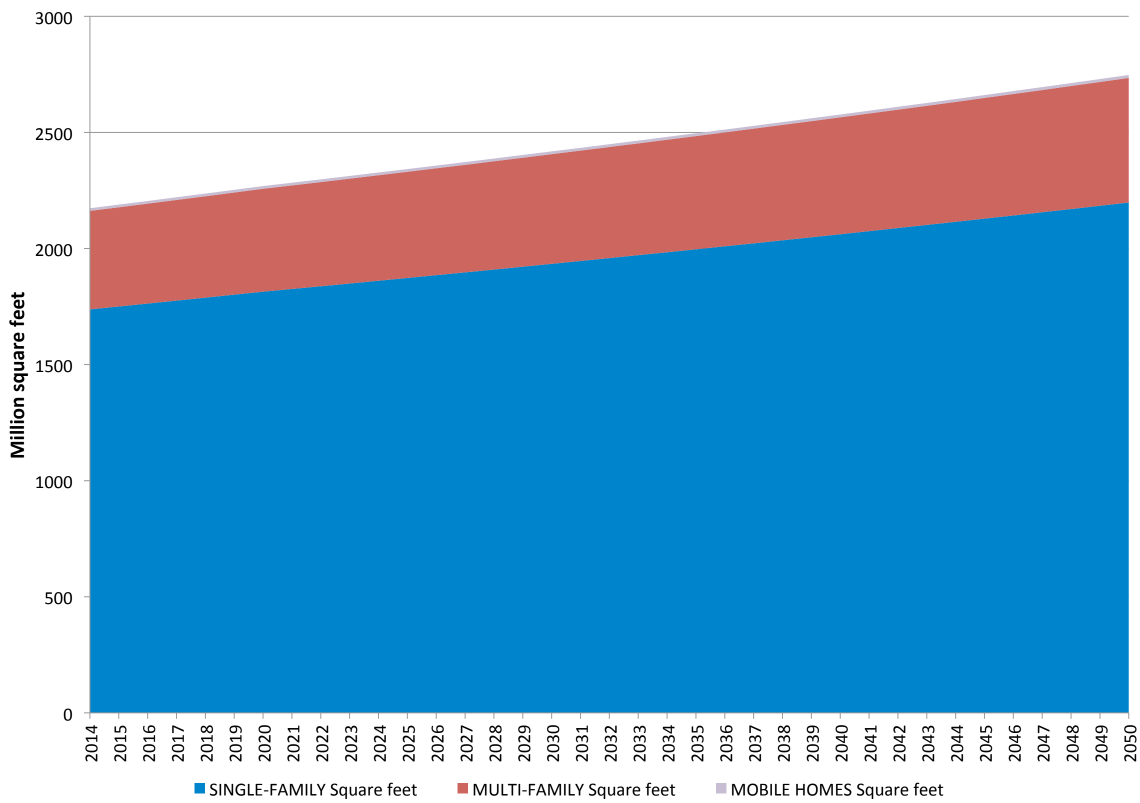


Figure 8 | Estimated heated floor space for occupied housing units, 2014–2050. Sources: CT DECD, American Community Survey, RECS 2009 and AEO 2015.[50]

The estimation shows a relatively steady building base over the time period.

The share of new residential buildings is relatively negligible compared to the existing building base. According to the analysis, approximately 89 percent of the estimated heated residential base in 2050 will have already been built. This represents a viable opportunity for RTTs and underlines the importance of replacing thermal installations at housing renovations.

50 Mobile homes are excluded from the rest of the analysis.

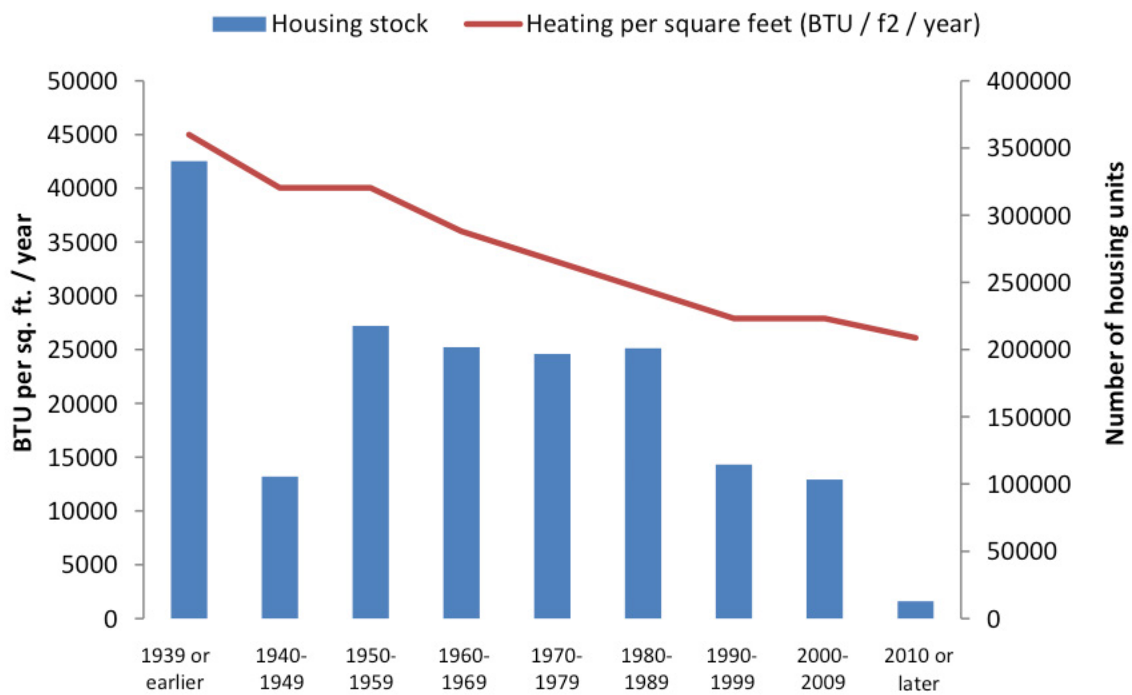


Figure 9 | Age Distribution of CT Housing. Sources: ACS 2014 and PSD 2016.

It is important to note the relation between building performance and age. As seen in Figure 9, the heating intensity declines for more recently constructed buildings. Older construction tends to have more air and heat leaks, which contribute to a higher demand for heating and cooling. In relation to age, it is also worth mentioning that relatively old buildings (built in 1939 or earlier) have a high representation in the distribution. The rate of new buildings has gradually declined since 1989.

The prevalence of older constructions has a direct relationship to the opportunity to install RTTs versus conventional technologies when retrofitting the building or heating system.

The size of buildings impacts its energy demand. This study assumes that the distribution between single-family and multi-family homes remains unchanged over time.

Energy demand is also related to occupancy levels and number of people per house. The occupancy rate distinguishes whether a building has occupants or is generally vacant. Data from the CT Department of Economic and Community Development[51] shows a great variation of vacancy rates across the state,

51 See http://www.ct.gov/ecd/cwp/view.asp?a=1106&q=250640

ranging from 3 to 38 percent (Tolland and Cornwall, respectively). While the average is 8 percent, it is challenging to forecast future social dynamics; occupancy nonetheless has implications on the energy demand of buildings.

The annual energy efficiency improvement rate applied to new construction is 0.73 percent for space heating, reflecting the historic development of Figure 9.

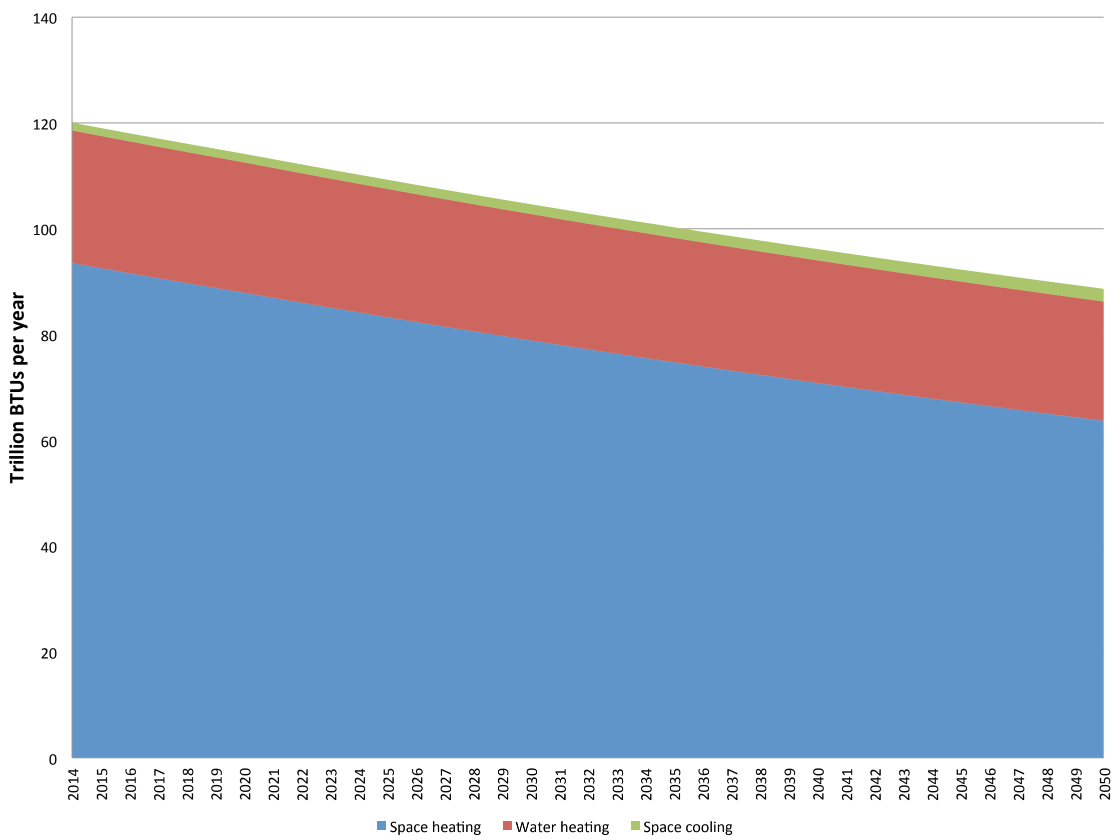


Figure 10 | Estimated residential thermal energy demand, 2014–2050.

The overall thermal energy demand follows a downward trend through 2050, despite the slight increase in the housing square footage. This decrease constitutes a lower burden on the electric and natural gas grid, and is a result, among other things, of the assumed rate of retrofit and energy efficiency.

The average EUI for space heating becomes 1.63 percent more efficient each year and remains the dominant thermal end-use.

Water heating is, expectedly, the second largest demand. The average EUI for water heating becomes 0.92 percent more efficient each year.

Looking to 2050, it is relevant to note the negligible contribution of cooling to the aggregate demand. With the potential increase in CDD and various other climate impacts, cooling may become a more sought after service and thus considerably drive the demand curve, particularly if trends shift from local units to centralized cooling systems. This explains the positive annual growth rate of average EUI for space cooling of 0.71 percent.

SENSITIVITY ANALYSES

Sensitivity analyses have been run against the base case above to account for the uncertainty of thermal demand. Table 7 describes one analysis as it reflects an increased share of cooled space and unchanged outdoor climate.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
75 percent cooled space	Cooled space as a share of heated space increases: • From 50 percent to 75 percent for single-family homes • From 41 percent to 75 percent for multi-family homes This can be caused by increasing the number of homes with installed air conditioning or by cooling a larger space in homes with cooling already installed.[52]	The technical potential is estimated at 89.8 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
No climate change	The number of HDD and CDD is assumed to be the same in the future as today. Base case assumes change rates of -0.5 and 0.9 for respectively HDD and CDD.	The technical potential is estimated at 100.4 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.

Table 7 | Sensitivity analyses residential sector. Share of cooled space and lower outdoor temperature.

Figure 11 shows the sensitivity alternatives related to a higher share of cooled space and other outdoor temperatures:

52 According to RECS2009, 75 percent of homes had air condition installed and 23 percent had central air conditioning.

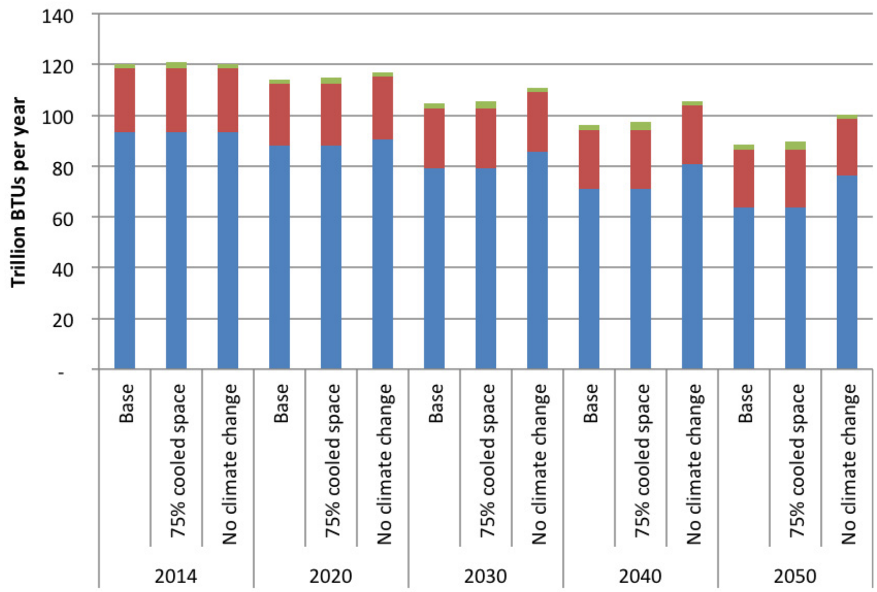


Figure 11 | Sensitivity analyses residential sector. Share of cooled space and lower outdoor temperatures.

Table 8 describes another set of sensitivity analyses allowing for an overall increase in energy efficiency of buildings through retrofits and stringent "passive house" standards.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
New Passive	Assumes passive house standard for all new residential homes. The passive house standard assumes an EUI of 4,755 BTUs per square foot of space heating and cooling.	The technical potential is estimated at 81.3 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
DR @ retrofit	Assumes all renovation is a deep retrofit corresponding to a 75 percent reduction in energy to space and water heating. The annual renovation rate remains at 1 percent per year.	The technical potential is estimated at 73.1 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.
Minus 80 percent[53]	Assumes 80 percent reduction of total thermal energy demand by 2050.	The technical potential is estimated at 24.0 Trillion BTUs in 2050 as compared to 88.6 Trillion BTUs in the base case.

Table 8 | Sensitivity analyses residential sector. Assumptions on energy efficiency.

53 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

Table 11 shows the sensitivity related to a more ambitious standard for new buildings and a higher rate of deep retrofit.

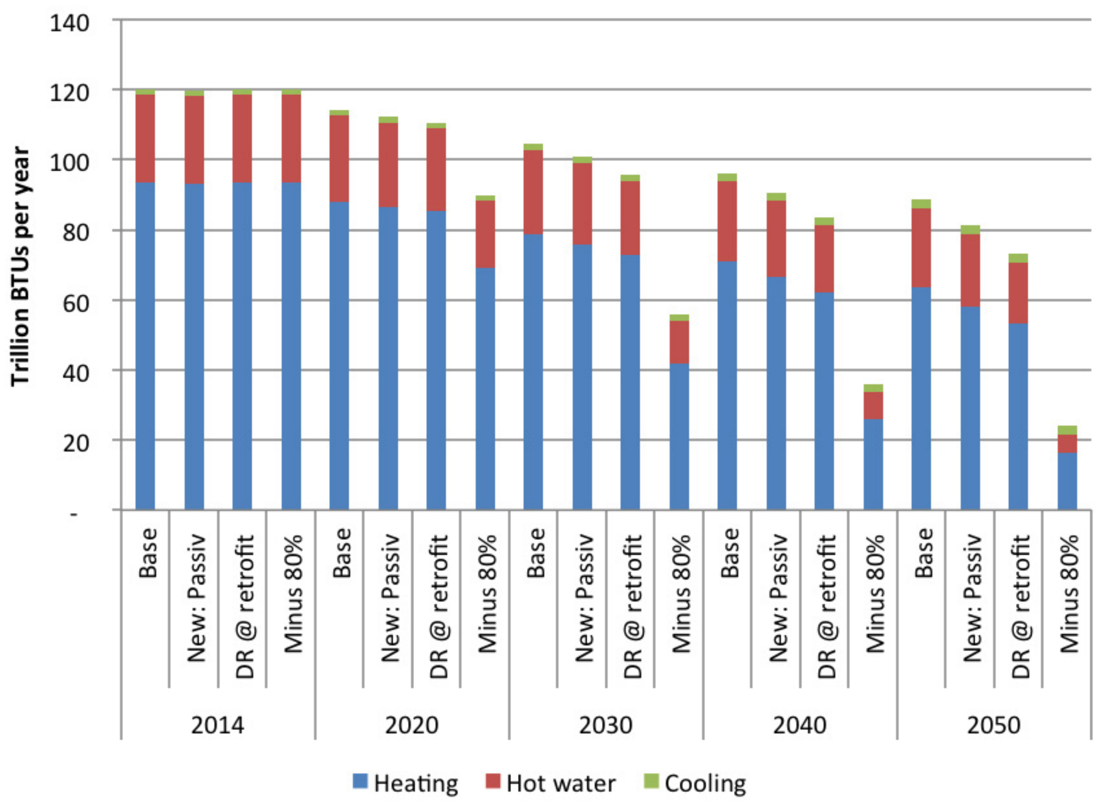


Figure 12 | Sensitivity analyses residential sector. Assumptions on energy efficiency.

In all sensitivity analyses, cooling remains a small portion of the total demand. In a 75 percent increase of the total cooled space there is a small increase by the end of the period.

The sustained levels of thermal demand over time translate to the need for reliable, affordable, and environmentally friendly sources of energy.

The sensitivity analysis on energy efficiency rates precludes a more rapid overall decrease in thermal demand due to efficiency measures. The assumptions for the sensitivity analysis of "Passive house" and "DR @ retrofit" speak to the importance of building codes in a transition to an efficient and low-carbon building base.

Commercial Sector

Although the energy demand of this sector is lower than in residential, extensive and steady growth of commercial office space is expected.

The technical potential of the commercial sector is estimated to 37.2 trillion BTUs in 2050 in the base case, with a sensitivity range between 30.3 and 41.3 trillion BTUs

- As the rate of new building is assumed to be high in the commercial sector, ambitious building codes can provide a considerable contribution to lowering thermal energy demand.
- While reducing the need for space heating through stricter codes, the need for space cooling may increase.
- Warmer winters and summers will provide a net reduction in thermal energy demand.
- The reference case of an 80 percent reduction in commercial thermal energy demand implies a technical potential of 9.8 trillion BTUs in 2050.[54] To achieve this, an annual rate of deep retrofit of around 4.7 percent would be required until 2050, *ceteris paribus*.

54 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector. The 80 percent reduction in emissions from commercial thermal energy demand envisioned here is hypothetical.

ENERGY USE INTENSITIES

The EUIs of different subsectors from the commercial sector relay important information about where the greatest opportunities and challenges lie.

Figure 13 shows the aggregated EUIs applied to existing commercial buildings in this study.

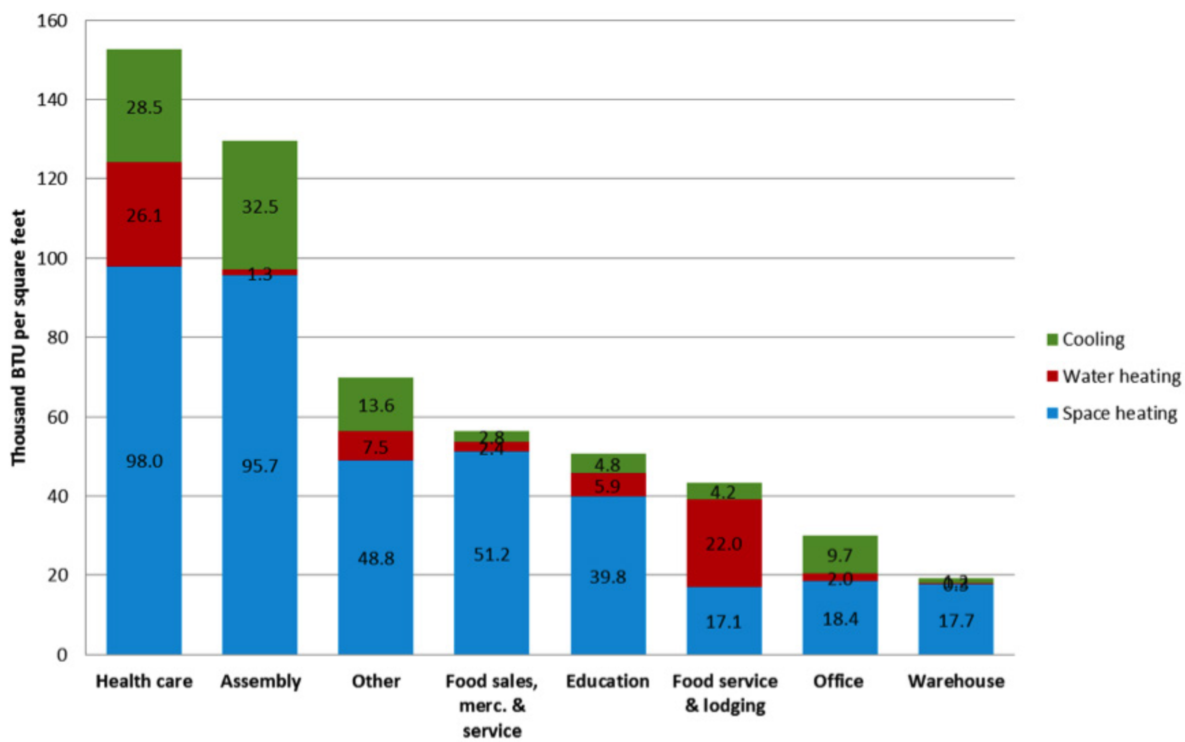


Figure 13 | Commercial Energy Use Intensity per square feet (2014 mean values). Source: CBECS 2012.

Health Care and *Assembly*[55] are the most energy intense categories in terms of space heating. Providing a reliable energy source that sustains life-supporting and supply chain operations is particularly crucial for *Health Care*.

Health Care also dominates water heating, followed by the *Food Service* and *Lodging sectors*. *Assembly* is the most space-cooling-intense sector, followed by *Health Care*.

The annual energy efficiency improvement rates applied to the EUIs of new construction and demolitions are 0.55 percent for space heating and 0.32 percent for cooling, informed by the AOE 2016.

55 Assembly: Buildings in which people gather for social or recreational activities, whether in private or non-private meeting halls

ESTIMATED THERMAL ENERGY DEMAND

The size of buildings along with the type of business they house is an important driver for thermal energy demand of commercial buildings. The square footage for the Connecticut commercial building stock has been established using AEO 2015 projections for New England. The projected distribution of employees relies on NAICS sectors and states, and has been applied to elaborate on the Connecticut commercial square feet.

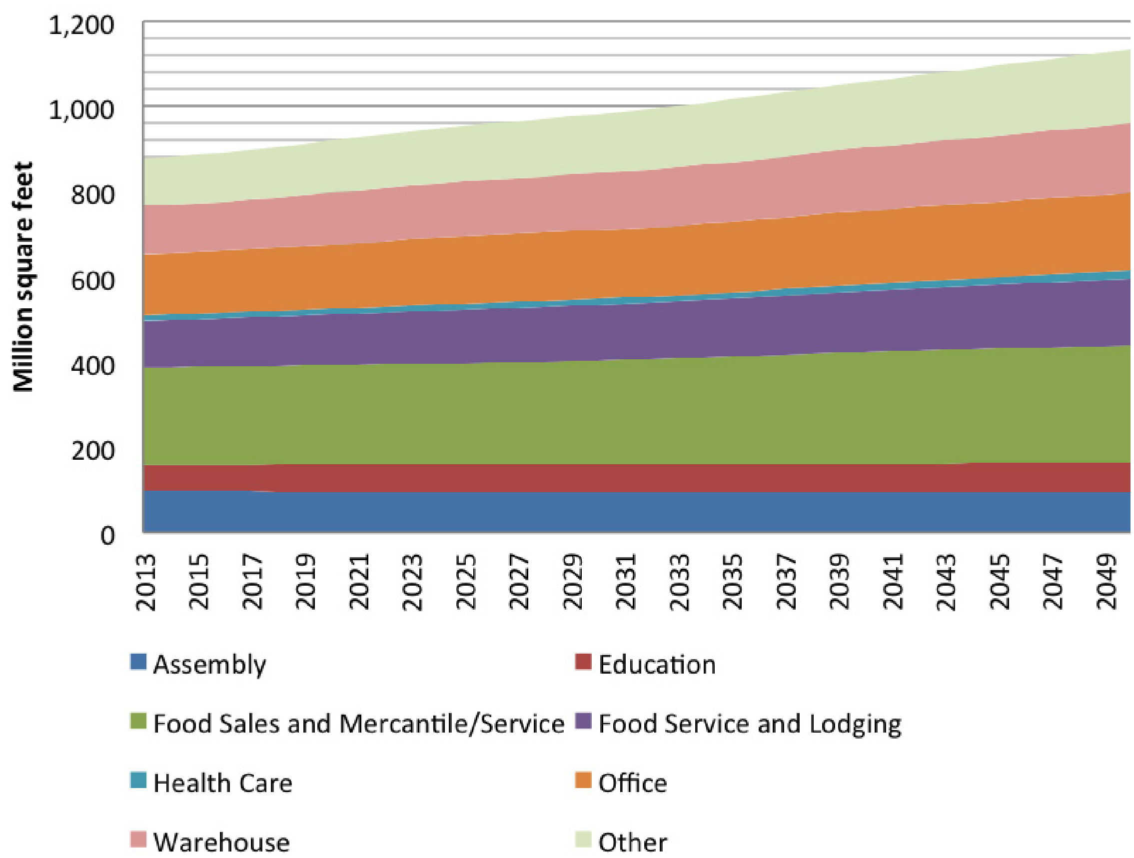


Figure 14 | Estimated floor space, commercial customers in CT. Sources: Elaborated from the AEO 2015 and the US Census Bureau.

The commercial space in Connecticut is dominated by *Food Sales* and *Mercantile/Service* buildings in particular, followed by *Office*.

The highest net positive annual growth of floor space is found in the category *Other*, followed by *Health Care, Warehouse*, and *Food Services and Lodging*. With the exception of *Assembly*, all commercial building categories have an expected net positive annual growth of floor space over the period.

Health Care occupies a moderately small portion of commercial floor space, but is the most energy intense in terms of BTUs per square feet and per year. Second to it in terms of BTUs per square feet and per year are the *Assembly* buildings.

Unlike the residential sector, the expected growth in new commercial construction is significant. According to the analysis, approximately 37 percent of the estimated commercial space in 2050 will have already been built, corresponding to an annual rate of new constructions of 2 percent.

New construction is more likely to have higher energy efficiencies through a better building envelope, as well as overall improved performance through more efficient technologies and enhanced energy management. New commercial buildings represent an important opportunity for RTTs.

There is an overall reduction in aggregate commercial thermal demand through 2050. Space heating declines most drastically, while space cooling demand increases slightly. Overall, the high rate of new construction in the commercial sector precludes a gradual transition to efficiency and reduced demand.

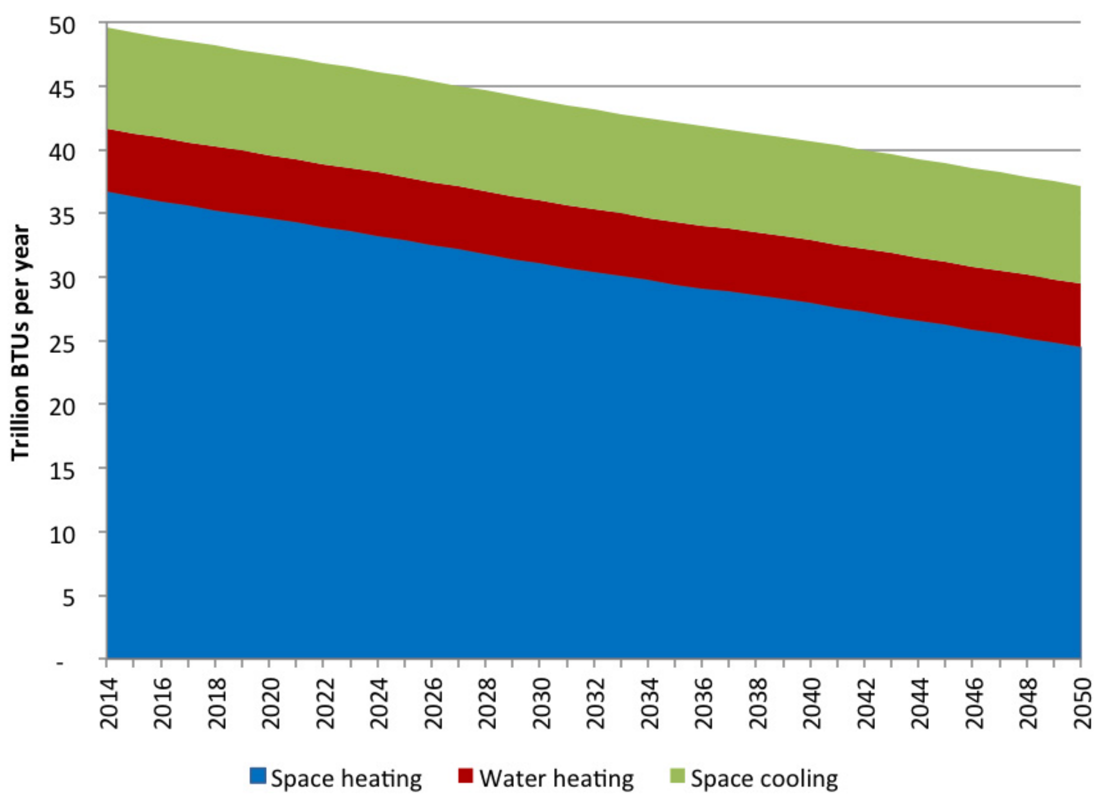


Figure 15 | Estimated commercial thermal demand by end-use. 2014–2050.

The average EUI for space heating becomes 1.76 percent more efficient, water heating becomes 0.68 percent more efficient and space cooling 0.76 percent more efficient each year.

The development can be explained by:

- New, more efficient commercial buildings replacing old inefficient ones at a high rate.
- Increased outdoor temperatures causing a reduction in the number of heating degree-days and an increase in the number of cooling degree days.
- Structural changes, where commercial buildings with high EUIs increase their share of the total floor space. Examples are *Health Care, Food Service and Lodging*, and *Other*.
- Energy efficiency achieved through renovations and replacement of less efficient technologies.

The largest commercial consumers of thermal end-uses are estimated to be the *Food Sales* and *Assembly* sub-sectors. Given their expansive floors spaces, they present a viable opportunity for RTTs.

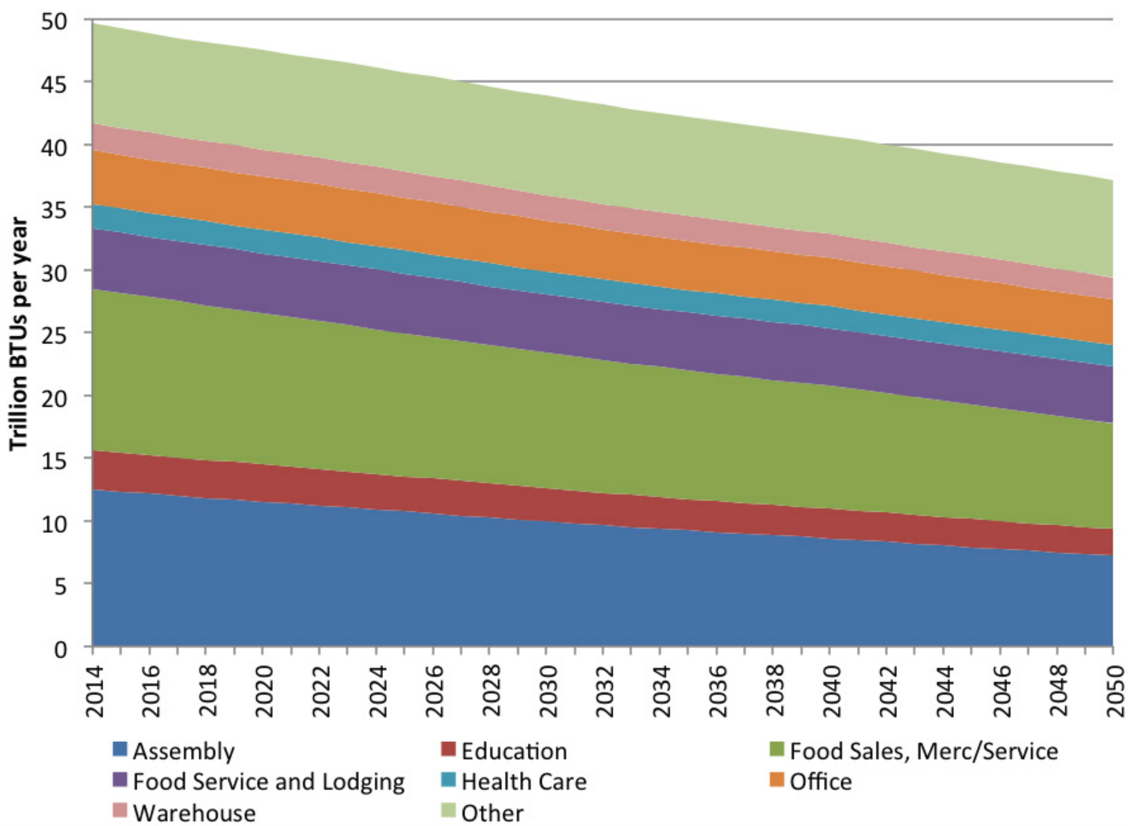


Figure 16 | Estimated commercial thermal energy demand by sector. 2014–2050.

SENSITIVITY ANALYSES

The following sensitivity analyses have been performed to analyze variations in the commercial thermal demand as a result of different references for EUIs.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
Buildings Energy Data Book (BEDB) EUIs[56]	The EUIs from the BEDB were applied for existing buildings. The EUIs have been adjusted for CT relative to the national HDD and CDD, as well as national energy efficiency growth rates from the AEO.	The technical potential is estimated at 37.4 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
International Energy Conservation Code (IECC) for New Construction[57]	The EUIs for new commercial buildings built today are based on the IECC 2012. The categorization of commercial sectors deviates from CBECS, and assumptions have been made to adapt the estimated IECC values to categorization used in this study.	The technical potential is estimated at 30.3 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
CBECS 2003	Based on the EUIs from CBECS 2003, adjusted to 2014 values for the growth of the regional HDD and CDD for the period 2003–2014 (AEO 2016).	The technical potential is estimated at 41.3 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.

Table 9 | Sensitivity analyses commercial sector. Alternative references for EUIs.

56 Department of Energy, Buildings Energy Data Book, table 3.1.13: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.13

57 As calculated by Pacific Northwest National Laboratory in the study "Energy and energy cost savings analysis of the IECC for commercial buildings", 2013 (PNNL-22760).

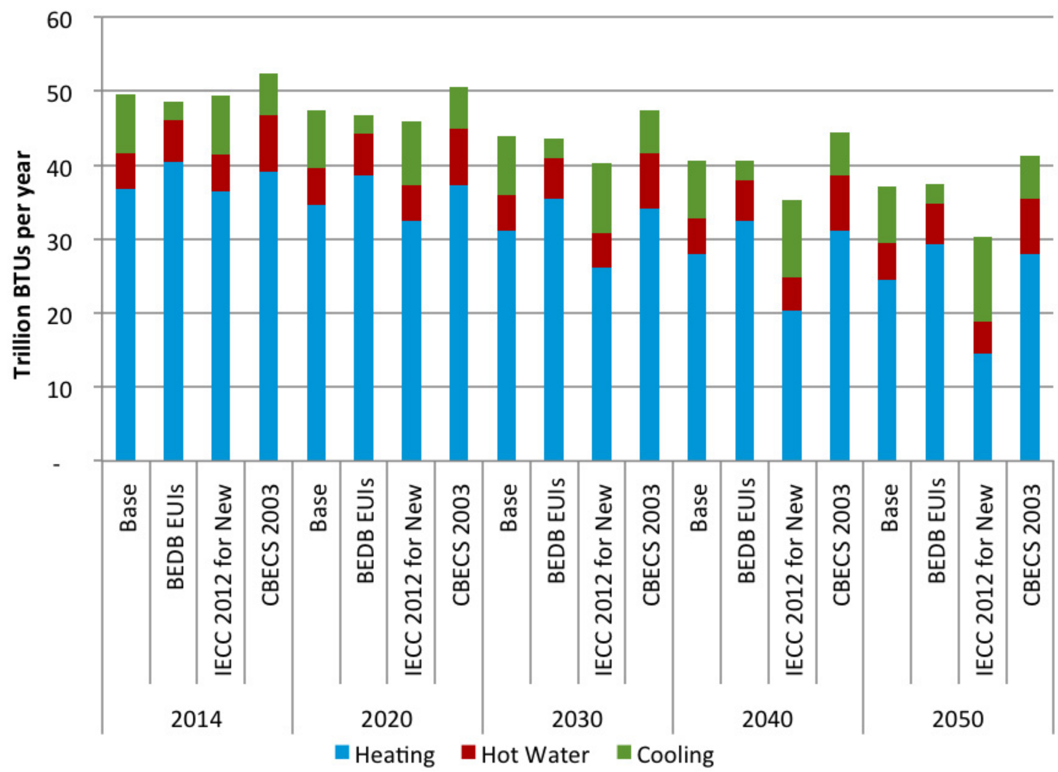


Figure 17 | Sensitivity analyses commercial sector. Alternative references for EUIs.

The BEDB EUIs preclude deviations from the base case on the distribution of thermal energy between both end-uses and customer groups. This results in a higher estimated technical potential with a higher share of space and water heating and a considerably lower share of space cooling.

The IECC 2012 EUI values for new commercial construction drive down technical potential in 2050 considerably. An ambitious building code in a customer segment with a high share of new construction makes a difference. The 2016 Connecticut State Building Code (CSBC) based on the International Code Council's 2012 International Codes is effective for projects in which permit applications were made on or after October 1, 2016.[58]

The CBECS 2003 sensitivity analysis concludes with higher space and water heating demand (but lower cooling demand) compared to the base case. The base case assumes EUIs from CBECS 2012, and the difference can be explained both by energy efficiency between 2003 and 2012, as well as the selection of participants.

58 See http://das.ct.gov/images/1090/NR_Connecticut_Codes_Final.pdf

Another set of sensitivity analyses assumes a higher share of energy efficiency and a choice of outdoor temperatures. Assumptions are presented in Table 10.

SENSITIVITY ALTERNATIVES	DESCRIPTION	TECHNICAL POTENTIAL
No climate change	The number of HDD and CDD is assumed to be the same in the future as today.	The technical potential is estimated at 40.4 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
DR @ retrofit	Assumes that all renovations are deep retrofits corresponding to a reduction of all thermal end-uses of 75 percent. The annual renovation rate remains at 0.4 percent per year.	The technical potential is estimated at 34.6 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.
Minus 80 percent[59]	Based on base case assumptions except for annual renovation rate and extent of retrofit. For 80 percent reduction in today's energy consumption, approximately 5.5 percent of the commercial floor space has to be renovated each year at an achieved reduction of thermal energy use of 75 percent.[60]	The technical potential is estimated at 9.8 Trillion BTUs in 2050 as compared to 37.2 Trillion BTUs in the base case.

Table 10 | Sensitivity analyses commercial sector. Assumptions on energy efficiency and outdoor temperature.

59 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

60 As a comparison, the new built rate in the AEO is assumed to be 2 percent per year.

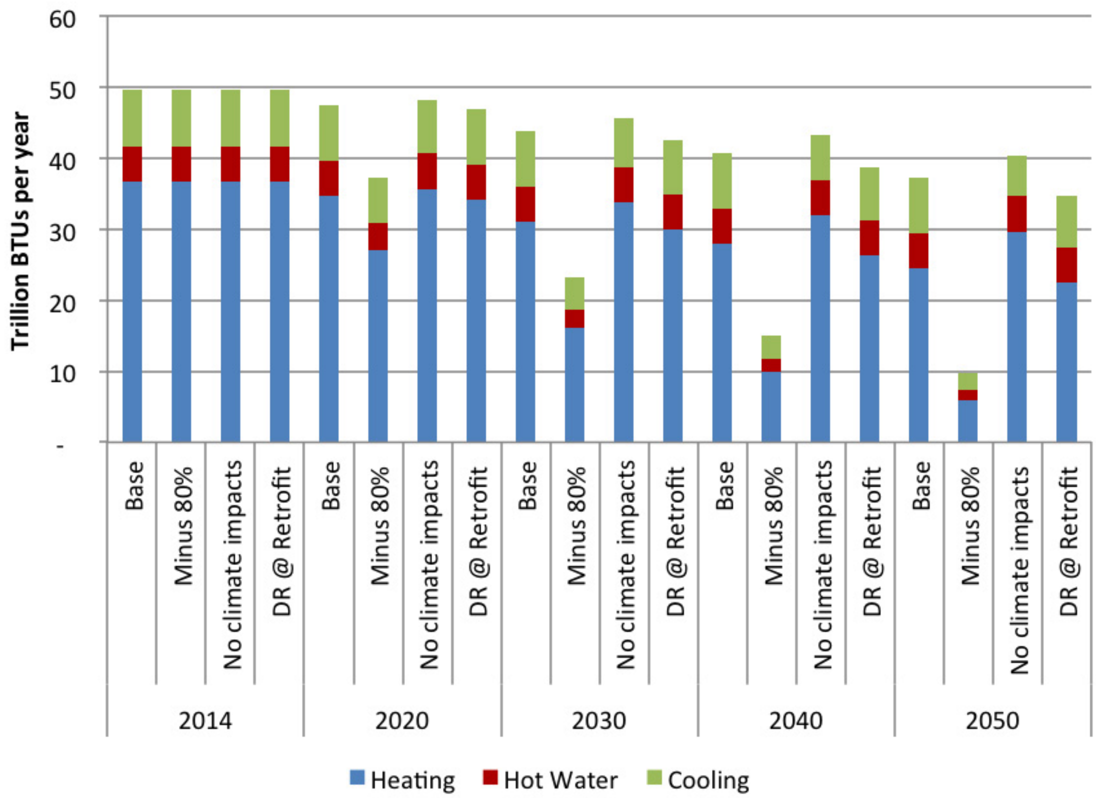


Figure 18 | Shows the results of the 3 sensitivity analyses.

In a No climate change sensitivity analysis, the technical potential remains steady over time with a slight decline.

Space cooling retains its relative ratio across the sensitivity alternatives. Overall, it plays a more significant role than in the residential sector, due to the implicit cooling needs of some of the services in the commercial sector.

Under the Minus 80 percent sensitivity analysis, the thermal energy use in the commercial sector in 2050 is estimated to be approximately 80 percent lower than 2014. An aggressive rate of deep renovations would drive the technical potential to as low as 9.8 trillion BTUs.

CHAPTER 5
Economic Potential—Competition Analysis

The financial competitiveness of technologies providing thermal services has been analyzed and the economic potential has been estimated. Main findings include:

- The economic potential for RTTs in residential and commercial building is currently around 31 trillion BTUs, representing 19 percent of the estimated thermal demand.
- RTTs are more competitive in the commercial sector than the residential sector.
- Heat pumps are financially favorable as a robust thermal solution replacing conventional electric technologies across all customer groups and end-uses.
- There is large, untapped, and financially favorable potential to replace old fuel oil in residential and commercial buildings with highly efficient natural gas boilers and biomass pellets. The adaptation of highly efficient natural gas boilers at a large scale will not offer sufficient reduction of GHG emissions to reach Connecticut's climate targets.
- Any existing fuel oil boiler replaced by a new fuel oil or standard natural gas boiler represents a lost opportunity for a cheaper and cleaner future.

Case Study Results

Different combinations of incumbent and proposed alternative thermal technologies have been analyzed for different archetypal customers, with financial viability and impact on GHG emissions quantified.

The competition analysis—examining how RTTs compete with conventional thermal technologies—is based on the assumptions in Appendix A, and detailed results by customer category can be found in Appendix B.

Physical limitations related to existing buildings have to some extent been handled through the level of incremental installation initial costs. See Appendix A for more information.

Financial incentives are not included in the competition analysis and will be discussed separately in the sensitivity analysis of Chapter 6. Appendix E offers an overview of current financial incentives in Connecticut.

The competition analysis assumes the relative installation costs of the technologies to remain unchanged over the period. The impacts of changes in relative installation costs between RTTs and conventional technologies are considered in the sensitivity analysis.

Due to the need for simplification, the analysis contains some limitations that may influence the financial feasibility of RTTs. Specifically:

- To avoid additional complexity in the analysis, the RTTs have been modeled to deliver the whole thermal demand of a building over the year, that being for space cooling, heating or hot water. Even if the incremental installation costs are given per installed BTU/h, this may exclude some financially favorable solutions. Oversizing RTTs should be avoided both to restrict installation costs and secure efficient operations; keeping the incumbent energy source for peak load operations may be desirable.
- Some RTTs can supply thermal end-uses in addition to those we have incorporated in our case studies. These could influence the financial evaluation.
- Technologies that provide low-temperature heat may have difficulty delivering enough heat to existing buildings on the coldest days. Improvements of the building envelope to accommodate heat pumps have not been accounted for.
- Economies of scale, particularly for the commercial sector, may be underestimated in the study.
- Some customer categories may face regulatory and technical requirements related to their thermal load that pose limitations on RTTs. For example, strict requirements stipulate hot water temperatures for certain processes in food and healthcare.
- Potential costs of gas grid connection or electricity grid upgrades have not been accounted for.

Table 11 summarizes the competition analysis, with the range of simple payback and cases with positive NPV marked in green.

RTT USED	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity	5–15	5–15	5–15	5–15	5–15	5–15	5–15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
ASHP space heating and cooling with ductwork needed	Electricity	5–15	5–15	5–15	>15	5–15	5–15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
ASHP Hot Water	Electricity	<5	<5					
	Fuel Oil	>15	>15					
	Natural Gas	>15	>15					
GSHP space heating and cooling	Electricity	5–15	5–15	5–15	>15	>15	>15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Solar Hot Water	Electricity	5–15	5–15	>15	5–15	5–15	>15	>15
	Fuel Oil	>15	>15	>15	>15	>15	>15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Biomass space heating and hot water	Fuel Oil	5–15	>15	5–15	5–15	5–15	5–15	>15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15
Highly efficient natural gas	Electricity	<5	<5	<5	5–15	<5	<5	5–15
	Fuel Oil	<5	<5	<5	<5	<5	<5	5–15
	Natural Gas	>15	>15	>15	>15	>15	>15	>15

Table 11 | Case study results for different combinations of incumbent and proposed technologies for different archetype customers.

- Replacing conventional electric technologies with ASHPs for space heating and cooling is a financially favorable alternative across all customer categories.
- ASHP water heaters are financially feasible alternatives to electric water heaters for residential customers. ASHP water heaters for commercial hot water demand have not been included in the analysis.
- SHW is a financially feasible alternative to electric water heaters for residential customers and commercial customers with high demand for hot water per square foot.
- GSHPs are financially feasible alternatives to conventional electric technologies for space heating and cooling for customer groups with a large total number of hours of use and high demand for space heating per square foot.
- Biomass-pellet boilers are a financially feasible alternative to fuel oil for commercial customers with a large demand for space heating and hot water per square foot.
- Highly efficient natural gas boilers are a financially feasible alternative to both conventional electric boilers and fuel oil for space and water heating across customer categories.

Overall Economic Potential in Connecticut

The competition analysis found the most cost efficient combination of incumbent and proposed technologies for archetypal customer. The total market for thermal energy, as estimated by the base case of the demand analysis of Chapter 4, was split across winning technologies, accordingly.

If several combinations of incumbent and proposed technology are favorable for an archetypal customer, the most favorable has been applied. The results are discussed from two scenarios:

1. Competitive RTTs have priority: efficient natural gas is excluded as an alternative to the incumbent.
2. Efficient natural gas included: efficient natural gas is included as an alternative to the incumbent.

RESIDENTIAL SECTOR

Residential demand for hot water and space heating and cooling was estimated to be 120 trillion BTUs in 2014. Fuel oil was the dominant energy source (46 percent), followed by natural gas (37 percent), electricity (11 percent), and biomass (5 percent). The total GHG emissions related to this residential thermal demand is estimated to be 9.1 million tons of CO2 equivalent.[61]

61 Estimations are based on the thermal demand estimated in Chapter 4, the consumption by energy sources from EIA SEDS 2014, the energy by end-use from AEO 2015, the GHG emission factors from Chapter 3, and the efficiency assumptions from Appendix A.

SCENARIO 1—COMPETITIVE RTTS HAVE PRIORITY

The economic potential of RTTs in the residential sector is estimated to be 16.2 trillion BTUs when highly efficient natural gas boilers are excluded from the analysis and competitive RTTs have priority. This is 14 percent of the estimated technical potential (see Figure 19).

- ASHPs replace thermal demand for space heating and cooling currently based on conventional electric technologies. Although GSHPs have a positive NPV for multi-family homes, they are less favorable than ASHPs.
- SHW has a positive NPV, but is less favorable than ASHP water heaters, which serve the domestic hot water demand with electricity as an incumbent.
- Biomass is not considered financially favorable through the competition analysis, but we assume that biomass maintains its current share of the demand for space heating and hot water.
- Under current market conditions, none of the RTTs are considered financially favorable to fuel oil or natural gas as the primary energy source, and we assume that the customer keeps or reinvests in the incumbent technology.

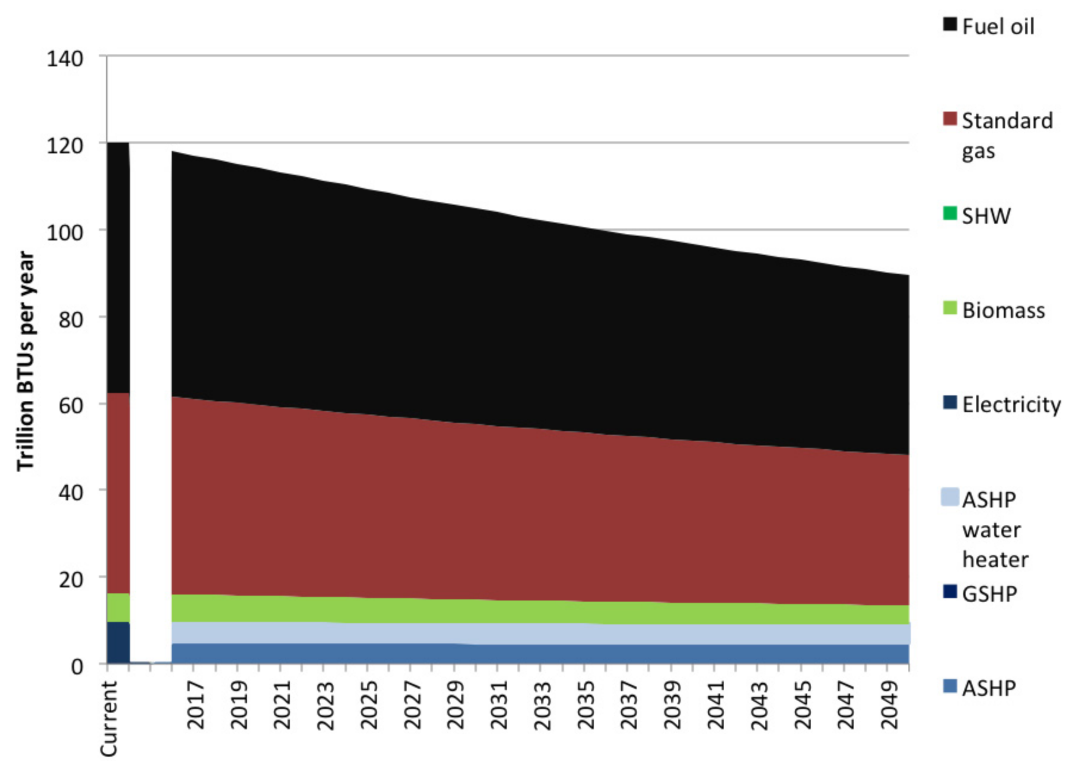


Figure 19 | Preferred thermal technology, excluding highly efficient natural gas boilers. Residential sector.

While energy efficiency is driving total thermal demand down over the period, fossil fuels will continue to dominate as energy sources if relative prices remain the same and customers are allowed to reinvest in incumbent technologies. Cooling is provided by ASHPs, water and space heating by a combination of thermal technologies. As a consequence of increased demand for cooling, the share of RTTs increases to 15 percent by 2050.

SCENARIO 2—EFFICIENT NATURAL GAS INCLUDED

The economic potential of RTTs in the residential sector has been estimated at 11.9 trillion BTUs when highly efficient natural gas is included in the competition analysis. This is 10 percent of the estimated technical potential (see Figure 20).

- In the current market, highly efficient natural gas seems to be the most financially favorable technology for replacing fuel oil and conventional electric technologies for space and water heating.
- Cooling is an additional service that may lead to ASHPs being chosen over efficient natural gas boilers. Cooled space has been used as a key for splitting the relevant part of the market between ASHPs and efficient natural gas boilers.[62]
- The demand for space cooling is served by ASHPs.
- Highly efficient natural gas replaces the demand that currently is served by fuel oil.

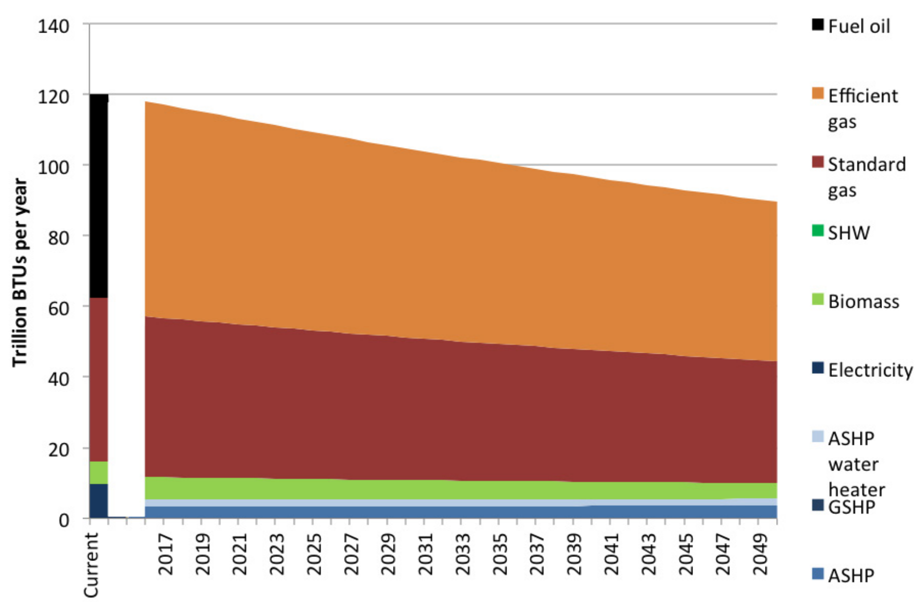


Figure 20 | Preferred thermal technology, including highly efficient natural gas boilers. Residential sector.

62 The cooled area of single-family and multi-family homes is 50% and 41%, respectively (RECS 2009).

Natural gas will be the main energy source when highly efficient natural gas boilers are included in the competition analysis. There are a few elements that have to be taken into consideration in this analysis:

- No connection fees have been included for natural gas grid expansions.
- No costs related to storage and transportation of natural gas have been included.

The economic potential for highly efficient natural gas boilers for customers located far from the existing gas grid may therefore be overestimated.

As a consequence of increased demand for cooling, the share of RTTs increases slightly over the period.

COMMERCIAL SECTOR

The commercial demand for hot water and space heating and cooling is estimated at 49.6 trillion BTUs for 2014. Natural gas was the dominant energy source (70 percent), followed by electricity (14 percent), fuel oil (13 percent), and biomass (3 percent). The total GHG emissions related to the commercial thermal demand have been estimated at 3.5 million tons CO2 equivalents.[63]

SCENARIO 1—COMPETITIVE RTTS HAVE PRIORITY

The economic potential of RTTs in the commercial sector has been estimated to be 15.4 trillion BTUs when highly efficient natural gas boilers are left out of the competition and competitive RTTs have priority. This is 32 percent of the estimated technical potential (see Figure 21).

- ASHPs replace thermal demand for space heating and cooling currently based on conventional electric technologies. Although GSHPs have a positive NPV for *Education* and *Health Care*, they are less favorable than ASHPs.
- SHW has a positive NPV for *Food Service* and *Health Care* and fulfills hot water demand, with electricity as the incumbent.
- With the exception of *Office* buildings, biomass appears to be a financially feasible alternative to fuel oil for space and water heating.
- The current demand served by biomass is assumed to continue being served by biomass.
- We assume that the customer keeps or reinvests in the incumbent technology when none of the RTTs are competitive.

63 Estimations are based on the estimated thermal demand from Chapter 4, the consumption by energy sources from EIA SEDS 2014, the energy by end-use from AEO 2015, the GHG emission factors from Chapter 2, and the efficiency assumptions from Appendix A.

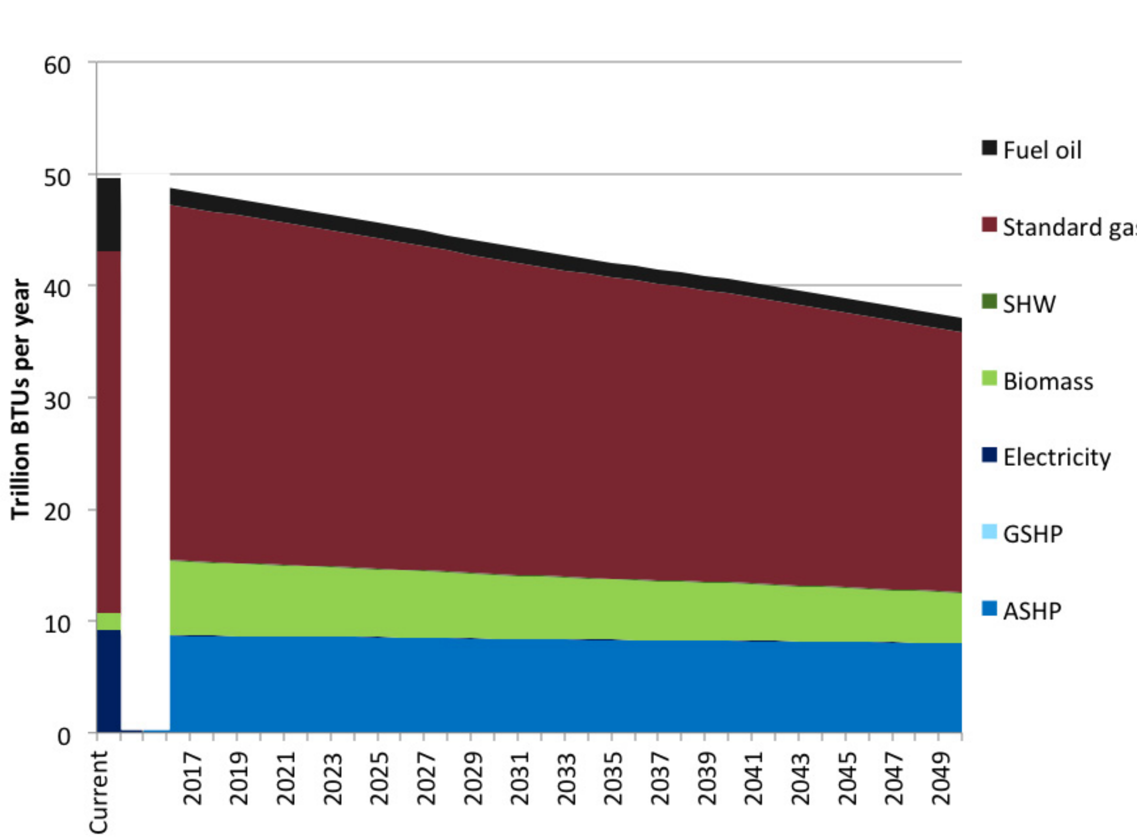


Figure 21 | Preferred thermal technology, excluding highly efficient natural gas boilers. Commercial sector.

While the total thermal demand is expected to be reduced over the period as a consequence of energy efficiency and structural changes, the demand for space cooling is expected to rise due to a warmer climate. As a consequence, the share of RTTs will increase to 34 percent over the period. Natural gas will maintain its dominant position in the commercial sector if the current market conditions prevail. With biomass pellets coming up as a financially favorable alternative to fuel oil, the issue of fuel availability should be investigated. Thin supply chains for biomass pellets may add transportation costs in some areas of the state.

SCENARIO 2—EFFICIENT NATURAL GAS INCLUDED

The economic potential of RTTs in the commercial sector has been estimated to be 10.2 trillion BTUs when highly efficient natural gas boilers are included in the analysis. This is 21 percent of the estimated technical potential (see Figure 22).

- Highly efficient natural gas seems to be the most financially favorable technology for replacing fuel oil and conventional electric technologies for space and water heating.
- Cooling is an additional service that may lead to ASHPs being chosen over efficient natural gas boilers. ASHPs serve the demand for space cooling and space heating currently served by conventional electric technologies.
- Highly efficient natural gas boilers replace the demand that currently is served by fuel oil.
- Biomass is less financially favorable than efficient natural gas boilers, and we assume that biomass maintains it current share of the demand for space heating and hot water.

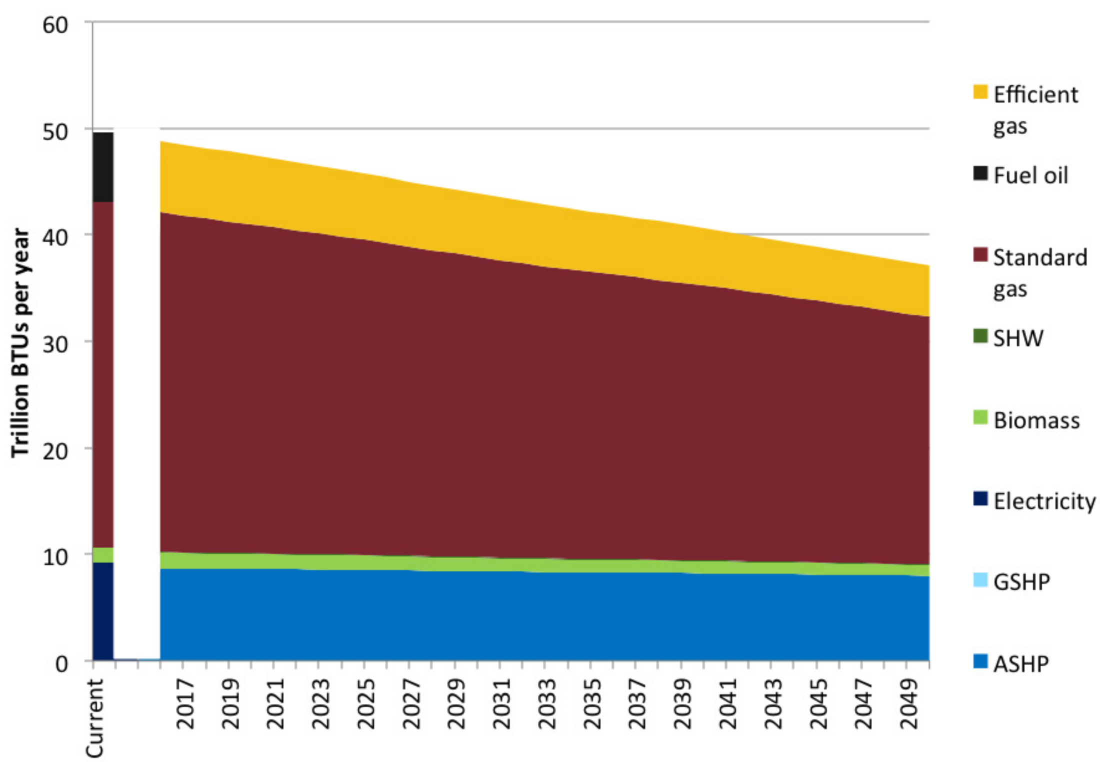


Figure 22 | Preferred thermal technology, including highly efficient natural gas boilers. Commercial sector.

Natural gas will be the dominant energy source when highly efficient natural gas boilers are considered in the financial analysis. Similar to the residential sector, distance to the current natural gas grid would impact the feasibility of highly efficient natural gas boilers replacing fuel oil.

Given the current and assumed market conditions, a considerable share of thermal demand will continue being served by standard natural gas boilers. Due to low natural gas prices and incremental investment costs, existing thermal demand served by standard natural gas boilers may be the most challenging share of thermal demand to turn cleaner absent market interventions.

As a consequence of increased demand for cooling, the share of RTTs increases slightly over the period.

Estimated GHG emissions

The GHG emissions of different combinations of thermal technologies have been estimated for the scenarios described in Table 12.[64]

	THERMAL TECHNOLOGIES		
	Competitive RTTs have priority	**Efficient natural gas boilers included**	**Competitive RTTs have priority, GSHPs replace fuel oil, efficient gas boilers replace standard boilers**
Current electric grid mix (GHG emission factor 0.301 $kgCO_2e/kWh$)	Scenario 1a	Scenario 2a	Scenario 3a
75 % renewable electricity by 2050 (GHG emission factor 0.075 $kgCO_2e/kWh$	Scenario 1b	Scenario 2b	Scenario 3b

Table 12 | Scenarios for combinations of thermal technologies and electricity generation.

- The b-scenarios are based on a gradual change of energy sources in the electricity generation. Achieving 75 percent renewables by 2050 corresponds to the scenarios presented to the Governor's Council on Climate Change on September 8th, 2016.
- Scenario 3 represents a situation in which more RTTs and efficient gas boilers are installed than the competition analysis suggests. The thermal demand is supplied by RTTs where RTTs were found to be competitive in scenario 1. Fuel oil as an energy source is fully replaced by GSHPs, and standard natural gas boilers are replaced by highly efficient natural gas boilers. This scenario would imply replacing incumbent technologies with several technologies that are not competitive at today's prices.

64 For reasons spelled out in footnote 43 in chapter 3.3, DEEP's view is that the GHG emissions reductions that this section associates with biomass combustion are not reliable.

RESIDENTIAL SECTOR

The GHG emissions of the energy sources delivering thermal service to meet current residential demand are estimated to be 9.1 million tons CO_{2e} per year.

Figure 23 shows the estimated GHG emissions related to residential thermal demand through 2050 given different combinations of thermal technologies at the customer end, and different energy sources used for electricity generation.

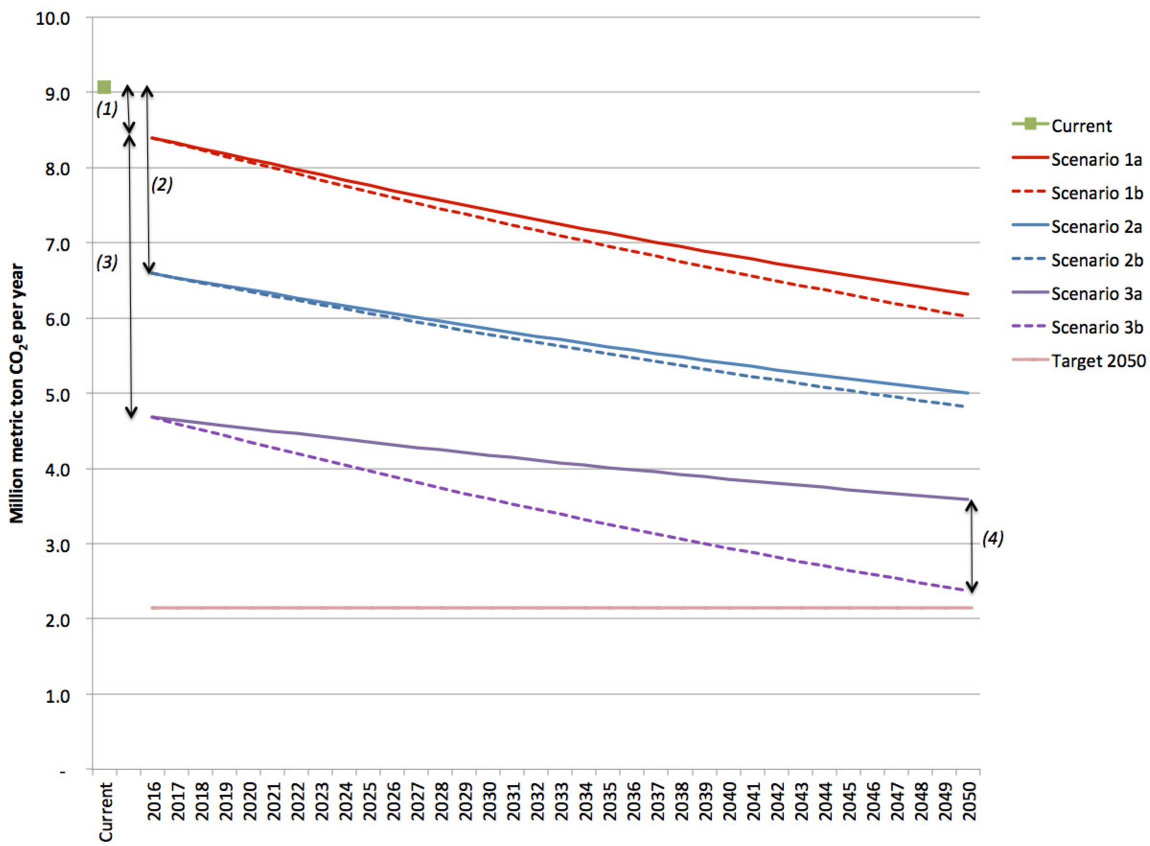


Figure 23 | Estimated GHG emissions for different combinations of thermal technologies. Residential sector.

- Installing all competitive RTTs from scenario 1 would bring an immediate reduction of 0.6 million tons CO_{2e} per year (1). This represents a financially viable but unrealized potential for reduced GHG emissions.
- Installing competitive efficient gas boilers and RTTs, represented by scenario 2, would bring an immediate reduction of 2.4 million tons CO_{2e} per year (2). This represents a financially viable but unrealized potential for reduced GHG emissions.

- Competitive RTTs and an expedited replacement of existing fuel oil and gas boilers with GSHPs and efficient natural gas boilers would reduce the GHG emissions by close to 50 percent of the current levels (3).
- With greater shares of heat pumps, a 75 percent renewable electricity mix would add a reduction of 1.2 million tons CO_2e by 2050 in scenario 3 (4).
- With scenario 3, the GHG emissions in 2050 are estimated at 2.4 million tons CO_2e. An 80 percent reduction of GHG emissions relative to 2001 would represent a target of around 2.1 million tons CO_2e.[65]

Achieving significant emissions reductions requires meeting thermal demand with a combination of a high share of RTTs and cleaner electricity. Replacing standard natural gas and fuel oil boilers with highly efficient natural gas boilers will give immediate GHG reductions, but not enough to achieve long term targets. Market interventions are necessary to realize RTT alternatives with both favorable and unfavorable economics.

65 The Global Warming Solutions Act (2008) requires an economy-wide reduction in GHG emissions by 2050 (relative to 2001) but does not specify a degree of reduction to be achieved in any particular sector or context. The 80 percent reduction in emissions from thermal energy demand envisioned here is hypothetical.

COMMERCIAL SECTOR

The GHG emissions of energy sources delivering thermal service to meet current commercial demand are estimated to be 3.5 million tons CO_{2e} per year.

Figure 24 shows the estimated GHG emissions related to commercial thermal demand through 2050 given different combinations of thermal technologies at the customer end, and different energy sources used for electricity generation.

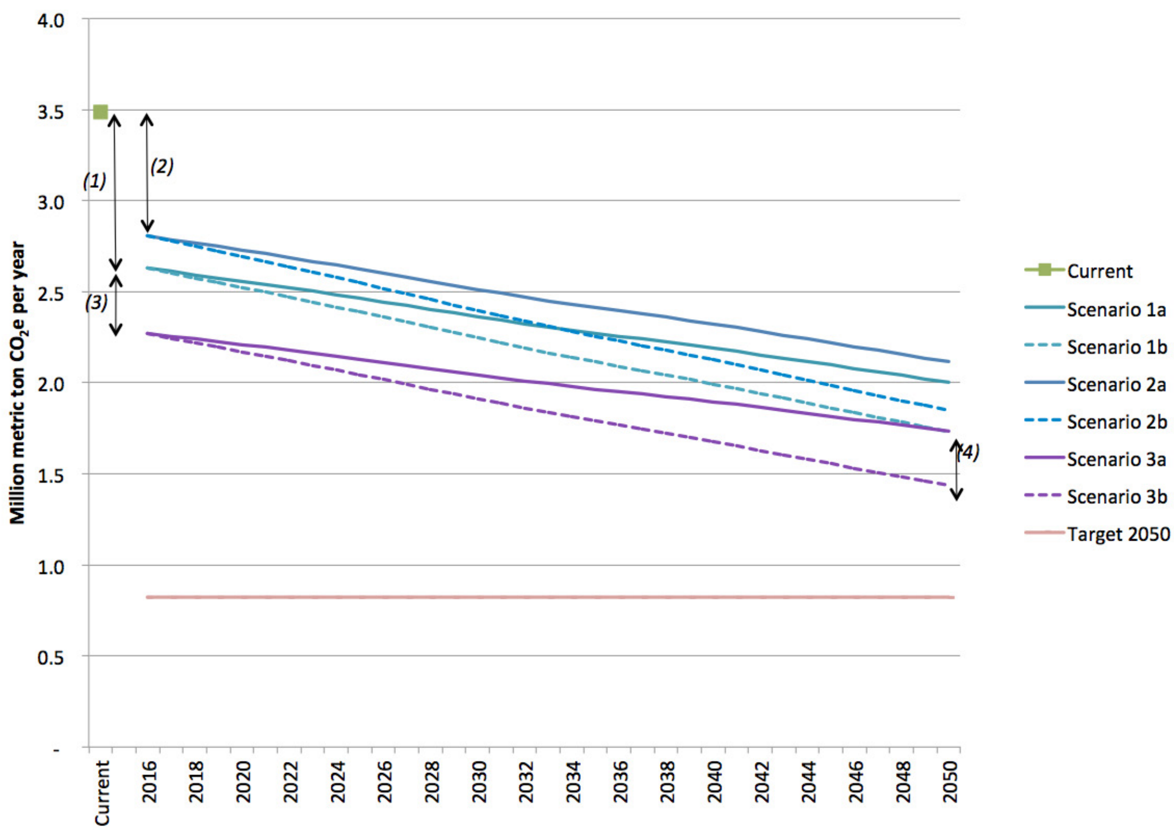


Figure 24 | Estimated GHG emissions for different combinations of thermal technologies. Commercial sector.

- Installing all competitive RTTs from scenario 1 would bring an immediate reduction of 0.8 million tons CO_{2e} per year (1). This represents a financially viable but unrealized potential for reduced GHG emissions.
- Installing competitive RTTs and efficient gas boilers (scenario 2) would bring an immediate reduction of 0.7 million tons CO_{2e} per year (2). This represents a financially viable but unrealized potential for reduced GHG emissions.

- Competitive RTTs and an expedited replacement of existing fuel oil and gas boilers with GSHPs and efficient natural gas boilers would reduce the GHG emissions to close to 65 percent of the current levels (3).
- With greater shares of heat pumps, a 75 percent renewable electricity mix would add a reduction of 0.4 million tons CO_2e by 2050 in scenario 3 (4).
- With scenario 3b, the GHG emissions in 2050 are estimated to be 1.6 million tons CO_2e. An 80 percent reduction of GHG emissions relative to 2001 would represent a target of around 0.8 million tons CO_2e.

While including financially favorable highly efficient natural gas boiler results in the lowest GHG emissions for the residential sector (scenario 2), excluding highly efficient natural gas boilers and allowing financially favorable RTTs to gain ground provides the lowest GHG emissions in the commercial sector (scenario 1). This is due to biomass pellets being financially favorable for commercial customers.[66] The GHG emission factor applied for biomass in this study was 0.036 kgCO_2e/kWh.

Realizing significant emissions reductions requires thermal demand to be served by a combination of a high share of RTTs and cleaner electricity. Replacing standard natural gas and fuel oil boilers in the commercial sector with highly efficient natural gas boilers will give GHG reductions, but not enough to achieve long term targets. Market interventions are necessary to realize alternatives both with favorable and unfavorable economics.

Although replacement of standard gas and fuel oil boilers with highly efficient gas boilers represents one of the cheapest means to reduce GHG emissions today, doing so extensively is not sufficient to reach the target and would lock in fossil fuel technologies that could prevent Connecticut from achieving an 80 percent reduction in GHG emissions by 2050. The high share of natural gas boilers in the commercial sector already represents a barrier to RTTs and thus inhibits the state's ability to achieve needed reductions in GHG emissions. Replacing standard natural gas boilers with highly efficient gas boilers and decarbonizing the gas grid by, for example, injecting biogas from anaerobic digestion could supplement market strategies to promote RTTs.

Removing the competitive biomass alternatives from the RTT mix, or applying a higher GHG emission factor, would increase the gap between the target and what the scenarios can achieve.

66 See chapter 3.3 for more information on the GHG emission factors used.

CHAPTER 6
Sensitivity Analysis

We have included sensitivity analyses both to test the solidity of the findings and to analyze the implications of market interventions.

Figure 25 summarizes a set of market interventions to increase the diffusion of RTTs in Connecticut.[67]

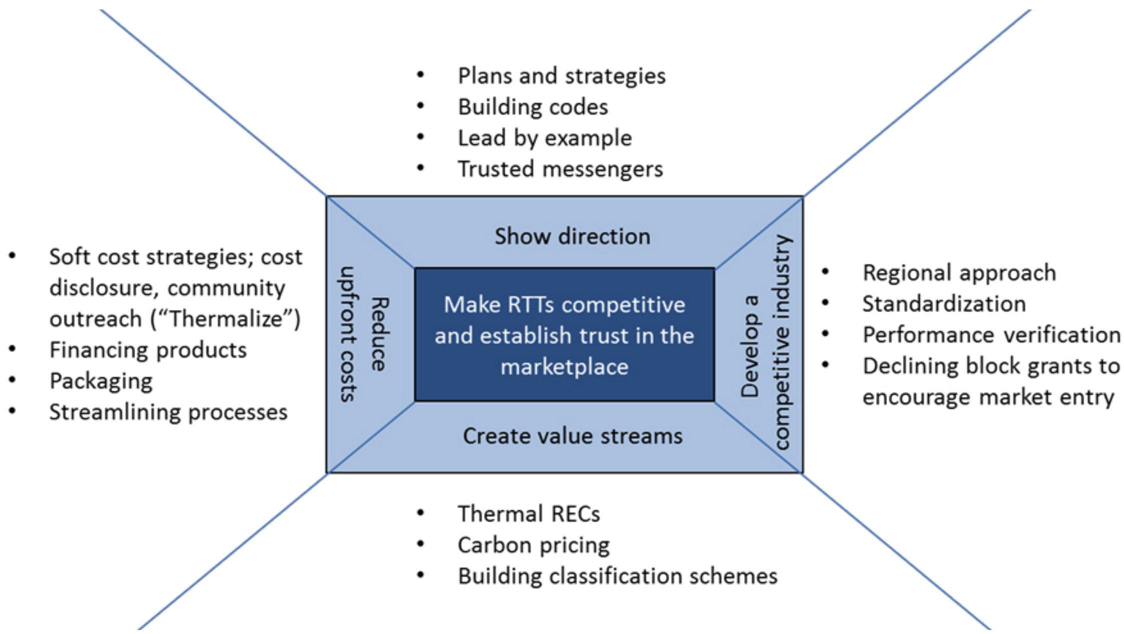


Figure 25 | Market interventions to increase the diffusion of RTTs.

The market interventions in Figure 25 consist of a range of regulatory measures, financial products, and marketing strategies. The analysis of this report focuses on the interventions that can be quantified through costs or revenue streams. However, a combination of regulations, financial incentives, and marketing efforts pulling the same direction will have a larger impact on RTT deployment than stand-alone measures.

The most influential parameters in the sensitivity analysis are incremental initial costs, fuel costs of incumbent case, and fuel costs of proposed case. Which is most influential varies from case to case, but the order of magnitude is typically that shown by Figure 26.

67 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

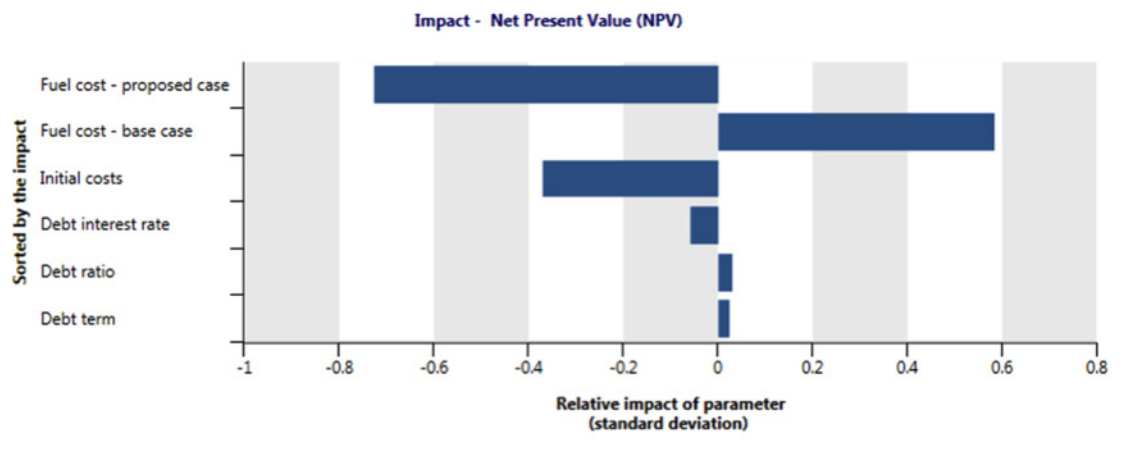


Figure 26 | Relative impacts of parameter from the financial evaluation. Example: ASHP replacing fuel oil in single-family homes.

The general trend presents the overwhelming importance of fuel costs to the competitiveness of the proposed (RTT) versus the base alternative (incumbent technology). Incremental initial costs have the greatest impact in cases including GSHPs, although fuel costs strongly influence even this technology. Overall, debt ratio, debt term, and debt interest rate are of relatively little significance to project economics. However, financial conditions are important for other reasons, such as reducing the upfront costs, shifting customer cash flow, and establish trust in the solution.

The importance of fuel costs in the financial analysis is evident from Figure 27 as well. Taking fuel content and efficiency of heating equipment into consideration, this shows the operating fuel costs of different heating alternatives for residential customers (assumptions in Appendix A).

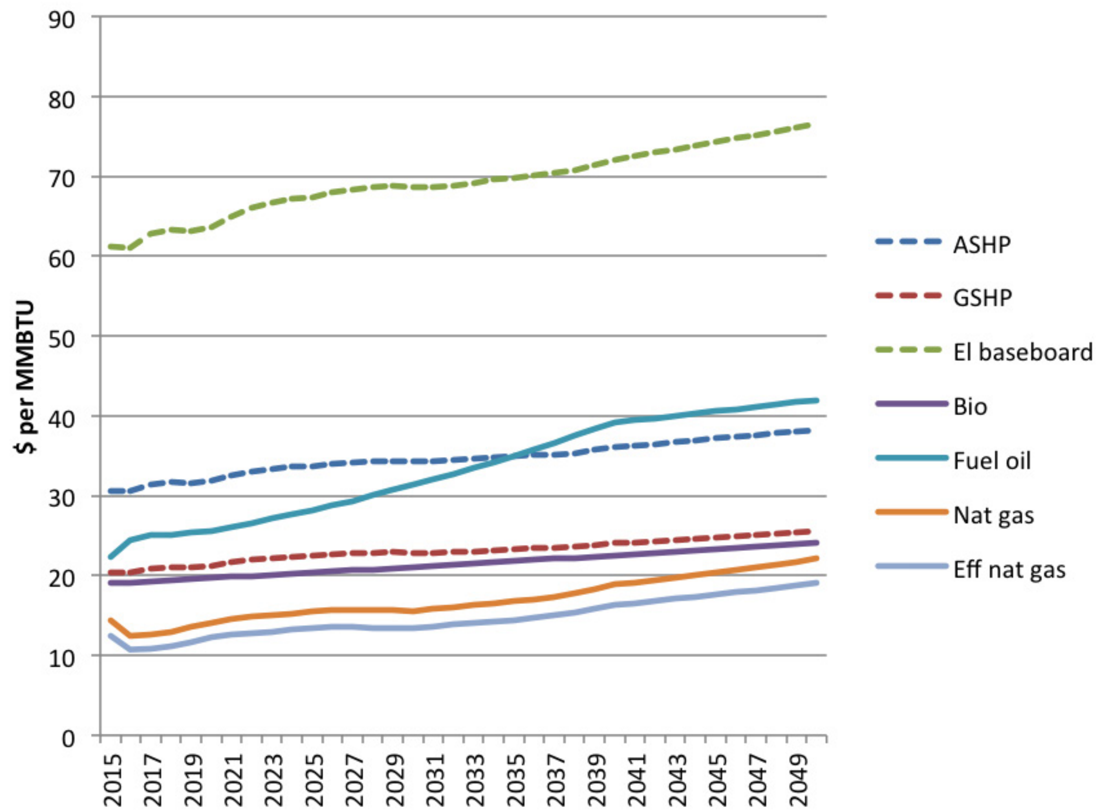


Figure 27 | Projected operational fuel costs for different energy sources for heating technologies (2013 prices). Residential sector.

Electricity for heating is currently considerably more expensive than fuel oil and natural gas, and projections through 2050 continue the trend. In order to pay for the higher installation costs of RTTs, the operational costs have to be proportionately lower for RTTs than for the conventional alternatives. With current price assumptions, operational fuel costs are lower than fuel oil for GSHPs and biomass, but higher than natural gas.

To analyze the most influential parameters and possible market interventions, we have included the sensitivity analysis shown by Table 13.

PARAMETER	DESCRIPTION OF ANALYSIS
6.1 Fuel costs	6.1.1. 50 percent increase of incumbent case
	6.1.2. 100 percent increase of incumbent case
	6.1.3. 25 percent reduction of proposed case
	6.1.4. Solar PV delivers drive energy of proposed case
6.2. Incremental initial costs	6.2.1. 25 percent reduction (whole load installation)
	6.2.2. RTT for partial load (60 percent of capacity and ~80 percent of load)
6.3 Carbon price	Carbon price corresponding to the social cost of carbon
6.4. Thermal Renewable Energy Certificates (TRECs)	TRECs corresponding to market prices
6.5. Financial terms	6.5.1. 25 percent reduction of debt interest rate
	6.5.2. 25 percent increase of debt term, with economic life of asset as maximum debt term
6.6. Sets of simultaneous changes	6.6.1. 25 percent reduction of initial costs, 25 percent reduction of electricity prices for the proposed case due to use of solar PV, 25 percent reduction of pellet prices and a carbon price of $120 per tCO_2
	6.6.2. 25 percent reduction of initial costs, 25 percent reduction of electricity prices for the proposed case due to use of solar PV, and a 50 percent increase of incumbent case fuel costs

Table 13 | Sensitivity analysis applied to the financial evaluation of RTTs. Numbering referring to chapter.

For sensitivity analyses 6.1 through 6.6 only one parameter has been analyzed at a time. Sensitivity analysis 6 shows the sensitivity of changing several parameters at a time.

6.1—Fuel Costs

Fuel costs, both for the incumbent and the proposed case, have a large impact on the competitiveness of the RTTs. Change of relative prices are particularly relevant.

Prices of different energy sources have varied extensively over the last 25 years, as shown by Figure 28.

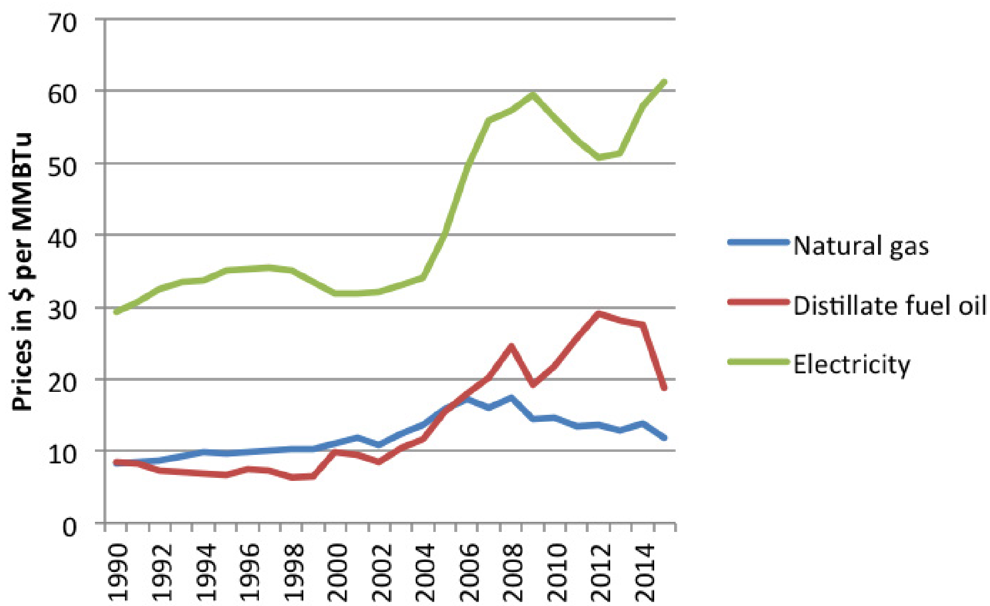


Figure 28 | Annual residential energy prices in Connecticut for the period 2000–2015 (nominal values). Source: EIA SEDS

Figure 28 shows larger price shifts for fuel oil and electricity than for natural gas over the period. Natural gas prices have been lower than fuel oil prices in the residential sector since 2005. The volatility within one year can be considerable as well. In 2015 the monthly residential natural gas prices varied between $11 and $21.5 per MMBTU and the weekly residential fuel oil prices varied between $16.4 and $25.1 per MMBTU.

As energy prices are volatile and may change considerably over time, we have analyzed the sensitivity of changes in fuel costs.

With the exception of sensitivity analysis 6.1.4—solar PV delivering the drive electricity for the proposed cases—both incumbent and proposed cases have been adjusted for alternatives where the energy source is the same for both cases.

50 PERCENT FUEL COST INCREASE FOR INCUMBENT CASE

Table 14 shows the implication for RTT competitiveness based on a 50 percent increase in fuel costs for the incumbent case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 14 | Sensitivity analysis for a 50 percent increase of incumbent fuel costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of increasing the fuel costs of the incumbent case by 50 percent are

- Heat pumps to replace conventional electric heating and traditional air-conditioning become competitive for all customer categories.
- ASHP water heaters to displace fuel oil for residential hot water become competitive for single-family homes.
- SHW is a competitive alternative to electricity for water heating across all customer segments.
- Biomass for space heating and hot water is competitive with fuel oil in all customer categories.
- Highly efficient natural gas boilers become economically feasible alternatives to standard natural gas boilers. Generally, higher fuel costs makes more energy efficient alternatives using the same fuel attractive.

100 PERCENT FUEL COST INCREASE FOR INCUMBENT CASE

Table 15 shows the implication for RTT competitiveness based on a 100 percent increase in fuel costs for the incumbent case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 15 | Sensitivity analysis for a 100 percent increase of incumbent fuel costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of increasing fuel costs of the incumbent case by 100 percent are:

- Heat pumps become a competitive alternative to fuel oil in many customer segments, including the more expensive heat pump systems.
- Heat pumps to replace conventional electric heating and traditional air-conditioning become competitive for all customer categories.
- ASHP water heaters to displace fuel oil for residential hot water become competitive.
- SHW is a competitive alternative to electricity for water heating and for fuel oil in several customer categories.
- Biomass for space heating and hot water is competitive with fuel oil and standard natural gas boilers in all customer categories.
- Highly efficient natural gas boilers are competitive alternatives to standard natural gas boilers. Generally, higher fuel costs makes more energy efficient alternatives using the same fuel attractive.

25 PERCENT FUEL COST REDUCTION FOR PROPOSED CASE

Table 16 shows the implication for RTT competitiveness given a 25 percent reduction of fuel costs for the proposed case.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 16 | Sensitivity analysis for a 25 percent reduction of fuel costs of the proposed case. Green cells indicate cases with positive NPV in the incumbent case, orange cells indicate cases that turn positive and blue cells indicate cases that turn from positive NPV in base case to negative NPV in the sensitivity analysis.

The main implications of reducing the fuel costs of the proposed case by 25 percent are:

- Replacing conventional electric technologies with heat pumps becomes less attractive when electricity purchased from the grid becomes cheaper. The operational expenses of both the proposed and incumbent case are reduced and the savings are lower.
- Replacing a standard gas boiler with a highly efficient gas boiler becomes less attractive. Lower gas prices will lower the operational expenses of both the proposed and incumbent cases. The benefit of a more efficient boiler is reduced.
- Biomass pellets for space heating and hot water is competitive for fuel oil in all customer categories.

SOLAR PV DELIVERS THE DRIVE ELECTRICITY OF THE PROPOSED CASE

Combining solar PV with electricity-driven RTTs offers an opportunity to reduce both the operational costs of RTTs and the GHG emissions related to the technology. The impact on GHG emissions for residential sector was illustrated in scenario 3b of Figure 23; the impacts on operational fuel costs are illustrated in Figure 29.

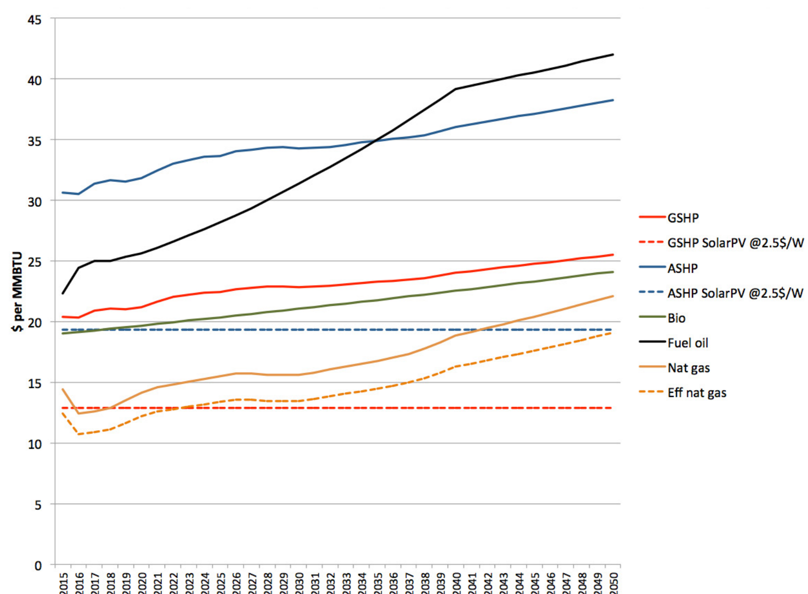


Figure 29 | Projected operational fuel costs for different energy sources for heating technologies. Residential sector.

The Solarize CT campaign,[68] initiated under the SunShot program and championed by the CT Green Bank, is a viable example of a community-based model that aggregates installations and streamlines the supply chain. In 2013, the program reported that since its beginning all participating towns had doubled their solar installations while homeowners saved at least 24 percent on the per-watt cost of

68 http://solarizect.com/

solar PV.[69] The solar PV market currently sees installation costs of $3 per Watt, tax credits taken into consideration.[70] Expectations are that the installation costs of solar PV will continue to drop.

Figure 29 compares the costs of electricity for operating a GSHP on grid electricity versus a solar PV. At installation costs of $2.5 per Watt,[71] GSHPs combined with solar PV have operational fuel costs at levels similar to natural gas. An installation cost of $2.5 per Watt corresponds to a 36 percent reduction of electricity prices.

Table 17 shows the implication for RTT competitiveness of a 36 percent reduction of the electricity costs of heat pumps and SHW as a consequence of bundling with solar PVs installed at $2.5 per Watt.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							

Table 17 | Sensitivity analysis for a combining heat pumps with solar PV at $2.5 per Watt. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

69 http://beccconference.org/wp-content/uploads/2013/12/BECC_gillingham.pdf

70 State incentives of $0.4 per Watt are not included.

71 Solar PV assumes 30 percent tax rebate

Combining solar PV with heat pumps and SHW offers a competitive financial case for the customer, given an expected future cost reduction of the installation of solar PV. The generation profile of the solar PV can influence this result, though, and should be looked into.

6.2—Incremental Initial Costs

High upfront cost appears to be one of the most important barriers to RTTs, both because it reduces the economic feasibility and because it increases the hurdle of mobilizing capital. Market interventions that reduce high upfront costs would have a positive impact on the competitiveness of RTTs, and successful programs and financial incentives influencing on initial costs have been implemented both for RTTs and other technologies:

- The Solarize CT campaign resulted in installation cost reductions of 13 percent as installation costs went from $3.45 to $3 per Watt.
- The HeatSmart Thompson pilot in New York State resulted in an average cost reduction of 20 percent.
- The current CT residential subsidies cover 3–5 percent of the incremental installation costs.
- Solar thermal installations placed in service by end of 2019 are given a tax rebate of 30 percent, after which the size of the credit is ramped down.

25 PERCENT REDUCTION OF INCREMENTAL INITIAL COSTS

The implications of reducing initial costs by 25 percent are shown by Table 18.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 18 | Sensitivity analysis for a 25 percent reduction of initial costs. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of reducing initial costs by 25 percent are:

- Heat pumps are competitive in almost all customer categories, replacing conventional electric technologies for heating and cooling.
- SHW is competitive in all customer categories except Office, replacing electric water heating.
- Biomass for space heating and hot water becomes competitive, replacing fuel oil in residential buildings.
- Highly efficient gas boilers become competitive against standard gas boilers in most customer categories.

RTTS FOR PARTIAL LOAD

To avoid additional complexity in the analysis, RTTs have been modeled to deliver the whole thermal demand of a building. Oversizing RTTs should be avoided both due to installation costs and efficient operations, and keeping the incumbent energy source for peak load operations may offer higher profitability. Partial-load strategies, such as the RTT providing thermal services to parts of the building or during parts of the year have not been included in the general competition and sensitivity analyses.

To gain insight into the economic implications of dimensioning the RTT for partial load, the RTT still being the primary thermal energy source, calculations have been done for residential GSHPs and ASHPs dimensioned for 60 percent of peak heating load. An installed capacity of 60 percent of peak heating load can typically deliver 80 percent of the demand for space heating due to the shape of the thermal demand curve over the year. The incumbent fuel oil boiler is used on the coldest days. The results are indicated by Figure 30 and 31.

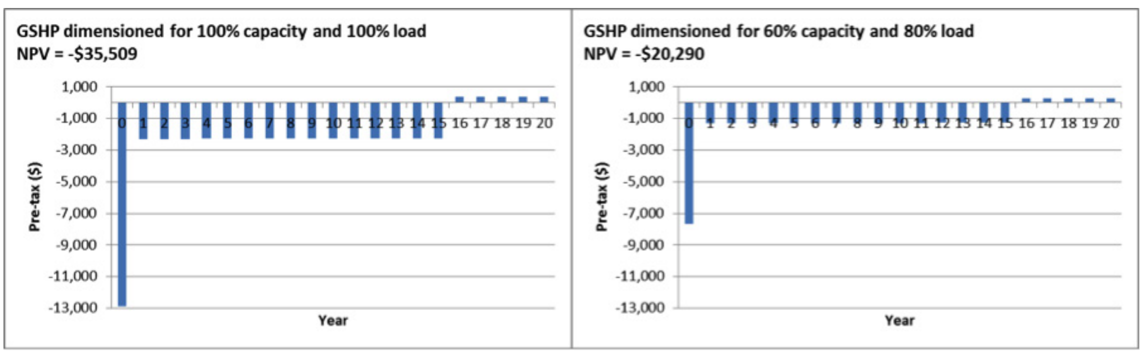


Figure 30 | Net present value and cash flow for a residential GSHP replacing fuel oil for respectively full and partial load.

When dimensioning the residential GSHP for 60 percent of the estimated peak heating load instead of 100 percent, the customer can save on installation costs. This can be seen from Figure 30, as the initial costs of year 0 change from just below $13,000 to $7,600. This case study shows an improvement in NPV of some 40 percent.

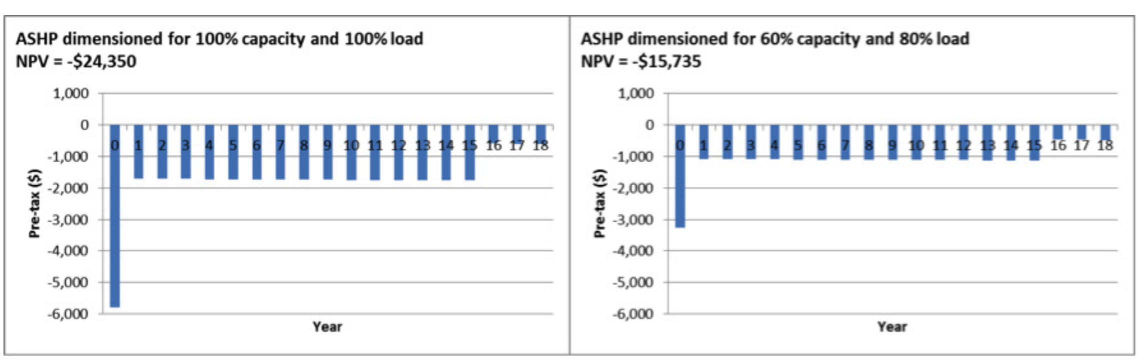


Figure 31 | Net present value and cash flow for a residential ASHP replacing fuel oil for respectively full and partial load.

When dimensioning the residential ASHP for 60 percent of estimated peak heating load instead of 100 percent, the customer can save on installation costs. This can be seen from Figure 31, as the initial costs of year 0 change from just below $6,000 to just above $3,200. The case studied shows an improvement in NPV of some 35 percent.

Allowing for strategies where the RTT is supplemented by the incumbent thermal technology at peak thermal demand will often improve the financial case.

6.3—Carbon Pricing

"The "social cost of carbon" (SCC) is a concept that reflects the marginal external costs of emissions; it represents the monetized damage caused by each additional unit of carbon dioxide, or the carbon equivalent of another greenhouse gas, emitted into the atmosphere." [72]

Many countries have begun accounting for the SCC in regulatory decisions and implementing market mechanisms to incentivize individuals and organizations to consider the full costs of their action on society. Examples include carbon taxes, or cap-and-trade systems, like the Regional Greenhouse Gas Initiative (RGGI) of the Northeast and Mid-Atlantic States of U.S. and the European Emissions Trading System (EU ETS).

The EPA and other federal agencies use the SCC to estimate regulatory climate benefits.[73] In our study we have included a carbon price corresponding to the EPA SCC with a 3 percent discount rate:

- A carbon price of $41 per metric ton CO_2e[74]
- The carbon price is applied over the whole lifetime of the asset
- An annual escalation rate of 1.9 percent

Table 19 shows the implication for RTT competitiveness of a carbon price as described above.[75]

72 Kotchen, Matthew J. (2016): Which social cost of carbon? A theoretical perspective. National Bureau of Economic Research, Working Paper 22246

73 https://www.epa.gov/climatechange/social-cost-carbon

74 United States central estimate for 2015 (Interagency Working Group 2013)

75 For reasons spelled out in footnote 43 in Chapter 3.3, DEEP maintains that the cost-competitiveness benefits described here as accruing to biomass from SCC are not reliable.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 19 | Sensitivity analysis for a carbon pricing alternative. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The main implications of a carbon price corresponding to the SCC are:

- Biomass pellets to replace fuel oil for space heating and hot water will be competitive across all customer categories.
- Heat pumps to replace conventional electric technologies for space heating and cooling will be competitive in a few additional customer categories.

The influence on the economics of RTTs depends on the set value of the carbon price, but it is undoubtedly a positive point of leverage for changing the relative operational fuel costs in favor of low-emitting technologies. However, the carbon price has to be around $90 per metric ton CO_{2e} to have the same impact on the competitiveness of RTTs in the analyzed customer segments as a 25 percent increase in fossil fuel prices.

6.4—Thermal Renewable Energy Certificates

The electric supply and distribution companies in Connecticut are mandated to meet a Renewable Portfolio Standard (RPS) requirement of 27 percent renewable electricity generation by 2020. The RPS generally does not create Renewable Energy Credits (RECs) for renewable thermal energy.

While a carbon price assigns a cost on the use of polluting technology, a REC awards the use of clean technologies and establishes an avoided cost of carbon. As of April 2016, 12 states have included renewable thermal technologies in their RPS, with variations over which technologies have been included, how performance is measured and monitored, how the thermal energy is valued, and how it is classified in the RPS.[76]

Regionally, New Hampshire has created a separate sub-category for RTTs in its RPS: TRECs. Electricity producers are now required to generate or acquire equivalent thermal RECs as part of their renewable energy portfolio. Massachusetts has created an Alternative Energy Portfolio Standard (APS) generating Alternative Energy Credits (AEC) for a range of RTTs. Massachusetts' APS is distinct from the RPS, but essentially acts as a separate tier.

76 http://www.cesa.org/assets/Uploads/Renewable-Thermal-in-State-RPS-April-2015.pdf

In our study we have included a TREC based on the experience of New Hampshire:

- One TREC is valued as the equivalent of 1 MWh. The drive energy of heat pumps is deducted in determining the TREC
- A TREC is priced at $25 per MWh[77]
- TRECs are given for a period of 15 years
- The TREC price escalates at an annual rate of 1 percent

Providing a monetary incentive under a state RPS requirement could influence the economics of RTTs and offer incentives to utilize resources across businesses.

Table 20 shows the implication for RTT competitiveness of a TREC, as described above.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							

77 The rate of TRECs in New Hampshire, as of 2016 is $25/MWh. http://www.puc.state.nh.us/sustainable%20energy/renewable_portfolio_standard_program.htm

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 20 | Sensitivity analysis for a TRECs alternative. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

The influence on the competitiveness of RTTs depends on the value of the TREC, but it is undoubtedly a positive point of leverage to change the relative operational fuel costs in favor of low-emitting technologies. The impact on the competitiveness of RTTs of a TREC of $25 per MWh seems to be similar to a carbon price of $41 per metric ton CO_2e in our analysis.

Representing technologies that can be measured with some degree of certainty, TRECs not only can be an instrument to fund larger installations, such as thermal loops and industrial fuel switching, but smaller projects through aggregation. Including TRECs would equate renewable energy from thermal technologies with renewable energy from electricity generation, which would make private investors optimize between thermal and electrical energy.

6.5—Financial Terms

Financial terms can reduce barriers to RTTs such as high upfront costs, financing costs, awareness, and risk through trust in the technology. This can involve low interest rates, longer debt terms, and conditions to make the investment cash flow positive for the customer.

Table 21 shows the impact of a reduction of the debt interest rate by 25 percent, from 3.5 to 2.6 percent, in the residential sector, and from 4 to 3 percent for commercial customers (with a 15-year debt term). As a comparison, the current interest rate of a residential Smart-e loan is 2.99 percent over 10 years, and 5 percent over 10 years for commercial PACE.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 21 | Sensitivity analysis for a 25 percent reduction of debt interest rates. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

Table 22 shows the impact of an increase of debt term by 25 percent, limited by the economic life of the asset.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 22 | Sensitivity analysis for an increase of debt term. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

From a purely economic point of view, the implication of reducing the debt interest rate and increasing the debt term seems to be small. Reducing the debt interest rate makes biomass competitive in the residential sector and ASHPs with ductwork competitive in additional commercial segments.

Although not the most impactful parameters on NPV, financial terms matter to the customers for other reasons. Favorable financing terms through a recognized organization:

- reduce the risk for private lenders, and the project can achieve lower rates on other loans.
- give attention and credibility to the technology.
- qualify the technology as an environmentally friendly technology.

6.6—Sets of Simultaneous Changes

Larger market impact and probability for success can be achieved through intervention on several parameters at a time. The impact of sets of simultaneous changes has been analyzed for the following packages of measures and technologies.

PACKAGE 1:
INCREMENTAL INITIAL COSTS, FUEL COSTS, AND CARBON PRICE

- Incremental initial costs 25 percent lower
- Solar PV reduces electricity costs of heat pumps and SHW by 25 percent
- Pellets prices 25 percent lower
- Carbon price of $120 per tCO_2

PACKAGE 2:
INCREMENTAL INITIAL COSTS, SOLAR PV, AND INCREASED FOSSIL FUEL COSTS

- Incremental initial costs 25 percent lower
- Solar PV reduces electricity costs of heat pumps and SHW by 25 percent
- Fossil fuel costs 50 percent higher

Table 23 shows the impact of changing several variables at the same time: initial costs, solar PV, lower pellet prices, and a carbon price. Table 24 shows the impact of changing several variables at the same time: initial costs, solar PV, and increased fuel costs for the fossil fuels.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 23 | Sensitivity analysis for sets of simultaneous changes in initial costs, solar PV for heat pumps, and carbon price. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

PROPOSED THERMAL TECHNOLOGY	INSTEAD OF	SINGLE-FAMILY	MULTI-FAMILY	EDUCATION	FOOD SERVICE	HEALTH	HOTEL	OFFICE
ASHP space heating and cooling with no ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP space heating and cooling with ductwork needed	Electricity							
	Fuel Oil							
	Natural Gas							
ASHP water heating	Electricity							
	Fuel Oil							
	Natural Gas							
GSHP space heating and cooling	Electricity							
	Fuel Oil							
	Natural Gas							
Solar Hot Water	Electricity							
	Fuel Oil							
	Natural Gas							
Biomass space heating and hot water	Fuel Oil							
	Natural Gas							
Highly efficient natural gas	Electricity							
	Fuel Oil							
	Natural Gas							

Table 24 | Sensitivity analysis for sets of simultaneous changes in initial costs, solar PV for heat pumps, and increased fuel costs incumbent case. Green cells indicate cases with positive NPV in the base case and orange cells indicate cases that turn positive in the sensitivity analysis.

- Combinations of market interventions are necessary to make heat pumps competitive against fuel oil.
- Natural gas is persistently the most economically favorable alternative for space and water heating.

6.7—Implications for Cash Flow

Net present value, payback, and internal return will indicate to what extent a project is economically favorable. As the future is uncertain, the implications on cash flow may be more interesting for the customer than NPV: How much money will I have to pay “net out of pocket” annually with this alternative compared to that? This can be illustrated with the single-family home category replacing conventional electric technologies with GSHPs for space heating and cooling, as shown by Figure 32. The cash flow over the lifetime of the project (20 years) is shown for 4 cumulative steps:

1. The base case analysis for the single-family home installing a GSHP for space heating and cooling instead of conventional electric heating and traditional air conditioning shows a positive NPV of $5,600. However, due to a 70 percent loan ratio, the customer has an initial cash payment of around $14,000 that has to come from his or her savings.

2. If, however, the initial incremental installation costs had been 25 percent lower, e.g. as a consequence of a grant, a “Thermalize” campaign, combinations of both, etc., the project would be economically more favorable and the initial cash payment would be $3,500 lower than for the base case. The customer would need 25 percent less savings to quality for a loan requiring 30 percent equity.

3. If, in addition to the 25 percent lower initial incremental installation costs, the customer had leased a solar PV installation at a rate 25 percent lower than the electricity prices from the electric grid, the GSHP would be considerably more economically favorable. The customer would be able to benefit from lower operational costs without increasing the need for raising capital upfront.

4. All prior steps imply that the customer has to raise capital upfront as the project is funded at a 70 percent debt ratio. Not all customers are able or willing to invest large amounts upfront, e.g. because they do not have the capital, they prefer constant and predictable payments, or they do not know how long they will stay in the house. The design of financial products, such as leasing, EPC, PACE, and on-bill financing, can overcome these barriers. As can be seen from the 100 percent debt ratio case, the cash-flow has shifted to positive for all years. The annual net benefit is somewhat lower for case 4 than case 3, but still favorable with a positive NPV.

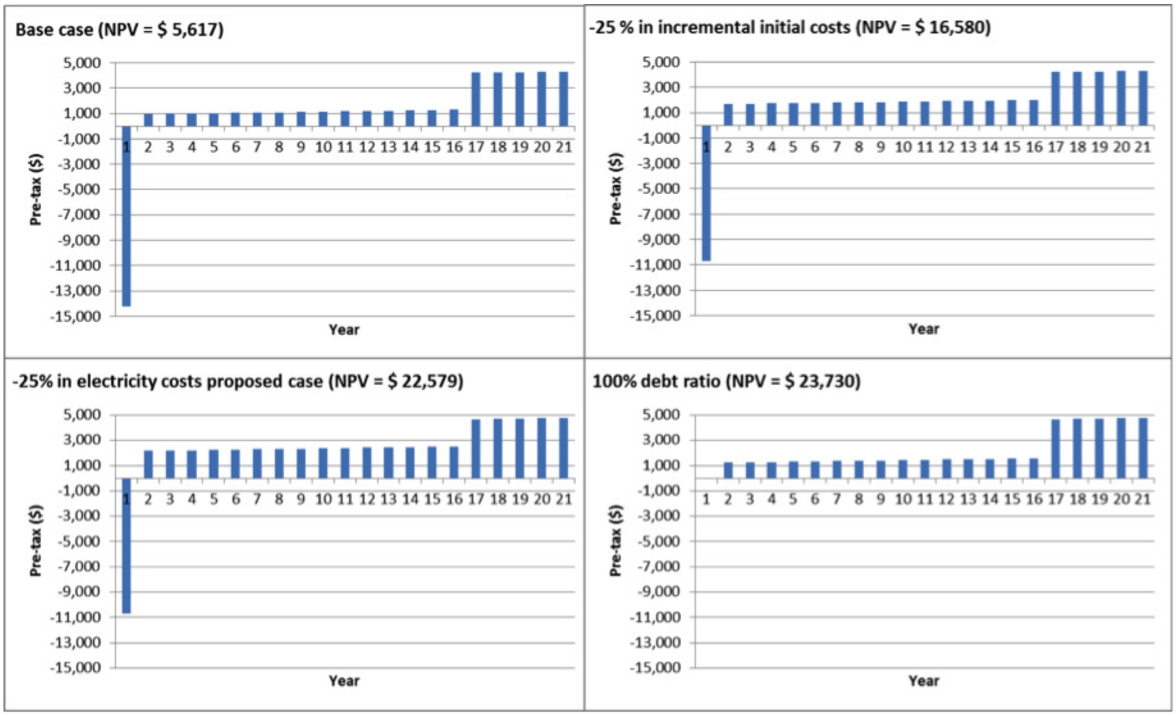


Figure 32 | Cash flow analysis. Single-family home replacing electricity with GSHP for space heating and cooling.

This example shows how combinations of marketing campaigns, financial products, and energy technologies can contribute to the attractiveness of RTTs.

CHAPTER 7
Recommendations

The market potential for RTTs remains considerable through 2050, and a high RTT deployment rate is needed to achieve the 2050 GHG emission targets. Several RTTs are currently challenged by unfavorable economics and non-economic barriers. To bring the market for RTTs to a scale capable of providing major contributions to reducing GHG emissions, a bundle of measures is needed.

While the companion field study[78] recommends a wide range of strategies and measures to break down barriers and build up drivers, the following recommendations focus specifically on market interventions directly targeting the technical potential and financial competitiveness of RTTs.

1. **Reduce upfront costs.** Initial installation costs have large impacts on RTT economics and how much capital the customer has to raise upfront. Initial installation costs are higher for RTTs than for the alternatives, and lower initial installation costs would considerably enhance favorability. The following market strategies would contribute to reducing the barrier of high upfront costs:
   - Cost reduction campaigns à la Solarize[79] that make RTTs more competitive with conventional thermal technologies, as shown in 6.2.1.
   - Partial-load strategies: using RTTs to displace most of the thermal demand for space heating but not requiring them to cover 100 percent of the capacity needed for the peak demand generally improves the financial evaluation, as shown in 6.2.2.
   - New business and financing models removing upfront costs and securing 100 percent financing: loans, leases, and property assessed clean energy (PACE) financing. This is illustrated by the cash-flow analysis in 6.7, where the need to raise money up front is leveled out.

2. **Implement market interventions to improve the operational cash flow.** The analysis shows that fuel costs have a large impact on the financial feasibility of RTTs. Strategies to reduce the operational costs of RTTs relative to the alternatives using fossil fuels would favor the cleaner technologies; so would strategies to establish revenue streams:
   - Packaging RTTs with solar PV and deep renovation may improve the economics, as shown solar PV in 6.1.4.
   - Favorable financing—interest rates and debt term—that reduces risk for private lenders, gives credibility to the technology, and qualifies it as environmentally friendly. This has been discussed in 6.5.

78 Grønli, Helle; Joseph Schiavo, Philip Picotte and Amir Mehr (2017): Feasibility of Renewable Thermal Technologies in Connecticut. A field study on barriers and drivers.

79 Solarize CT is a community-based program that leverages social interaction to promote the adoption of solar through a group-pricing scheme to reduce soft costs.

- Carbon pricing, as discussed in 6.3, would provide leverage for changing the relative operational fuel costs in favor of RTTs.
- Thermal Renewable Energy Certificates (TRECs), discussed in 6.4, reward the use of clean technologies much as a carbon price would.
- Explore rate mechanisms that recognize the value of RTTs in reducing demand for natural gas and electricity.

3. **Enhance awareness of—and trust in—RTTs through marketing efforts, trusted messengers, and proven installations.** Strategies include:
   - Performance verification through metering and monitoring to show that the technologies deliver as promised. Over- or underperformance would have implications similar to those illustrated by the fuel cost sensitivities discussed in 6.1. Performance verification would facilitate new revenue streams and business models, such as Thermal Renewable Energy Certificates, third-party ownership, green bonds, and Energy Performance Contracts. The level of required accuracy would influence the additional cost. We recommend evaluating the cost-benefits of various methods for performance verification with respect to the purpose it will serve, differentiated by customer segments.
   - Green Bank involvement, which enhances credibility, as discussed in 6.5.
   - Declining block grants[80] enhance the competitiveness of RTTs through a reduction of the incremental initial costs, as shown by Chapter 6.2.1.

4. **Use the building code and building standards to establish a predictable minimum market for RTTs.** In addition to stricter requirements for the building envelope (see Chapter 4), which eventually will favor low-temperature solutions such as heat pumps, the code can signal clearly which energy systems to install and which to avoid in new buildings. This will help attain the GHG emission targets as discussed in 5.3, and we recommend evaluating the possibilities of using the building code to:
   - Avoid oil boilers in new construction.
   - Establish a minimum efficiency level for fossil fuel boilers.
   - Require a share of renewable heating and cooling in new construction.

This market potential study has not evaluated the feasibility of district energy. District energy and thermal grids may represent opportunities for cheap and clean thermal energy, exploiting waste energy from electricity generation and industrial processes. The field study on barriers and drivers does provide some recommendations to promote thermal grids.

80 Declining block grants are grants and rebates that decrease over a certain time period according to a pre-determined profile.

This study has revealed some areas where further research could be valuable:

- An evaluation of where limited bioenergy resources would bring the highest value: transportation, electricity generation, or heating buildings and processes.
- A quantification of GHG emission factors across all energy sources specific for Connecticut or New England.
- Demand and generation profiles of different energy technologies and their interaction with the electricity and natural gas grids.

Appendices

APPENDIX A
Assumptions for the Competition Analysis

Building Size and Efficiency

		RESIDENTIAL		COMMERCIAL				
		SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES
Building size (sq ft)[1]		2000	29063	119479	48438	201554	38750	5651
Energy Use Intensities (MBTU/ year/ sq ft)[2]	Space heating	46.4	58.5	25.8	33.4	112.7	61.5	58.9
	Space cooling	1.4	1.7	1.7	7.1	10.4	3.1	3.5
	Hot water	5.6	7.3	31.7	3.3	39.6	7.2	31.1
Peak load (kW)[3]	Space heating	15	328	637	363	4383	427	83
	Space cooling	1	20	82	126	468	59	7
	Hot water	4	86	841	30	1489	80	48
Annual demand (MMBTUs)[4]	Space heating	79	1701	3081	1618	22722	2385	333
	Space cooling	3	49	199	344	2086	120	20
	Hot water	11	213	3787	162	7978	280	176

Table 25 | Building Size and Efficiency

1. The average building size of different categories have been informed by the Connecticut Program Savings Document for 2016, RECS 2009, and CBECS 2003.
2. The Energy Use Intensities have been informed by the Connecticut Program Savings Document for 2016, RECS 2009, and CBECS 2003 (adjusted for the energy efficiency rate from the reference case of the Annual Energy Outlook 2015).
3. The peak load has been elaborated based on the estimated annual thermal demand and hours of utilization time from the Connecticut Program Savings Document for 2016.
4. The annual demand has been estimated based on the building size and the EUIs.

The following dimensioning rules have been applied to the case studies:

- For technologies delivering both space heating and hot water, the peak load for space heating has generally defined the installed capacity. The installation costs for the largest users of hot water—Food Service, Health Care, and Hotel—have been increased by 50 % of the needed capacity to capture hot water.
- For technologies delivering both space heating and cooling, the peak load for space heating has defined the installed capacity.

Cost and Efficiency Assumptions

TECHNOLOGY	SECTOR	INSTALLED COST PER KW ($/KW)[1]	EFFICIENCY[2]	FUEL BTU CONTENT[3]	FUEL COSTS[4]	FUEL COST ESCALATOR[5]	PROJECT LIFE[6]	COMMENT
Natural gas (standard)	Residential	255	82%	1028 Btu/ft3	11.82 $/ thousand ft3	1.6%	20	
	Commercial	255	82%		8.18 $/ thousand ft3	1.6%	30	
Natural gas (highly efficient)	Residential	470	95%		11.82 $/ thousand ft3	1.6%	As proposed case	
	Commercial	470	95%		8.18 $/ thousand ft3	1.6%		
Ductwork[7]	Residential	560						
	Commercial	660						
Electric water heater	Residential	500 $/unit	0.71 energy factor	3412 Btu/kWh	0.209 $/kWh	0.6%	10	
	Commercial							
Electric cooling	Residential	320	SEER 13	3412 Btu/kWh	0.209 $/kWh	0.6%	As proposed case	
	Commercial	320	EER 11		0.1595 $/kWh	0.6%		
Fuel oil	Residential	255	84%	0.1371 mmBtu/gal	1.96 $/gal	0.7%		
	Commercial	255	84%		1.96 $/gal	0.7%		
ASHP	Residential	1100	200% for heating. 18 SEER	3412 Btu/kWh	0.209 $/kWh	0.6%	18	
	Commercial	1100	200% for heating. 18 SEER		0.1595 $/kWh	0.6%	18	
ASHP water heater	Residential	1100 $/unit	2.0 energy factor		0.209 $/kWh	0.6%	10	
	Commercial					N/A	N/A	
GSHP	Residential	2110	300% for heating / cooling 15.1 EER (22.61 SEER)	3412 Btu/kWh	0.209 $/kWh	0.6%	20	
	Commercial	2010	300 % for heating / cooling 15.1 EER (22.61 SEER)		0.1595 $/kWh	0.6%	25	
Biomass pellets	Residential	920	80%	7750 Btu/lb	$260 / ton	260	20	Storage included
	Commercial	790	85%		$230 / ton	230	25	
SHW	Residential	960 $/ m2 aperture	2.5 SEF	0.35 kWh/ ft2/day	0.209 $/kWh	0.6%	20	
	Commercial	1440 $/m2 aperture	2.5 SEF		0.1595 $/kWh	0.6%	20	

Table 26 | Installation costs, efficiency, fuel BTU content, fuel prices, and project life per technology

1. The installation costs have been informed by regional project data provided by the CT Green Bank, Massachusetts Clean Energy Center, New Hampshire Public Utilities Commission, Vermont Public Services Department, and the Northern Forest Center. In addition, we have consulted the RETScreen cost database, the report "Massachusetts renewable heating and cooling opportunities and impacts study" (Meister Consulting Group 2012), and the report "Research on the costs and performance of heating and cooling technologies" (Sweett, 2013). See Appendix C.
2. The efficiencies of different technologies have been informed by the CT Program Savings Document, the RETScreen database, Massachusetts Clean Energy Center central biomass program, and Energize CT.
3. The fuel BTU content is from the Annual Energy Outlook 2015.
4. The fuel costs have been informed by the Energy Information Agency SEDS and the regional project portfolio.
5. The fuel costs escalators have been derived from the reference case of the Annual Energy Outlook 2015.
6. The project life of different technologies has been informed by the CT Program Savings Document 2016 and the Annual Energy Outlook 2015. The project life for the incumbent technology follows the project life of the proposed technology in our financial calculations.
7. The term "Ductwork" is used for all necessary retrofit of thermal infrastructure.

TECHNOLOGY	SECTOR	INCREMENTAL COST OVER INCUMBENT ALTERNATIVE ($/KW) OR ($/M2 APERTURE)			
		NATURAL GAS	ELECTRIC	FUEL OIL	AC
Natural gas (highly efficient)	Residential	215	1030	215	
	Commercial	215	1030	215	
ASHP no ductwork	Residential	1100	1100	1100	-320
	Commercial	1100	1100	1100	-320
ASHP ductwork	Residential	1660	1660	1660	-320
	Commercial	1760	1760	1760	-320
ASHP water heater	Residential	600 /unit	600 /unit	600 /unit	
	Commercial				
GSHP	Residential	2415	2670	2415	-320
	Commercial	2415	2670	2415	-320
Biomass pellets	Residential	665	1480	665	
	Commercial	535	1450	535	
SHW	Residential	960	960	960	
	Commercial	1440	1440	1440	

Table 27 | Incremental installation costs per installed kW, unit or aperture

PROPOSED TECHNOLOGY	BASE TECHNOLOGY	RESIDENTIAL ($PER UNIT)		COMMERCIAL ($PER UNIT)				
		SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES
Natural gas (highly efficient)	Electricity	18,437	337,903	719,484	410,082	4,952,593	482,277	94,108
	Natural gas	3,849	70,533	136,893	78,024	942,308	91,761	17,905
	Fuel oil	3,849	70,533	136,893	78,024	942,308	91,761	17,905
ASHP no ductwork	Electricity	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
	Natural gas	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
	Fuel oil	19,333	359,660	674,065	358,777	4,671,453	450,465	89,391
ASHP ductwork	Electricity	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
	Natural gas	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
	Fuel oil	29,357	543,375	1,094,294	598,294	7,564,119	732,149	144,356
ASHP water heater	Electricity	600						
	Natural gas							
	Fuel oil							
GSHP	Electricity	47,794	875,923	1,700,019	968,955	11,702,146	1,139,538	222,361
	Natural gas	42,871	791,061	1,511,340	835,996	10,434,870	1,011,698	198,906
	Fuel oil	42,871	791,061	1,511,340	835,996	10,434,870	1,011,698	198,906
Biomass pellets	Electricity	26,492	485,530	923,231	526,211	6,355,098	618,850	120,758
	Natural gas	11,904	218,161	340,641	194,154	2,344,812	228,334	44,555
	Fuel oil	11,904	218,161	340,641	194,154	2,344,812	228,334	44,555
SHW	Electricity	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101
	Natural gas	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101
	Fuel oil	5,135	117,642	1,732,342	65,578	3,065,587	169,409	99,101

Table 28 | Incremental installation costs per installed system

	END USES	DUCTWORK NECESSARY	STATUS OF TECHNOLOGY	DISPLACES EXISTING TECHNOLOGY
Natural gas (highly efficient)	Space heating; Hot water	No	Primary	Yes
ASHP no ductwork	Space heating; Space cooling	No	Supplementary	Incumbent as back up
ASHP ductwork	Space heating; Space cooling	Yes	Supplementary	Incumbent as back up
ASHP water heater	Hot water	No	Primary	Yes
GSHP	Space heating; Space cooling	Yes	Primary	Yes
Biomass pellets	Space heating; Hot water	No	Primary	Yes
SHW	Hot water	No	Supplementary	Incumbent as back up

Table 29 | Summary of assumptions determining incremental installation costs

	RESIDENTIAL		COMMERCIAL					IND
	SINGLE FAMILY	APARTMENT	HOTEL	OFFICE	HOSPITAL	EDUCATION	FOOD SERVICES	BAKERIES
Depreciation rate[1]	5.2%	5.2%	4.9%	5.8%	4.6%	5.4%	4.5%	4.7%
Debt interest rate[1]	3.5%	3.5%	3.5%	3.5%	3.5%	4.0%	3.5%	3.5%
Debt ratio	70%	70%	70%	70%	70%	70%	70%	70%
Inflation	2%	2%	2%	2%	2%	2%	2%	2%
Debt term	15 years	15 years	15 years	15 years	15 years	15 years	15 years	15 years

Table 30 | Summary of assumptions determining incremental installation costs

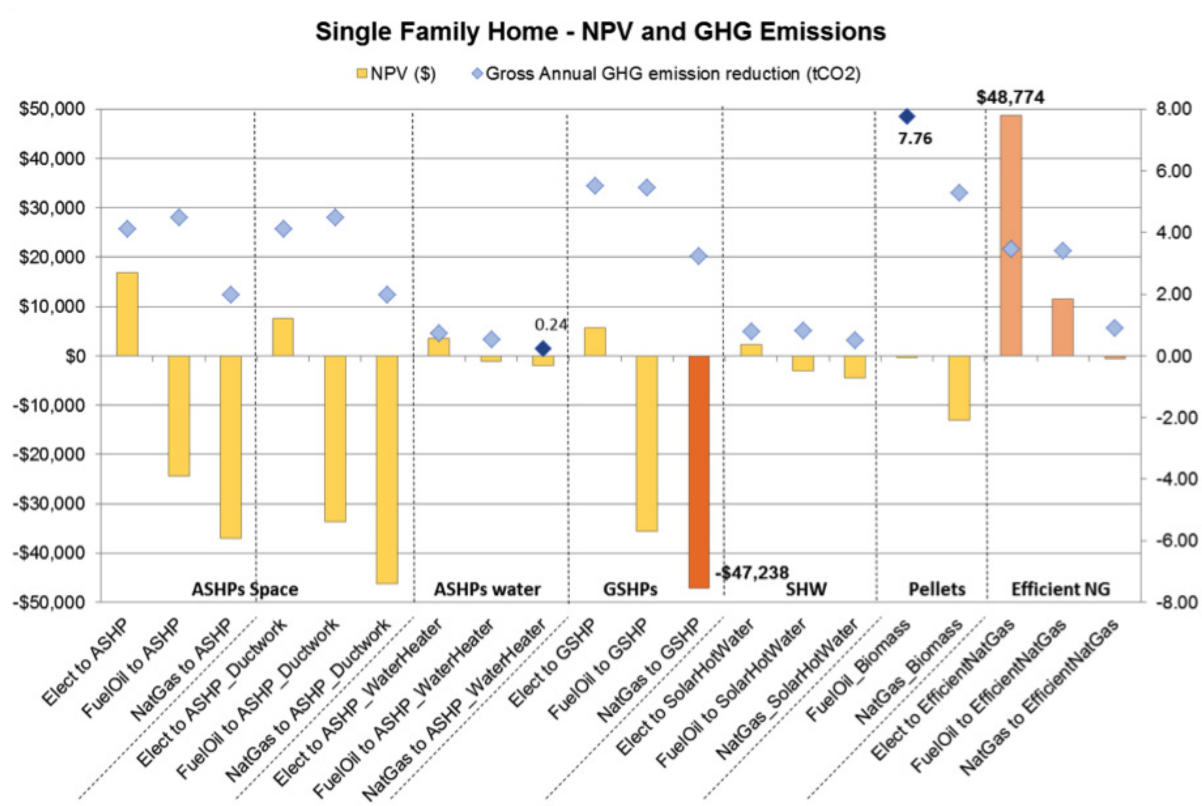
1. Informed by http://people.stern.nyu.edu/adamodar/New_Home_Page/datafile/wacc.htm.
The depreciation rate is the weighted average of the debt interest rate and the equity interest rate.

APPENDIX B
RETScreen Calculation Archetypes

Single Family Home (SFH)

MAIN FINDINGS

- All cases replacing electricity with ASHPs, SHW, or efficient natural gas boilers have a positive NPV
- The case with the highest NPV for SFH is replacing electricity with Efficient Natural Gas
- The case with the lowest NPV for SFH is replacing natural gas with GSHP
- The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
- The lowest GHG emission reductions result from replacing a standard natural gas boiler with an ASHP water heater



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 2,000 sq. ft.

2. Capacity needed for installation (kW):
   - 17.9 for proposed cases including space heating
   - 3.77 for proposed cases including water heating
   - 1.12 for proposed cases including cooling

3. Operating hours:
   - 1,519 hours per year for heating
   - 708 hours per year for cooling

4. Hot water:
   - 54.4 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency

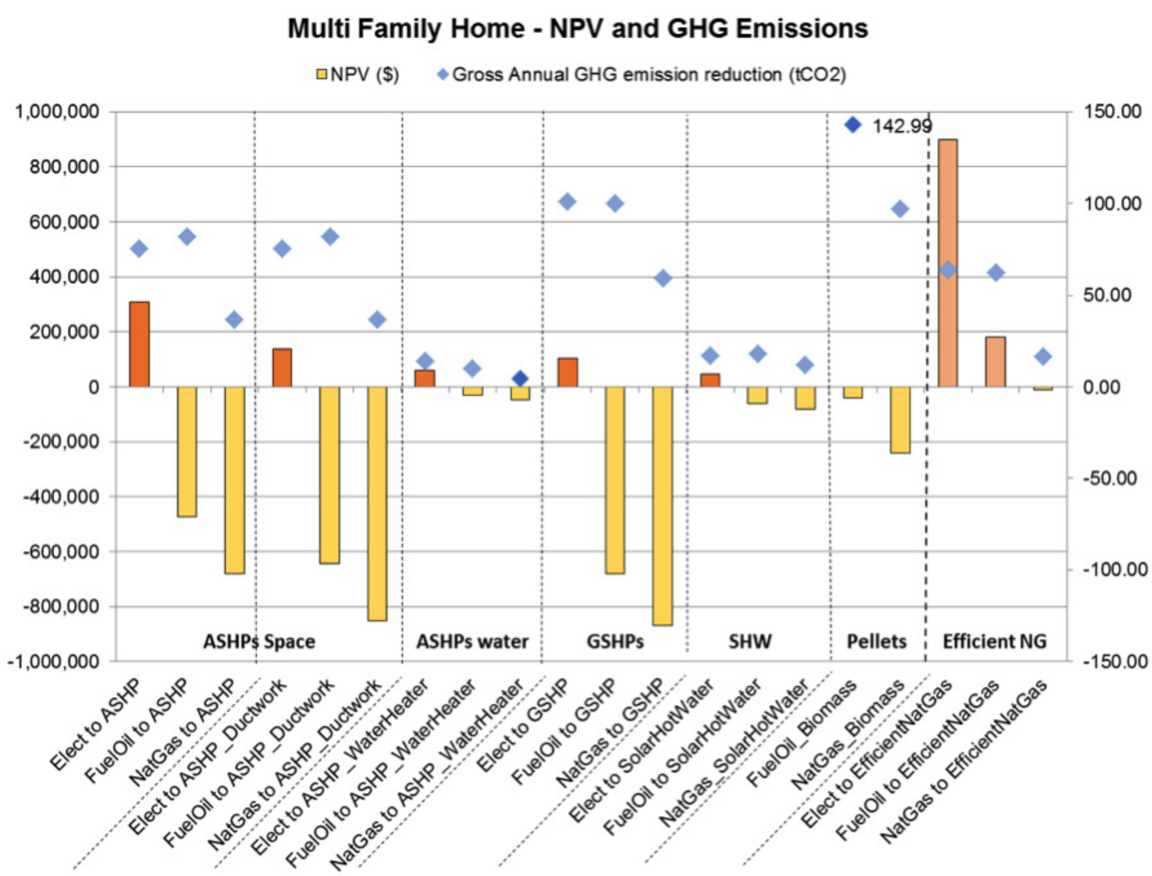
5. Annual demand (MMBTUs):
   - Space Heating: 92.8
   - Space Cooling: 2.7
   - Domestic Hot Water: 11.1

6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $19,332
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $29,356
   - Electricity, Fuel oil or Natural Gas to ASHP Water Heater: $600
   - Electricity to GSHP: $47,435
   - Fuel oil or Natural Gas to GSHP: $42,870
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $5,135
   - Fuel oil or Natural Gas to Biomass: $11,904
   - Electricity to Efficient Natural Gas: $18,437
   - Fuel oil or Natural Gas to Efficient Natural Gas: $3,849

Apartment—Multi Family Home (MFH)

MAIN FINDINGS

- Replacing electricity with heat pumps, SHW, or efficient natural gas boilers has a positive NPV
- The case with the highest NPV for SFH is replacing electricity with Efficient Natural Gas
- The case with the lowest NPV for MFH is replacing natural gas with GSHP
- The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
- The lowest GHG emission reductions result from replacing a standard natural gas boiler with an ASHP water heater



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 29,063 sq. ft.

2. Units: 33

3. Capacity needed for installation (kW):
   - 328 for proposed cases including space heating
   - 86 for proposed cases including water heating
   - 20 for proposed cases including cooling

4. Operating hours:
   - 1,519 hours per year for heating
   - 708 hours per year for cooling

5. Hot water:
   - 1,046 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency

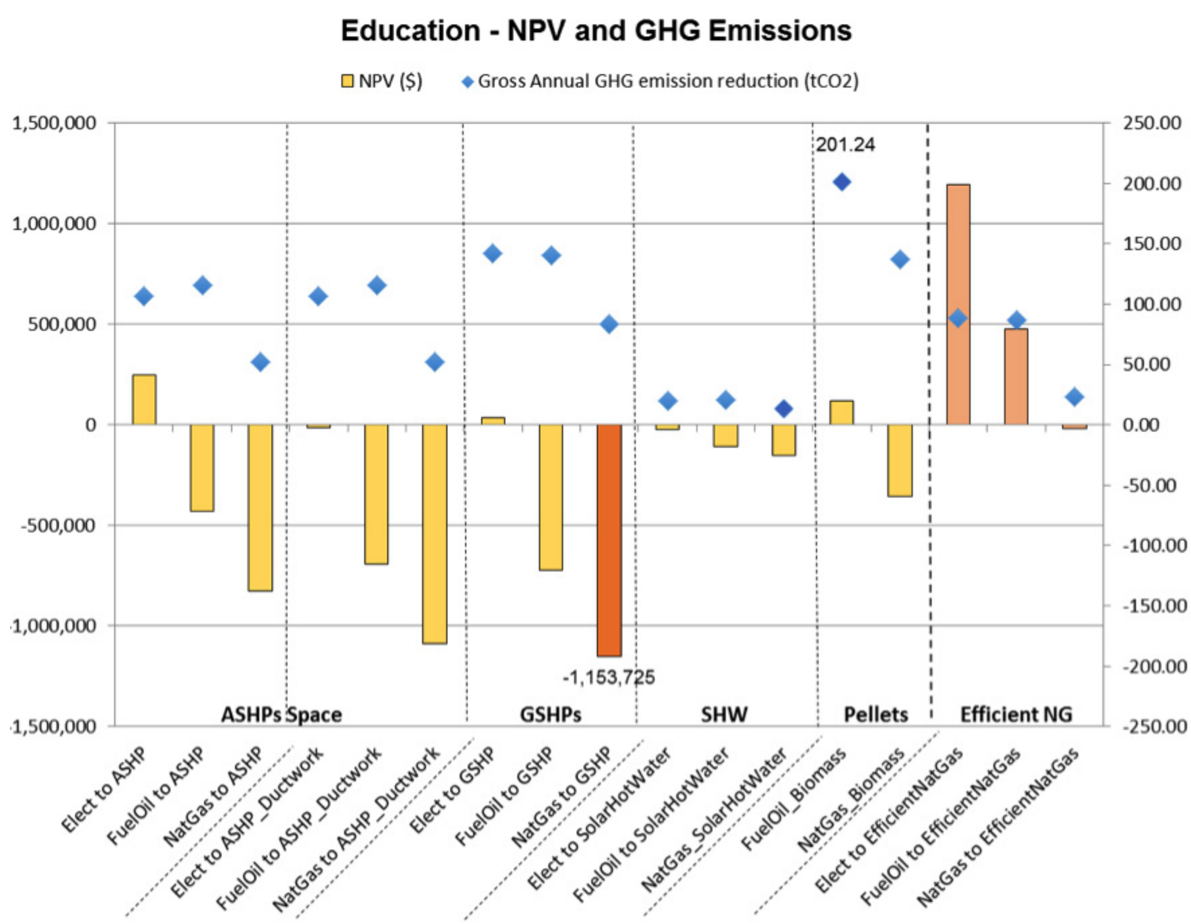
6. Annual demand (MMBTUs):
   - Space Heating: 1,700
   - Space Cooling: 48.3
   - Domestic Hot Water: 213

7. Incremental initial costs:
   - Electricity, Fuel oil or natural gas to ASHP: $354,294
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $538,080
   - Electricity, Fuel oil or Natural Gas to ASHP Water Heater: $19,800
   - Electricity to GSHP: $869,254
   - Fuel oil or Natural Gas to GSHP: $785,759
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $117,642
   - Fuel oil or Natural Gas to Biomass: $218,160
   - Electricity to Efficient Natural Gas: $337,840
   - Fuel oil or Natural Gas to Efficient Natural Gas: $70,520

Education

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to GSHP
   - Fuel Oil to Biomass
   - Electricity to ASHP
   - Electricity or fuel oil to efficient natural gas (highest NPV)
2. The case with the lowest NPV for education is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

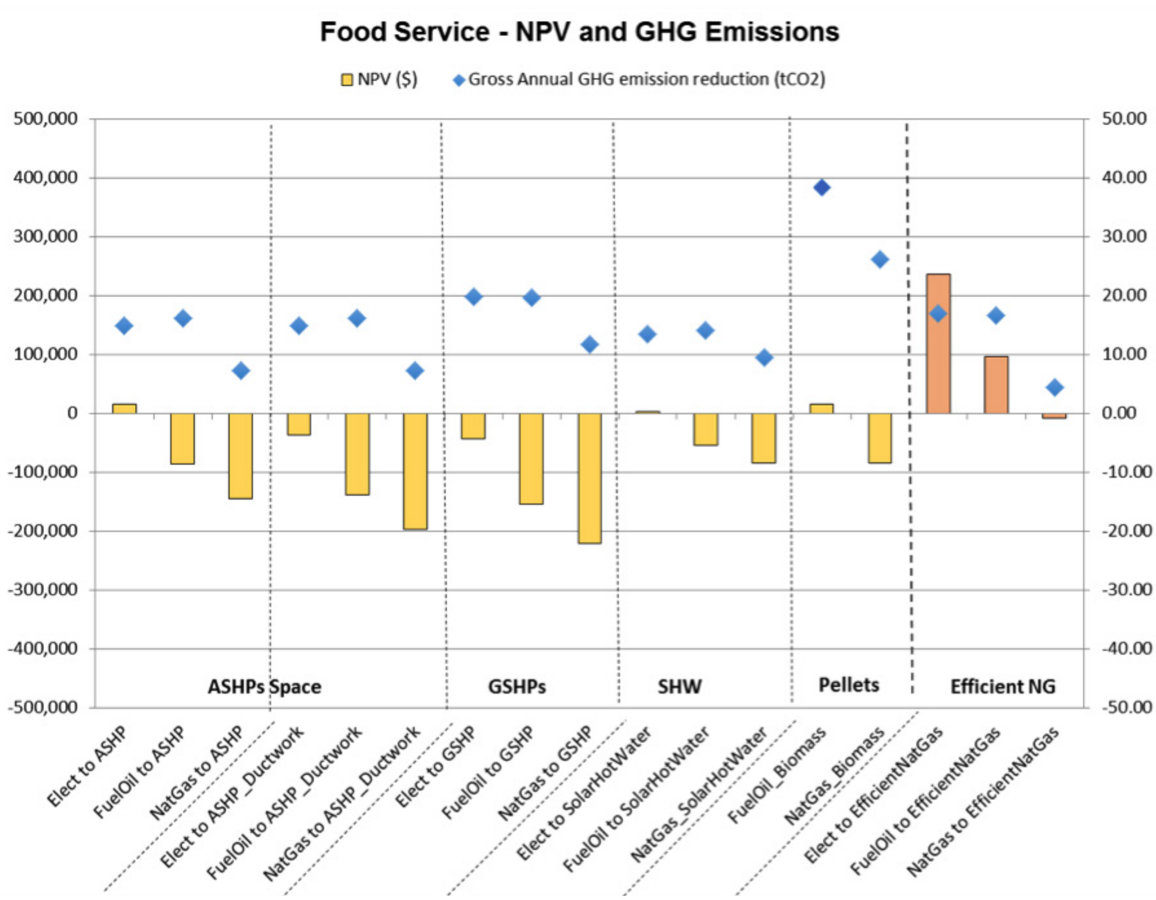
MAIN ASSUMPTIONS

1. Building size: 38,750 sq. ft.
2. Capacity needed for installation (kW):
   - 427 for proposed cases including space heating
   - 80 for proposed cases including water heating
   - 59 for proposed cases including cooling
3. Operating hours per year:
   - 1,637 hours per year for heating
   - 594 hours per year for cooling
4. Hot water:
   - 1,373 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency
5. Annual demand (MMBTUs):
   - Space Heating: 2,384.5
   - Space Cooling: 120.42
   - Domestic Hot Water: 279.98
6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $450,820
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $732,640
   - Electricity to GSHP: $1,121,210
   - Fuel oil or Natural Gas to GSHP: $1,012,325
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $169,409
   - Fuel oil or Natural Gas to Biomass: $228,445
   - Electricity to Efficient Natural Gas: $439,810
   - Fuel oil or Natural Gas to Efficient Natural Gas: $91,805

Food Service

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to Solar Hot Water
   - Electricity to ASHP
   - Fuel Oil to Biomass
   - Electricity or fuel oil to efficient natural gas (highest NPV)
2. The case with the lowest NPV for food service is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with an efficient natural gas boiler



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

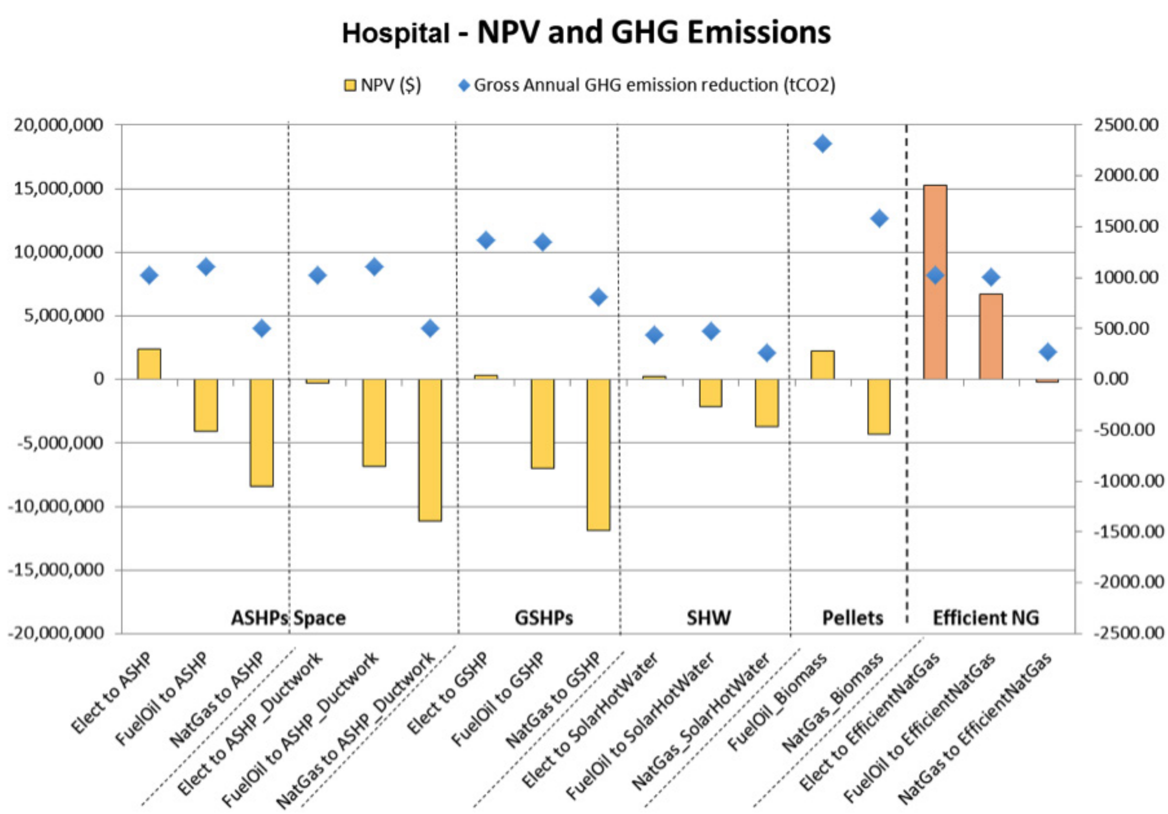
1. Building size: 5,651 sq. ft.
2. Capacity needed for installation (kW):
   - 83.28 for proposed cases including space heating
   - 48 for proposed cases including water heating
   - 7 for proposed cases including cooling
3. Operating hours per year:
   - 1,172 hours per year for heating
   - 837 hours per year for cooling
4. Hot water:
   - 862 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency
5. Annual demand (MMBTUs):
   - Space Heating: 333.12
   - Space Cooling: 19.8
   - Domestic Hot Water: 175.75
6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $89,368
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $144,333
   - Electricity to GSHP: $220,118
   - Fuel oil or Natural Gas to GSHP: $198,881
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $99,101
   - Fuel oil or Natural Gas to Biomass: $44,555
   - Electricity to Efficient Natural Gas: $85,778
   - Fuel oil or Natural Gas to Efficient Natural Gas: $17,905

Hospital

MAIN FINDINGS

1. The cases with a positive NPV include:
    - Electricity to Solar Hot Water
    - Electricity to GSHP
    - Electricity to ASHP
    - Fuel Oil to Biomass
    - Fuel oil or electricity to efficient natural gas (highest NPV)

2. The case with the lowest NPV for hospital is replacing natural gas with GSHP
3. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
4. The lowest GHG emission reductions result from replacing a standard natural gas boiler with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO_2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 201,554 sq. ft.

2. Capacity needed for installation (kW):
   - 4,383 for proposed cases including space heating
   - 1,489 for proposed cases including water heating
   - 468 for proposed cases including cooling

3. Operating hours per year:
   - 1,519 hours per year for heating
   - 1,307 hours per year for cooling

4. Hot water:
   - 38,476 gallons per day used (for the cases from electricity, fuel oil or natural gas to solar hot water, natural gas to biomass, and natural gas to efficient natural gas)
   - 39,112 gallons per day used (for the cases from fuel oil to biomass and from electricity or fuel oil to efficient natural gas)
   - 126 °F
   - 10% heat recovery efficiency

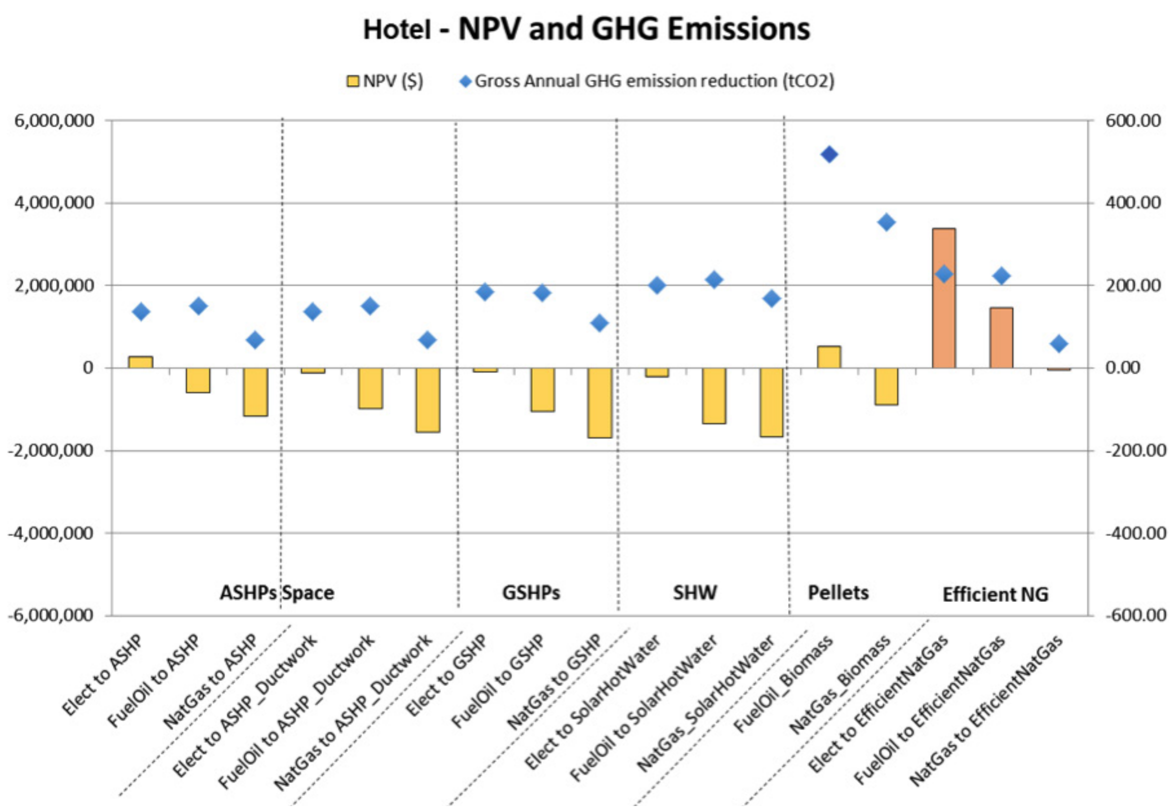
5. Annual demand (MMBTUs):
   - Space Heating: 22,721.88
   - Space Cooling: 2,086.17
   - Domestic Hot Water: 7,977.92

6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $4,671,540
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $7,564,320
   - Electricity to GSHP: $11,552,850
   - Fuel oil or Natural Gas to GSHP: $10,435,185
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $3,065,587
   - Fuel oil or Natural Gas to Biomass: $2,344,905
   - Electricity to Efficient Natural Gas: $4,514,490
   - Fuel oil or Natural Gas to Efficient Natural Gas: $942,345

Hotel

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to ASHP
   - Fuel Oil to Biomass
   - Electricity, fuel oil or natural gas to efficient natural gas
2. The case with the highest NPV for hotel is replacing electricity with efficient natural gas
3. The case with the lowest NPV is replacing natural gas with GSHP
4. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
5. The lowest GHG emission reductions result from replacing a standard natural gas boiler with an efficient natural gas boiler



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 119,479 sq. ft.

2. Capacity needed for installation (kW):
   - 637 for proposed cases including space heating
   - 841 for proposed cases including water heating
   - 82 for proposed cases including cooling

3. Operating hours per year:
   - 1,418 hours per year for heating
   - 708 hours per year for cooling

4. Hot water:
   - 18,264 gallons per day used (for the cases from electricity, fuel oil, or natural gas to solar hot water)
   - 18,566 gallons per day used (for the cases from fuel oil or natural gas to biomass and from electricity, fuel oil, or natural gas to efficient natural gas)
   - 126 °F
   - 10% heat recovery efficiency

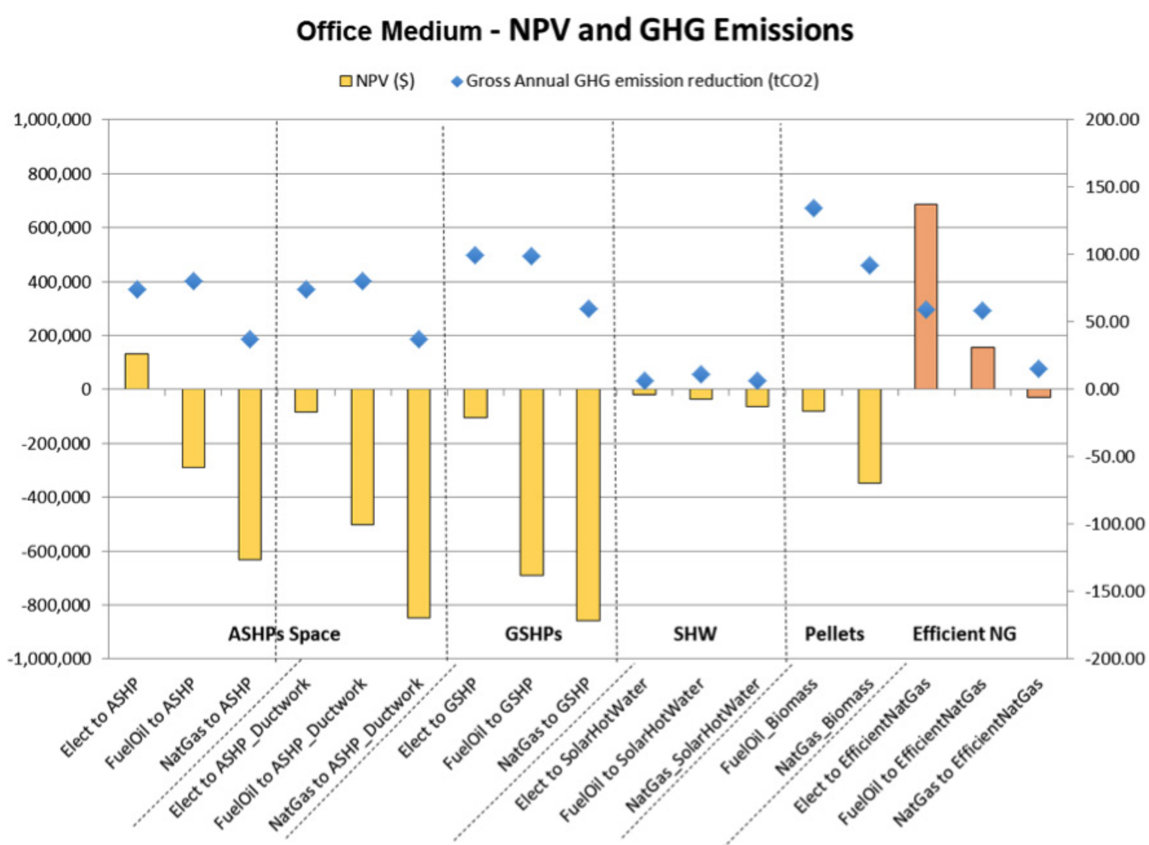
5. Annual demand (MMBTUs):
   - Space Heating: 3,081.42
   - Space Cooling: 198.73
   - Domestic Hot Water: 3,787

6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $674,460
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $1,094,880
   - Electricity to GSHP: $1,674,550
   - Fuel oil or Natural Gas to GSHP: $1,512,115
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $1,732,342
   - Fuel oil or Natural Gas to Biomass: $340,795
   - Electricity to Efficient Natural Gas: $656,110
   - Fuel oil or Natural Gas to Efficient Natural Gas: $136,955

Office Medium

MAIN FINDINGS

1. The cases with a positive NPV include:
   - Electricity to ASHP
   - Electricity or fuel oil to efficient natural gas
2. The case with the highest NPV for office medium is replacing electricity with efficient natural gas
3. The case with the lowest NPV is replacing natural gas with GSHP
4. The largest GHG emission reductions result from replacing fuel oil boilers with biomass boilers
5. The lowest GHG emission reductions result from replacing electricity with solar hot water



HOW TO READ THE FIGURE

- The cases are grouped by Proposed Case (RTT) and then organized based on the fuel used in the Base Cases (incumbent)
- The left y-axis shows the NPV amount in USD (bar chart)
- The right y-axis shows the gross annual GHG emission reduction as tons of reduced CO_2 equivalents (scatter marks)

MAIN ASSUMPTIONS

1. Building size: 48,438 sq. ft.

2. Capacity needed for installation (kW):
   - 363 for proposed cases including space heating
   - 30 for proposed cases including water heating
   - 126 for proposed cases including cooling

3. Operating hours per year:
   - 1,306 hours per year for heating
   - 797 hours per year for cooling

4. Hot water:
   - 793 gallons per day used
   - 126 °F
   - 10% heat recovery efficiency

5. Annual demand (MMBTUs):
   - Space Heating: 1,617.6
   - Space Cooling: 343.6
   - Domestic Hot Water: 161.7

6. Incremental initial costs:
   - Electricity, Fuel oil or Natural Gas to ASHP: $358,980
   - Electricity, Fuel oil or Natural Gas to ASHP with ductwork: $598,560
   - Electricity to GSHP: $928,890
   - Fuel oil or Natural Gas to GSHP: $836,325
   - Electricity, Fuel oil or Natural Gas to Solar Hot Water: $65,578
   - Fuel oil or Natural Gas to Biomass: $194,205
   - Electricity to Efficient Natural Gas: $373,890
   - Fuel oil or Natural Gas to Efficient Natural Gas: $78,045

APPENDIX C
Cost Analysis

Project-specific installation costs for different RTTs have been provided by different program administrators across New England, as shown by Table 31.

TECHNOLOGY	YEARS OF DATA POINTS	MASSACHUSETTS	VERMONT	CONNECTICUT	NEW HAMPSHIRE
GSHP	**2010–2015**	Hard costs / Soft costs / Abnormal costs		Total costs / Abnormal costs	
ASHP	**2015**	Total costs			
Biomass	**2010–2015**	Hard costs / Soft costs / Abnormal costs	Total costs		Hard costs / Soft costs / Abnormal costs
Solar Thermal	**2009–2015**	Total costs	Total costs	Total costs	
Efficient Oil Boilers	**N/A**			Total costs	

Table 31 | Project-specific data available for the project

The resolution of the installation costs varies across states and technologies. Table 31 shows the available resolution of the costs. To the extent possible we differentiate between

- Hard costs—the costs of the equipment. Hard costs include equipment such as the central heater or cooler, collectors, drilling, bulk, and thermal storage.
- Soft costs—the costs of the installation work.
- Abnormal costs—the costs of necessary adaptations of the existing building and HVAC system. Examples of costs included in this category are upgrading distribution and ductwork.
- Total costs indicate that no differentiation has been made by type of costs.

The costs have been adjusted for inflation and are nominated by 2015 values. The cumulative rate of inflation was found through the US Inflation Calculator:[81]

- 2009–2015 10.5 %
- 2010–2015 8.7 %
- 2011–2015 5.4 %
- 2012–2015 3.2 %
- 2013–2015 1.7 %
- 2014–2015 0.1 %

The average installation costs per kW are shown by Table 32.

TECHNOLOGY	RESIDENTIAL			COMMERCIAL		
	Hard Costs ($/kW)	Soft Costs ($/kW)	Total Costs w/o ductwork ($/kW)	Hard Costs ($/kW)	Soft Costs ($/kW)	Total Costs w/o ductwork ($/kW)
GSHP	1,358	753	2,111	N/A	N/A	2,003
ASHP	N/A	N/A	1,089	N/A	N/A	N/A
Biomass	759	165	924	626	161	786
Solar Thermal	1,703	1,118	2,821	1,971	1,264	3,235
Efficient boilers	N/A	N/A	470	N/A	N/A	N/A
Ductwork	N/A	N/A	558	N/A	N/A	664

Table 32 | Average installation costs ($/kW) Renewable Thermal Technology projects in New England

- The installation costs for GSHPs in residential buildings are for retrofit projects. Due to a small selection, the installation costs for GSHPs in commercial buildings are for retrofit projects and new buildings.
- The installation costs for GSHPs include equipment and installation work related to drilling loops. Costs related to upgrading distribution systems and ducts are not included.
- The installation costs for Biomass include storage. The cost category “Miscellaneous” has been excluded.
- The installation costs for SHW exclude the cost category “Miscellaneous.”
- The installation costs for each RTT do not include costs related to upgrading the distribution system/ductwork. Costs related to upgrading the distribution system / ductwork have been calculated separately.
- The installation costs for Ductwork in residential buildings are for GSHP retrofit projects.
- The installation costs for Ductwork in commercial buildings are for GSHP retrofit and new construction projects.

81 http://www.usinflationcalculator.com/

The number of projects included in the statistics of New England projects is shown by Table 33.

	RESIDENTIAL	COMMERCIAL
GSHP	321	25
ASHP	1,913	
Biomass	385	47
Solar Thermal	1,832	189
Efficient boiler	96	
Ductwork	285	18

Table 33 | Number of samples in the New England average installation costs.

For some technologies, particularly for the commercial sector, the extent of the data is limited. We have therefore compared the New England cost data to other sources, as shown by Table 34.[82, 83, 84]

<table>
<tr><th colspan="2" rowspan="2">TECHNOLOGY ($/KW)</th><th colspan="2">RETSCREEN AVERAGE</th><th colspan="2">NEW ENGLAND PROJECTS AVERAGE</th><th colspan="2">MEISTER CONSULTING GROUP</th><th colspan="2">SWEETT</th></tr>
<tr><th>RES</th><th>COM</th><th>RES</th><th>COM</th><th>RES</th><th>COM</th><th>RES</th><th>COM</th></tr>
<tr><td colspan="2">ASHP</td><td colspan="2">1300</td><td>1089</td><td>N/A</td><td colspan="2">N/A</td><td>820–1590</td><td>1981</td></tr>
<tr><td rowspan="3">GSHP</td><td>Equipment & Installation</td><td colspan="2">1236</td><td rowspan="3">2111</td><td rowspan="3">2003</td><td rowspan="3">2131</td><td rowspan="3">2841</td><td rowspan="3">2770–3360</td><td rowspan="3">1640–2410</td></tr>
<tr><td>Horizontal Loop Total</td><td colspan="2">1996</td></tr>
<tr><td>Vertical Loop Total</td><td colspan="2">3156</td></tr>
<tr><td colspan="2">Biomass Pellets</td><td colspan="2">306</td><td>924</td><td>786</td><td>800 to 1700</td><td>400 to 600</td><td>1323</td><td>290 to 800</td></tr>
<tr><td colspan="2">Biomass chips</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td><td>491 to 600</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">Solar Thermal</td><td colspan="2">Glazed: 480–960 $/aperture
Evacuated: 840–1440 $/aperture</td><td>2821</td><td>3235</td><td>2000 to 2500</td><td>1412 to 2763</td><td>1440 to 2880</td><td>N/A</td></tr>
<tr><td rowspan="2">Gas Boiler</td><td>Standard</td><td>182</td><td>182</td><td colspan="2">N/A</td><td>8450 to 9100 $/unit</td><td>24000 to 28000 $/unit</td><td colspan="2">N/A</td></tr>
<tr><td>Highly efficient</td><td colspan="2">N/A</td><td>470</td><td>N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">Fuel oil boiler</td><td>182</td><td>182</td><td colspan="2">N/A</td><td>8450 to 9100 $/unit</td><td>24000 to 28000 $/unit</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">ASHP water heater</td><td colspan="2">N/A</td><td colspan="2">1000 to 1200 $/unit (50 gallon)</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">Electric water heater</td><td colspan="2">N/A</td><td colspan="2">450 to 500 $/unit (50 gallon)</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">Ductwork</td><td colspan="2">N/A</td><td>558</td><td>664</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
<tr><td colspan="2">Air-conditioning</td><td colspan="2">320</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
</table>

Table 34 | Comparison of different sources of RTT cost data.

The average New England installation costs have been used in the RETScreen calculations where these data seem reasonable compared to the references: ASHPs, GSHPs, biomass pellets, and highly efficient gas boilers. For other proposed and base case technologies, RETScreen values have been used. With the exception of solar hot water, the average RETScreen installation costs have been applied. The New England cost analysis suggests that the costs for solar hot water installations per aperture are on the higher end.

82 http://www.nrcan.gc.ca/energy/software-tools/7465

83 Meisters Consultants Group (2012): Massachusetts renewable heating and cooling opportunities and impacts study. March 2012

84 Sweett (2013): Department of Energy and Climate Change. Research on the costs and performance of heating and cooling technologies. February 2013

APPENDIX D
RETScreen Expert

The RETScreen International Clean Energy Project Analysis Software (www.retscreen.net) is a clean energy decision-making tool specifically aimed at facilitating pre-feasibility and feasibility analysis of clean energy technologies as well as ongoing energy performance analysis. RETScreen empowers professionals and decision-makers to identify, assess, and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to measure and verify the actual performance of their facilities and helps find additional energy savings and production opportunities.

RETScreen Expert has been developed by Natural Resources Canada (NRCan), a department of the Government of Canada.

The software can be used worldwide to evaluate the energy production, lifecycle costs, greenhouse gas emission reductions, financial viability, and risk for various types of proposed energy efficient and renewable energy technologies, as well as cogeneration projects.[85]

RETScreen Expert (available in 36 languages from September 2016) leverages a global database of project inputs including:

- A climate database of 6,700 ground-station locations around the globe and incorporation of the improved NASA Surface Meteorology and Solar Energy Dataset for populated areas. (These are input directly into the RETScreen software).
- A product database consisting of technical features of energy technologies and cost ranges.
- An emission factor database representing, among other things, the national or state specific electricity generation mix.

All clean energy technology models in the RETScreen Software have a common look and follow a standard approach to facilitate decision-making with reliable results. Each model also includes integrated product, cost, and weather databases and a detailed online user manual, all of which help to dramatically reduce the time and cost associated with preparing pre-feasibility studies.

85 Clean Energy Project Analysis, RETScreen® Engineering & Cases Textbook https://web.archive.org/web/20150711130124/http://www.retscreen.net/ang/d_t_info.php

The standard analysis in the RETScreen Software consists of several steps:

1. Choose location for the climate data
2. Define the facility, including benchmark analysis and the performance of the building envelope and industrial processes
3. Define the energy demand and equipment, both for base case and proposed case
4. Pursue cost analysis, including incremental installation costs, fuel costs, and escalation rates
5. Emission reduction analysis at different levels of detail
6. Financial analysis including net present value, internal rate of return, and cash flows
7. Sensitivity and risk analysis on financial variables such as fuel costs, installation costs, debt ratio, interest rates, and carbon price

The RETScreen Software facilitates project implementation by providing a common evaluation and development platform for the various stakeholders involved in a project. The tool can be used for zzmarket studies; policy analysis; information dissemination; training; sales of products and/or services; project development & management; and product development/R&D.[86]

Thus the analysis of RET Screen provides output for a constructive dialogue between funders and lenders; regulators and policy makers; consultants and product suppliers; developers and owners.

The vast capabilities of RETScreen enrich the depth of the analysis although this translates into high levels of complexity and require some specialized training and familiarization with the tool.

Overall, the RETScreen Software is increasing and improving access to clean energy technologies, building awareness and capacity, and helping to identify opportunities that facilitate the implementation of energy projects that save money, while reducing greenhouse gas emissions.

More information: www.retscreen.net

86 Clean Energy Project Analysis, RETScreen® Engineering & Cases Textbook

APPENDIX E
Tax Credits, Rebates and Other Incentives

TECHNOLOGY	SECTOR	INCENTIVE			
		ITC	OTHER TAXES	REBATES	LOANS
Natural gas boilers (highly efficient)	Residential		6.35%[4]	$300	2.99% / 10 years[3]
	Commercial		6.35%[4]	$8/unit MBH	5% / 10 years[5]
ASHP	Residential		6.35%[4]	$500	2.99% / 10 years[3]
	Commercial		6.35%[4]	$5000 and up[2]	5% / 10 years[5]
ASHP water heater	Residential			$400[7]	2.99% / 10 years[3]
	Commercial				
GSHP	Residential		6.35%[4]	$500—$1500	2.99% / 10 years[3]
	Commercial		6.35%[4]	$5000 and up[2]	5% / 10 years[5]
Biomass pellets boilers	Residential				2.99% / 10 years[3]
	Commercial				5% / 10 years[5]
SHW	Residential	30%[1]	6.35%[4]		2.99% / 10 years[3]
	Commercial	30%[1]	6.35%[4]		5% / 10 years[5]

Table 35 | Tax credits, rebates and other incentives

1. 30% for facilities put under construction prior to December 31, 2019. Thereafter phase out by end of 2022. For commercial facilities there will be continued tax credits of 10% after 2022.
2. Eligibility in the service areas of Eversource and United Illuminating, Cool Choice program.
3. The interest rate and loan term is for Smart-e bundles implying that the customer has to bundle several measures.
4. Sales tax incentive through Connecticut Department of Revenue Services.
5. The interest rate is the lowest C-PACE rate, which starts at 5% for 10-year and goes up by 10 basis points for each year. Loan term is for C-PACE.
6. Eligibility in the service areas of Eversource and United Illuminating. Energy Star Heat Pump Water Heater program.

Feasibility of Renewable Thermal Technologies in Connecticut

A FIELD STUDY ON BARRIERS AND DRIVERS

Helle H. Grønli, Joseph Schiavo, Philip Picotte and Amir Mehr

March 2017

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The Yale team is solely responsible for any errors or omissions in this report.

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Executive Summary

Renewable thermal technologies (RTTs) constitute a broad class of renewable energy technologies that provide thermal energy services. Examples include solar hot water, heat pumps, biomass, and district energy systems, among other technologies and means of implementation. Increased deployment of RTTs can shift carbon-intensive thermal end-uses to cleaner energy sources. Diffusion of RTTs in Connecticut is relatively low, motivating an interest in how proliferation of these renewable technologies might be improved in the state.

The purpose of the research project, “Feasibility of renewable thermal technologies in Connecticut,” is to assess a realistic contribution from RTTs in achieving Connecticut’s transition to a less carbon-intensive economy, and to establish the knowledge necessary for effective policies and strategies to advance RTTs in Connecticut. In addition to this field study on barriers and drivers, the project includes an assessment of market potential, published separately.[1]

This report documents the results of a field study conducted in 2015 and 2016 to identify key barriers to and drivers of deployment. The field study consisted of a series of in-person and telephone interviews with stakeholders from across the value chain of RTTs, ranging from residential and commercial customers to installers and regulatory agencies. Factors influencing a customer’s decision to invest in RTTs at different stages of the value chain are shown below.

Scaling up deployment of RTTs in Connecticut will require a mix of actions involving energy policy, financing products, financial incentives, and relevant industries. Connecticut’s efforts to advance RTT deployment should aim to create a marketplace for thermal energy technologies in which RTTs are both competitive relative to non-renewable technologies and trusted as practical and reliable solutions.

Recommendations stemming from the field study are grouped into four focus areas for overcoming barriers to adoption: 1) show direction, 2) reduce upfront costs, 3) develop a competent and competitive regional industry and 4) create value streams.

1 Grønli, Helle; Fairuz Loutfi, Iliana Lazarova, Paul Molta, Prabudh Goel, Philip Picotte and Tanveer Chawla (2017): Feasibility of Renewable Thermal Technologies in Connecticut. Market potential.

	UPSTREAM	Heating and cooling market	DOWNSTREAM
BARRIERS	• Fuel availability • Price volatility	• Competence and experience of experts • Unclear potentials due to lack of performance data (prior to and after RTT) • Nascent industry with unproven business models	• High upfront costs • Access to capital • Unfavorable economics compared to alternatives • Awareness of RTTs and its applicability • Physical constraints
DRIVERS	• Local resources that offer opportunities (e.g. waste heat from processes and buildings, wood chips from local industry, favorable ground conditions)	• Diligent stakeholders • Local governments as facilitators • Green Bank funding and investment support opens doors to other funding	• Long term plans and strategies • Grants and rebates • Value proposition; classification schemes, revenue streams • Being in a decision mode • Financing products

Barriers and drivers across the value chain for RTTs.

SHOW DIRECTION

Increasing awareness and creating demand through institutional means

RTTs are an integral part of the built environment. **Building codes** and performance standards represent powerful regulatory tools for influencing the selection of RTTs where they are most frequently deployed (building stock) and contributing to a market for RTTs.

Public institutions can **lead by example** as large property owners and energy users and as land-use planners. When state government, municipalities, and educational institutions take the lead in early technology adoption, the learning from these projects can be widely diffused. Government support and involvement in RTT projects can also show direction in the marketplace. For example, in Bridgeport, municipal support (both financial and in-kind) facilitated the development of a thermal grid[2] that would otherwise carry significantly more risk than private developers might be willing to accept. Governments' early adoption and institutional support is important to the deployment of thermal grids, which are particularly capital- and infrastructure-intensive.

2 A "thermal grid" distributes steam, hot or chilled water produced at a central or decentralized plant or facility for thermal purposes.

The Green Bank and utilities can serve an important role as "**trusted messengers**", and can help establish trust by providing loans and support programs targeted towards RTTs.

REDUCE UPFRONT COSTS

Addressing unfavorable project economics and high capital outlays

The most significant barrier encountered in the field study was cost: in many cases, RTTs are not yet cost-competitive with other technologies and high upfront costs are challenging with regard to cash flow.

Technologies tend to be expensive at the point of market introduction, and high upfront costs can be reduced by expanding market volume. This leads to increased competition and streamlined installations through repetition. Thermal energy installations typically are characterized by a need for case-by-case design and customization in the installation process, adding to project costs. Connecticut's "Solarize" campaign around solar photovoltaic panels has proven successful for reducing costs. A similar campaign ("Thermalize") for renewable thermal technologies is recommended as a **strategy to reduce soft costs**. Standardization in terms of system designs, installation procedures, contracts, and sizing would go far toward reducing customization needs.

Financing products can be designed to address several aspects of high upfront costs, including access to capital and cash flow over the life of the asset. Various financing products have different strengths in addressing barriers, and include on-bill financing, loans, leasing, property assessed clean energy (PACE), and savings-backed products such as Thermal Service Contracts or Energy Performance Contracts.

The field study found that financing played a pivotal role in project economics, and more broadly the decision to select RTTs over competing technologies. Financing products should account for the fact that **packaging** RTTs with other renewable energy technologies and energy efficiency measures is a reliable way to boost return on investment and increase the value that a customer can get from an investment. The process from when the customer decides to install thermal technology to the point when the installation is finalized can be time-consuming and full of hurdles if it is not **streamlined** as much as possible. This includes access to financing.

DEVELOP A COMPETITIVE INDUSTRY

Creating a well-supported and trustworthy base of installers and experts

A pool of qualified RTT installers, designers, and developers is a prerequisite for a well-functioning RTT market. To be attractive, the market should promise a certain volume, have low entry barriers, and be predictable over time. A **regional market approach** could address barriers and drivers affecting both installers and customers.

The field study found that the industry would benefit from **standardization**, which would help to establish viable business models and lower soft costs associated with these technologies. This standardization applies not only to technological best practices and installations, but also to the contracting, permitting and financing processes, where administrative simplification would benefit installers and customers.

Finally, the field study found that verification of RTTs' **performance** is an important prerequisite for widespread adoption, either through metering or validated monitoring methods. Technologies that can be metered and monitored facilitate benchmarking that increase customer trust in the products. Performance verification also facilitates new revenue streams and business models such as Thermal Renewable Energy Certificates, third-party ownership, green bonds, and Energy Performance Contracts.

Declining block grants with an announced profile will encourage market entry and help create momentum for a "Thermalize" (or other) marketing campaigns.

CREATE VALUE STREAMS

Reducing unfavorable operational economics and an unclear business case

To improve the economics, the marketplace should look to new business and financing models as well as energy policies for additional sources of revenue. This study proposes the creation of **Thermal Renewable Energy Credits** (TRECs), which can serve as a production incentive for RTT installations, and **carbon pricing**, which would improve the project economics of RTTs by internalizing the cost of carbon into the operation of conventional alternatives. These incentives scale with project size and provide a consistent cash flow to improve project economics; they also encourage project developers to optimize the use of clean energy sources.

Building certification schemes make it possible for customers to separate high-quality buildings from low-quality buildings in terms of energy efficiency and energy costs. This quality difference would be reflected in the property value and market rents, creating revenue related to the RTT investment.

Introduction

Thermal end-uses accounted for 70 percent and 44 percent of energy delivered to US residential and commercial customers in 2013, respectively (EIA, 2015). Renewable Thermal Technologies[3] (RTTs) can replace existing thermal end-uses based on fossil fuels and electricity, and thus provide an essential contribution to achieving states' climate ambitions. As such, RTTs are gaining increased interest across the Northeastern United States.

Connecticut's ambition is to achieve an 80 percent emissions reduction by 2050 compared to year 2001, as spelled out in the state's 2008 Global Warming Solutions Act. The 2013 Connecticut Comprehensive Energy Strategy highlights strategic measures based on the idea of moving away from subsidies; these measures are intended to use public funds to leverage a larger share of private capital, and thus increase funds into energy efficiency, renewable power, natural gas availability, and transportation infrastructure. The strategy proposes economic incentives designed to drive down the costs of new technologies, making them competitive with fossil fuel alternatives. Furthermore, natural gas is recognized as a bridge to a sustainable energy future, with manufacturing industries anchoring this expansion. RTTs are currently included in the state's energy strategy to the extent that they can be considered energy efficiency measures.

In 2014, a total of 344 trillion BTU was delivered for stationary energy purposes in residential, commercial, and industrial sectors in Connecticut.[4] Of that, roughly 39 percent was based on natural gas and 28 percent on fuel oil. Connecticut's electricity mix is dominated by natural gas and nuclear power. Connecticut is part of the regional wholesale market operated by the Independent System Operator for New England (ISO New England). New England increasingly relies on natural-gas fired generation, which can expose the region to significant energy supply, reliability, and price issues. Natural gas as a proportion of the electric system capacity mix is expected to increase to 49.2 percent by 2018 and 56.7 percent by 2024 (ISO New England, 2015).The region experiences issues related to lack of fuel certainty particularly in winter, due to limited gas pipeline capacity in New England. Increased use of dual-fuel units is discussed as one of the solutions to this issue, which would be an economical choice but have concerns regarding burning oil.

Connecticut has among the highest retail electricity rates in the US. The introduction of shale gas has made natural gas an economically attractive choice, and oil prices are currently at a record low.

3 Renewable thermal technologies (RTTs) harness renewable energy sources to provide heating and cooling services for space heating and cooling, domestic hot water, process heating, and cooking. For the purpose of this report, both onsite supply and distribution through district heating and cooling are included.

4 EIA State Energy Data System: http://www.eia.gov/state/seds/. Delivered energy is net of electricity losses.

Building characteristics may pose functional limitations on the range of RTT alternatives that customers can realistically choose. Heat pumps deliver low-temperature heat, and their ability to deliver sufficient heat is influenced by how well a given building is insulated and the distribution system in place. Pellets and wood chips require space for fuel storage and chimneys. These functional limitations can be overcome by investment in energy efficiency and retrofits to the distribution systems—often a barrier to adoption. However, if customers are already retrofitting their house and heating system, the additional costs of better insulation or a novel distribution system (based on a different medium and temperature) may not be particularly high. RTTs can be scaled to serve the whole thermal load or partial loads.

Around 60 percent of residential units in Connecticut were built before 1970 (ACS, 2014), and new residential buildings were constructed at an estimated annual rate of 0.7 percent over the period 2000-2014.[5] An estimated 45 percent of the commercial square feet in the New England census were built before 1970 (EIA, 2015b). This indicates that a large share of the building stock is older than 50 years, with heating systems of a similar age.

There are several financial incentives available for RTTs in Connecticut, including: rebates provided by the Connecticut Energy Efficiency Fund through the electric utilities, favorable loans and green bonds from the Connecticut Green Bank, tax exemptions on both state and federal levels,[6] and property assessed clean energy (PACE) (Appendix 1). Following the financial turmoil of 2008, an economic stimulus package was made available through the American Recovery and Reinvestment Act (ARRA) of 2009. The Connecticut Clean Energy Fund (CCEF)[7] offered grants for ground source heat pumps and solar thermal installations with ARRA and CCEF funding over the period 2009–2012; at the time of writing, several of these incentives are no longer available.

A total of 523 residential and 27 commercial ground source heat pumps were installed with the support of the ARRA program over the period 2009 through 2012. Solar assisted thermal systems were supported through the ARRA program in late 2009 through 2011 and a utility-funded follow-on program from 2011 through 2013. The two programs together funded 278 residential and 86 commercial solar thermal installations. The ARRA funded solar thermal systems are monitored by remote metering. The metering data is to a limited extent available due to non-functioning data transmission to a central hub. The ground source heat pumps supported through the ARRA program are not metered, and insight into actual performance of these installations is not easily available.

The electric suppliers and distribution companies in Connecticut are mandated to meet a Renewable Portfolio Standard (RPS) of 27 percent renewable electricity generation by 2020. The RPS generally does

5 Based on statistics on demolitions and housing inventory estimates by State of Connecticut, Department of Economic and Community Development

6 From 2017, the only RTT covered by the federal Investment Tax Credit (ITC) is solar thermal.

7 CCEF was the predecessor of the CT Green Bank

not create Renewable Energy Credits (RECs) for renewable thermal energy. Waste heat recovery systems capturing waste heat or pressure from industrial or commercial processes, or electricity savings from conservation and load management programs, may count as Class III resources[8] under certain conditions. Connecticut has existing programs that incentivize or otherwise support RTTs, but more generally, a comprehensive support scheme for RTTs is lacking.

To be able to develop a market for RTTs in Connecticut based on scalable and replicable incentives, an in-depth understanding of what influences this market is necessary. We address the following research questions:

- What makes different categories of customers decide to invest in RTTs?
- What stops different categories of customers from investing in RTTs?

The study builds on empirical literature covering the energy efficiency gap, diffusion of technologies, and customers' decision making related to energy investments. Most of this empirical literature focuses on residential customers. The research was built on qualitative interviews of stakeholders with different roles in the market. This included a sample of customers, financial institutions, government institutions, installers, and industry associations. Stakeholders were selected from each group such that representation was obtained for residential, commercial, and industrial markets. Detailed interview guides can be found in Appendix 2.

8 Department of Energy and Environmental Protection. Public Utilities Regulatory Authority: http://www.ct.gov/pura/cwp/view.asp?a=3354&q=415186

The Literature Framework

Literature on consumer and behavioral economics defines a broad theoretical foundation for consumer behavior and rationality. In the context of deploying new energy technologies, consumers may face complex sets of decisions and preferences that encourage or inhibit the adoption of technology, even if adoption is rational from a purely economic standpoint. The purpose of this research is to map and categorize drivers that promote and barriers that inhibit investments in economically competitive RTTs. This research will seek to identify market, regulatory, and behavioral forces across the value chain that influence the adoption potential of RTTs, using Connecticut as a case.

Although a considerable number of studies exist on the adoption of energy efficiency measures in the residential sector, there is less literature on the adoption of RTTs. There is even less empirical work on identifying barriers and drivers to energy related investments in the commercial and industrial sectors. This chapter gives a brief overview of the research framework for barriers and drivers to energy efficiency in general, and RTTs in particular, across all sectors. Due to the focus of the literature, the main findings center downstream on the residential segment. Characteristics of RTTs may cause some additional barriers and drivers as compared to those of energy efficiency.

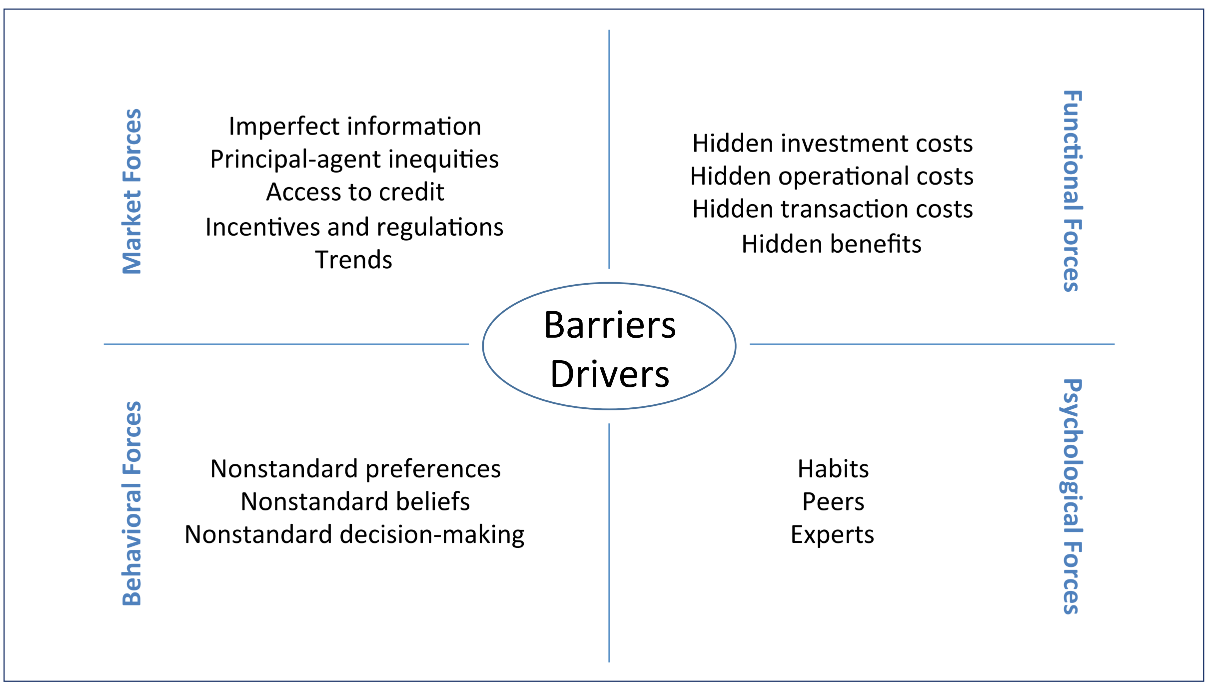

Figure 1 | Explanations for the energy efficiency gap and investments in thermal technologies. Adapted from Gillingham and Palmer (2013) and Michelsen and Madlener (2015).

The phenomenon of consumers failing to make energy saving investments with a positive net present value is known as the "energy efficiency gap". While first discussed from a neoclassical economics perspective (Hausman, 1979), the literature now incorporates other economic perspectives (e.g., Gillingham and Palmer, 2013). Figure 1 shows a framework for discussing barriers and drivers from different perspectives. In this framework, each force can act as a barrier or driver, depending on the particular circumstance.

Gillingham and Palmer (2013) discuss a range of explanations for the energy efficiency gap as described by neoclassical and behavioral economics. They conclude that more than 30 years of literature suggests that consumers behave as if they have high discount rates; at the same time, recent engineering studies indicate a vast untapped potential for negative-cost energy efficiency investment. Measurement errors may contribute to the observed gap, due to explanations such as hidden costs, exaggerated engineering estimates of energy savings, consumer heterogeneity, and uncertainty.

Klöckner and Nayum (2016) tested 24 barriers to and drivers of energy efficiency upgrades in private homes based on a stage-based model of decision-making. The four stages of decision-making assumed in their study were 1) “not being in a decision mode,” 2) “deciding what to do,” 3) “deciding how to do it,” and 4) “planning implementation.” The perception that it was not the right point of time was found to be a barrier to energy efficiency upgrades across most stages in the decision-making process. Owning the dwelling was necessary to even be in a decision mode. Expecting higher comfort levels and lower energy costs appeared to be drivers to start deciding what to do, while indecision was an important barrier to deciding how to go through with upgrades. The time required to supervise contractors was an important obstacle to planning implementation. While some barriers and drivers appeared relevant to all stages of the decision-making process, others were distinct to specific stages.

“An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption” (Rogers, 2003). Rogers’ studies of diffusion of innovation concluded that an early adopter is generally younger, has more financial resources, higher education, higher social status, searches more for information, interacts with innovators, is more social, and shows higher degree of opinion leadership than a late adopter.

Stieß and Dunkelberg (2013) tested several hypotheses related to the adoption of low- and zero-carbon (LZC) technologies like loft insulation, high-efficiency condensing boilers, and renewable heating systems in households. Their findings showed that the adoption of LZC technologies followed both economic and non-economic motives, where benefits such as increased thermal comfort and the adoption of a prestigious technology or a low-carbon lifestyle were valued. The majority of homeowners in the study associated the economic benefits of LZC technologies with a medium- or long-term perspective and a desire to become less exposed to fluctuating energy markets. The study also showed that the adopters of LZC technologies consult a broader range of experts and sources than the non-adopters.

Graziano and Gillingham (2015) found a strong relationship between adoption of solar photovoltaic installations and the number of nearby previously installed systems—a peer effect. The built environment and policies were also found to be of importance. Their findings suggest that the peer effect is conveyed through social interaction and visibility.

Ruokamo (2016) studied household preferences of hybrid home heating systems in new detached buildings—hybrid home heating systems being combinations of complementary heating technologies, such as district energy, solid wood, wood pellet, electric storage heating, ground source heat pumps, and air source heat pumps. The results showed that district heating and ground source heat pumps were the favored main heating alternative, with combined solar and water heater systems and air source heat pumps both favorable supplemental sources.

Michelsen and Madlener (2015) classified resistance to innovation with a framework of functional barriers, psychological barriers, and socio-demographic factors. They found that homeowners who replaced a fossil-fuel based heating system with a renewable heating system were driven by external threats such as expected price increase of oil, knowledge of renewable heating system, and the wish to contribute to environmental protection. Homeowners in rural German areas and homeowners with bigger homes were more likely to switch. Homeowners who did not replaced their fossil-fuel based system perceived that renewable heating systems require relatively more attention during their operation; maintaining existing habits was important to them. The likelihood of switching was lower for older homes, where the compatibility with existing infrastructure was a challenge.

Sopha et. al. (2011) found that adopters of wood pellet heating showed characteristics of early adopters according to diffusion and innovation theory (Rogers, 2003), while non-adopters displayed characteristics of late adopters. A few deviations existed between the empirical findings of the study and the theory; the adopter group had lower incomes and education levels compared to the non-adopter group. This was explained by functional limitations related to retrofitting the house and localization. Early adopters were found to have more peers recommending the solution than non-adopters.

Sopha and Klöckner (2011) demonstrated that habit is significant in explaining decision making for heating systems, where lack of perceived behavioral control and behavioral lock-in pose relevant barriers to the adoption process.

Sopha et. al. (2013) simulated the heating system decision-making by Norwegian households based on empirical research. Their results suggested that increased adoption of wood-pellet heating is dependent on improved functional reliability and fuel stability. Spatial results of simulations indicated that wood-pellet adopters resided near wood-pellet suppliers, whereas heat-pump adopters and electric heating adopters were distributed all over Norway.

Organizations often adopt innovation through one of two types of decision: 1) collective decision by consensus, or 2) authority decision by a few high-level individuals within an organization (Rogers, 2003). Within an organization, certain individuals are termed “champions”. These individuals stand behind an innovation and break through opposition. The innovation process of organizations contains five stages: agenda setting, matching, redefining, clarifying, and routinizing.

Enova (2012b) commissioned a comprehensive study on potentials and barriers to energy efficiency in the building sector in 2012. Barriers were placed in five categories: 1) practical, 2) technical, 3) economic, 4) attitude, and 5) knowledge. Barriers in the commercial sector (both public and private buildings) were analyzed by applying qualitative methods that differentiated between existing and new buildings. The study pointed out that barriers were often interdependent. For instance, the costs at any given time were not only influenced by the price of competing technologies but also by competence and experience in the market. Economic barriers, such as high upfront costs, rigid rules, and difficulty getting access to capital for public building owners were found to be the most important. Skepticism and lack of internal support, conflicting governmental requirements, low awareness of current energy use, and potential improvements to a building were also important barriers.

Enova (2009) mapped the potential of and barriers to energy efficiency in Norwegian land-based process industries. The most important barrier to reaching full potential was found to be economic infeasibility due to a low rate of return and internal and external risks. Other barriers to energy efficiency in the process industry were limited access to capital, lack of external infrastructure to utilize waste energy, low awareness, and lack of competency and capacity within organizations.

District energy systems were among the lowest cost and most efficient solutions for a low-carbon pathway in cities, according to the United Nations Environment Programme (UNEP, 2013). Through studying 45 modern district energy systems in cities around the world, a research project led by UNEP compiled different drivers for realizing district heating projects. The study concluded that local governments were the most important actors in catalyzing investments in district energy systems, juggling several roles at once: planner, regulator, role model, advocate, provider of infrastructure, and facilitator of finance. The study also mapped some typical barriers to district energy: awareness of technology applications and their benefits, integrated infrastructure and land-use planning, knowledge and capacity in structuring projects to attract financing, data to evaluate energy density, accounting methods for efficiency ratings, high upfront capital costs, high costs of feasibility studies, and disadvantageous energy pricing regimes or market structures.

Methodology

This research, based on a series of in-depth qualitative interviews, aims to gain deeper insight into what makes different categories of customers decide to invest in RTTs in Connecticut. The advantage of in-depth interviews is that they provide a flexible and iterative method, and therefore offer detailed information on the interviewee's personal experience, perspectives, and histories.

As the perception of what drives or inhibits investments in RTTs may differ depending on what role you have in the market, we wanted to study the research question from different stakeholders' perspectives. The study involved market participants from the whole RTT value chain, including residential customers, commercial customers, industrial customers, installers, financing institutions, and governmental agencies.

Based on a framework from surveying the empirical literature, we developed a set of interview guides for each stakeholder group (Appendix 2). These guides were designed with open-ended questions. Most interviews involved two investigators from the research team. The interviews were partly organized as in-person meetings, and partly as phone interviews. The interviews were documented through field notes. As the constellation of investigators varied from interview to interview, the interviews were audio recorded when possible. The interviews lasted from 30–90 minutes.[9]

In general, customers in Connecticut are unfamiliar with RTTs. To gain insight into what makes customers invest in RTTs we needed participants with some familiarity with the various thermal technologies. Therefore, we chose to recruit the participants from the list of private persons and organizations involved in incentives from the Connecticut Green Bank, or its predecessor, CCEF. An introductory email was sent from the Connecticut Green Bank to around 30 customers and installers, after which the research team reached out directly by mail or phone. In addition, the research team contacted directly some stakeholders that were known to be familiar with RTTs. Altogether the team completed 25 interviews; a descriptive overview of the interviewees can be found in Appendix 3.

Generally, customers participating in the study are more knowledgeable than most people about energy solutions. The commercial customers cover private and public companies with a long-term perspective on their existence; this provides longer-term considerations on investments in energy technologies. The installer group is dominated by companies that install different types of RTTs, although some of them also install traditional oil and gas boilers.

9 This qualitative field study was conducted between January and May 2016, by a team consisting of the principal investigator and three graduate student research assistants. Interviews were recorded where feasible and permission was obtained for quotation usage. The protocols for this field study were filed with and approved by Yale University's Institutional Review Board.

After finalizing the interviews, we explored possible solutions to barriers to and drivers of customer investment in RTTs. This followed an iterative process according to the “Design thinking” approach developed by the Hasso Plattner Institute of Design at Stanford University. The results are summed up in Appendix 4.

Findings and Analysis

At a high level, RTTs have characteristics that are unique relative to other energy technologies, such as solar photovoltaic panels and energy improvements of the building envelope. These characteristics informed our analysis of what RTTs need to achieve widespread diffusion in the Connecticut marketplace.

This section, organized by thematic categories of barriers and drivers, elaborates on the factors that influence RTT deployment, in residential, commercial, and industrial customer classes.

Project Economics

Over the course of the field study, the research team consistently heard that favorable project economics relative to alternative technologies were a prerequisite for RTT investments. High upfront costs to RTT project implementation—capital requirements of RTT vary from technology to technology—presented a barrier for all stakeholders interviewed. Beyond initial capital costs, the long-run operating costs (maintenance and performance) were a further concern among customers, though these represented a smaller barrier relative to upfront costs.

Residential customers described long-run energy cost savings as a principal goal of RTT installation; high upfront costs made these investments prohibitive, gave these projects an intolerably long payback time, or made non-RTT alternatives more attractive. Customers were able to overcome these barriers through combinations of personal savings, tax benefits, grants, and loan financing. Cash flow presented itself as a concern for several customers, given the structure of incentives and the need for financing at particular milestones in the project. This problem was particularly acute for customers receiving the Federal Government's Investment Tax Credit for project costs; these tax credits could not be realized until tax filing in the first quarter of each year, while construction costs were often incurred at other times throughout the year. A residential customer emphasized the need for a large cash outlay, in spite of available incentives:

> *We were looking for rebates and just called up the companies. Installers really know the rebate rules well. The problem is: when you put everything up on your roof, there's an outlay of money—and you're cash poor until the tax rebate is returned.*[10]

Residential customers were acutely aware of the "run rate" that they could expect to realize with RTTs relative to other technologies. Several customers interviewed switched to RTTs from an oil boiler, which they consistently remarked was expensive and unpredictable to maintain. Several residential customers

10 Radmanovic, Daniel. Interviewed by Joseph Schiavo. Telephone. New Haven, CT, 7 April 2016.

added that volatility of fuel costs was an additional motivator for switching away from fossil fuel systems. Establishing a positive comparison in terms of operating costs was important for these customers—expected savings would prompt a switch to RTTs, while negligible improvements tended to dissuade larger RTT investments. Surprisingly, customers seemed willing to expand the size of upfront investments when incremental benefits could be obtained. Specifically, we encountered several customers who combined energy efficiency improvements (insulation, window upgrades, etc.) with large geothermal investments to maximize the benefits of a new energy system, in spite of appearing to worsen the initial barrier of high upfront costs. A residential customer explained that combining energy investments made sense from both efficiency and financing perspective:

> *Investments were synergistic. As geothermal becomes more efficient, so does use of Solar PV, which made spray foam insulation in the attic a good investment.*[11]

We asked all residential customers interviewed about the payback period on their RTT investment that they would consider acceptable; but no customers in the sample expressed a hard-and-fast time period. One customer implied that long-term savings, or the strategic nature of an RTT investment, was more important than a tangible financial payoff.

Commercial and industrial customers generally face stricter economic constraints than residential customers. One school district remarked that a project payback period of greater than 5 to 6 years was intolerable from an investment perspective and a non-profit organization stipulated a 2- to 3-year payback period. Several interviewees mentioned the difficulty of justifying large capital outlays for benefits perceived as small and occurring over a long time horizon, even if this runs counter to the long-term existence of the business or institution. Many organizations also require formalized business cases or solicitation processes to quantify expected costs and benefits of projects. This is not always easy to estimate for RTTs due to poor insights into existing energy consumption alongside uncertainty around technology performance. Larger businesses face further constraints, such as investors who operate on very short time horizons. Maintenance costs and feasibility assessments were also on the minds of commercial customers. The management company for a multi-family housing complex pointed out that, for geothermal systems in particular, they were fearful that a small marketplace of competent contractors would make service costly and difficult to obtain at times. This is contrasted with traditional fossil energy technologies, where local expertise is more widely available and commoditized. Businesses and institutions that consider thermal energy systems critical to operations expressed concerns that a small network of contractors and suppliers represents a risk to the continuity of business.

In terms of operating costs, a consistent theme of sensitivity to fuel prices was evident. Installers of ground source heat pumps remarked that demand for these RTTs is directly related to fuel prices,

11 Radmanovic, Daniel. Op. cit.

following the costs of oil and natural gas. The recent sustained period of low oil and gas prices has depressed demand for these technologies as a hedge for fossil fuel prices. Indeed, customers can be expected to seek less-costly substitutes when fossil fuel prices are high, as high fossil fuel prices support the financial justification for an RTT system.

Mitigating these barriers requires both reductions in installed costs for RTTs, and increased access to and flexibility in financing deployments of these technologies.

Awareness and Perceived Risk of RTTs in the Marketplace

Thermal technologies are normally not visible, placed in basements or mechanical rooms. As such, there is a tendency to take them for granted, to remain unaware of their presence unless they stop working. This contrasts with renewable electricity technologies, such as solar photovoltaic panels or wind turbines, which are generally easy to see in the landscape or on rooftops. This attribute of RTTs prevents them from benefiting from salience as a driver of deployment. Customers are not as easily made aware of the availability of RTTs and the value these technologies can provide. With this in mind, it should be expected that the marketplace is less aware of RTTs, compared to the solar PV market, where installations are easily visible. An installer remarked:

> *PV is killing solar thermal. The payback [for solar thermal technologies] with the tax credit is good, but it's not as sexy as PV," calling attention to the salience benefits solar PV technologies enjoy relative to solar thermal.*[12]

Indeed, the relative invisibility of RTTs may prevent these technologies from benefiting from an important 'peer effect' discussed by Bollinger and Gillingham (2012). One installer remarked that the solar thermal panel market is essentially competing for roof space with PV, which compounds the relative lack of awareness RTTs face among likely customers. However, the small footprint of RTTs may act as a driver: some customers perceive a small or invisible footprint as a benefit. Seamless integration of RTTs into the home or landscape can have the appeal of hiding unsightly energy infrastructure.

Relative to traditional thermal technologies, RTTs tend to suffer from a deficit of awareness in the mainstream marketplace. Interviews with residential customers revealed wide variance in conceptions of which technologies are considered "renewable thermal" and the types of energy services these technologies are meant to provide. Solar thermal technologies were frequently confused with photovoltaics, and some customers were unaware of applications where solar thermal technologies work to provide heating or cooling. Some customers were unaware that geothermal systems are able to provide

12 Wierzbicki, Stephen. Interviewed by Philip Picotte. Telephone. New Haven, CT, 12 May 2016.

cooling services in addition to heating. Similar differences in product conceptions were encountered in air source heat pumps, with some customers surprised to learn of the heating and cooling potential these technologies can provide. Some customers were unaware of recent advances in air source heat pump technologies, and had a conception that these technologies would be ineffective if installed in cold climates.

The geothermal market, however, tended to include classes of customers that were highly informed and aware of these technologies and their applications. One installer observed:

> *Geothermal customers are normally well-researched and ready to make the investment.*[13]

RTTs can, to various degrees, be complex to operate and understand. RTT systems are interconnected and interdependent with the rest of the building and infrastructure. Furthermore, customers may be unaware of the impact a ground source heat pump may have on electricity consumption. A customer remarked that he felt installers had a tendency to oversell the expected performance of systems, which has the effect of creating dissatisfied customers and discredited technologies. As another example, a customer may find the process of securing a biomass supply contract to be complex or time consuming. Whereas renewable electricity technologies produce a fungible commodity in electricity, RTTs provide benefits that are less obvious to realize. One residential customer remarked that it's possible to "see" the value of net-metered electricity, while the thermal comfort RTTs provide is more ethereal.

A lack of awareness of RTT capabilities extends to district energy applications. Commercial and industrial customers who were interviewed expressed skepticism toward locally centralized generation sources, and perceived dependence on an external heat source as a vulnerability, instead preferring traditional technologies (such as oil or gas boilers) that allow for autonomous generation. The long-term cost and procurement of fuel for a district energy heat source was a further uncertainty, which can have major implications for the economics of the system. This can be mitigated through a long-term contract that specifies a quantity of energy to be provided at an agreed-upon service level, with provisions for procuring alternative sources of energy during an interruption.

Across all market segments, we discovered a similar unawareness of the incentives and support programs available to RTTs. Customers in all classes expressed that information about incentives and educational resources were disparate and difficult to discover. Existing state resources, principally Energize CT, make it easy for customers to discover the tactical details of financial products and incentives for energy technologies, but these resources do not include neutral information about different technologies, permitting, or how to discover which technology might be best suited to the need at hand. Furthermore, the incentives that do exist are somewhat uncoordinated, in that

13 Elkin, Steve. Interviewed by Philip Picotte. Telephone. New Haven, CT, 27 April 2016.

customers, in many cases, needed to combine local and federal incentives to make their installations economic. This presented many logistical and financial challenges of cash flow, paperwork, and administration. Similarly, opportunities to introduce customers to RTTs through complementary incentive programs (i.e. energy efficiency) are lacking in the marketplace.

Installer Business Models and Access to Expertise

RTTs are at a comparative disadvantage in terms of the business models available for deployment and access to a large market of installers. Well-developed industry structures that exist for fossil fuel technologies are not established for RTTs.

A particular feature of the market is the lifecycle by which thermal energy technologies tend to be replaced or upgraded. For all customer classes, many replacement situations arise from an unplanned maintenance event in which a system fails when it is needed. Residential customers described situations in which oil boilers needed replacement during the winter months. In these situations, sufficient lead time does not exist to undertake the involved planning process of correctly designing and installing of RTTs—customers require heat *immediately,* and so they seek the fastest and most cost-effective path, typically replacing the component of the fossil fuel system that needed repair. In these emergency situations, we noted that customers typically call an oil company they have a maintenance or fuel contract with, explaining why replacement of these technologies with newer models is the most common path. This “stickiness” is a barrier to RTT deployment. Installers competent in both fossil technologies and RTTs would be better positioned to facilitate consideration of other options. One customer went as far as to emphasize that his family considered reliable heating to be an issue of security.

Another class of customers exists that undertakes thermal energy investments proactively. Several residential customers completed substantial RTT installations upon purchase of an unoccupied home, which they noted allowed them to avoid substantial construction while they were living in their homes and to obviate the need for heating or cooling systems to function. This class of customer was able to explore energy system options, get estimates from multiple installers, and make decisions free of time pressure. Customers described the challenges of coordinating project financing and administration. One customer explained that he was able to invest significant time and effort into coordinating a ground source heat pump installation because of a part-time work schedule that allowed him flexibility with his time.

Successful installers seemed to recognize that in the sale of thermal energy technologies to residential customers, emphasizing a technology’s ability to provide thermal comfort is key. One installer remarked that thermal comfort is the primary driver of sales, with savings acting as a secondary benefit. Interviews with residential customers revealed that conversations about RTTs with installers showed considerable focus on the question of thermal comfort, particularly around system sizing and decisions to make incremental investments (for example, supplementing a smaller geothermal system with an air source heat pump). Placing an inordinate emphasis on the financial or environmental benefits of RTTs is then a barrier: customers care about thermal comfort and installer sales forces should speak to this customer need. The manager of local utility's energy efficiency program observed:

> *When we talk to customers after the fact, they never talk about energy savings. They are always thrilled about how comfortable/quiet the home now feels. It's an interesting transformation—'forget the savings, we love how comfortable our home is'.*[14]

More broadly, the resources available to allow customers to discover and learn about RTTs are limited in scope and availability, hindering deployment. From all sectors, we consistently heard that the resources available to facilitate the discovery of RTT technologies, demonstrate their capabilities, and show customers how to get started are disparate, uncoordinated, and not robust. One installer spoke of the long-term problem of finding skilled employees to install and service RTTs. This labor shortage, to the extent that it has not already constituted a barrier to RTT diffusion, will continue to worsen without a larger volume of RTT projects. One installer remarked that his firm established an in-house training and certification program to provide knowledge where they felt it was lacking. One RTT industry representative remarked that possibilities exist for installers to collaborate amongst each other to offer bundled or lower cost solutions, but installers are not incentivized to develop these partnerships.

Installers also pointed out that many wholesale supply channels and infrastructures, such as those for the delivery of biomass, are relatively underdeveloped in comparison to fossil fuels. Unstable supply chains for bio resources were also noted by a commercial customer; pellets have to be bought out of state and might not be available in sufficient quantity when most needed. Current distributor or wholesale business models are simply not configured to provide a robust set of systems and parts for ready deployment.

Commercial and industrial customers further described the nascent development of the RTT market as a barrier to undertaking large-scale, sophisticated projects. Energy Service Companies (ESCOs) have a business model wherein commercial and industrial customers agree to share the savings of an energy technology upgrade with the financing and installing entity. Commercial and industrial customers are willing to pay a premium for these services as a means of contractually guaranteeing savings, reducing risk, and outsourcing the expertise required to undertake energy projects. Several commercial and industrial customers interviewed remarked that ESCOs limit most of their business to lighting and straightforward building envelope measures, leaving out more complicated and costly investments. A manager for a university's energy projects pointed out that:

14 Gibbs, Matt. Interviewed by Philip Picotte. In-person. New Haven, CT, 19 February 2016.

> *ESCOs are typically incentivized to choose projects that are most easily executed and can guarantee savings with relatively short payback periods. This approach may not allow for deep investigation and retrofits of whole building systems.*[15]

This is likely a function of the added expense of deeper infrastructure upgrades and the need for a long payback time horizon (lighting, for example, is essentially immediate). For ESCOs, these "low hanging fruit" investments are the least-cost and least-risk ways to deliver energy savings. These factors are barriers to easy integration of RTTs to installer and ESCO business models. Commercial and industrial customers are willing to pay a premium for these services as a means of contractually guaranteeing savings, reducing risk, and outsourcing the expertise required to undertake energy projects.

A skills gap and small talent pool may also be barriers to the Connecticut RTT market. Reflecting on the marketplace, a university's energy project manager observed:

> *Projects such as the deep retrofit of the Empire State Building are highly successful when they are executed by teams with sophisticated technical and project management skills as well as strong systems perspectives. Such teams are not easy to find or create. The work force needs to be developed.*[16]

Along similar lines, standardization also presented a potential driver to RTT markets through cost reduction and streamlining processes.End-use needs, existing structures, and available resources are not homogenous across customers and customer groups. Although some RTT applications can be standardized across customers, each particular thermal energy demand may dictate wide variance in installation parameters and viability. Furthermore, locally varying resources often offer opportunities for applying RTTs —such as waste heat for a district energy system or wood chips from forestry for a biomass system. Therefore, RTTs are characterized by a need for tailor-made solutions and expert advice, both with regards to choice of technology and systems design. The degree of customization required tends to scale directly with the size of projects; by implication, commercial and industrial customers tend to require more customization than residential customers. Standardization of technology, installation, systems design, and agreements can drive market development through lower costs, less hassle, and greater trust in the solution.

A more general theme was the observation that large players have yet to emerge in the RTT market, in the way that SolarCity, Sunrun, Posigen, and others have in the solar PV market. These players, who are present in many markets, have established credibility that commercial customers, in particular, find

15 Paquette, Julie. Interviewed by Philip Picotte. New Haven, CT, 15 April 2016.

16 Paquette, Julie, op. cit.

important. An educational institution explained that working with a well-established and well-known installer makes management and governmental approval of projects easier to obtain. Also of note is the heterogeneity that exists between technologies: some RTTs enjoy wider market penetration than do others. One installer of solar hot water systems characterized the challenges his business model faces as a product of a small overall market for this technology in Connecticut. In contrast, installers characterize air source heat pumps as having a much wider scope of demand that has attracted a larger network of installers. Another installer, calling attention to the challenge of running a profitable and effective RTT installation business, said:

> *It's tough to do business in this State. Customers apply pressure for lower prices. It's challenging to run a good business that pays employees well and provides healthcare. I need to maintain a talented staff to design and install systems.*[17]

Split Incentives to Ownership[18]

The literature of energy efficiency has extensively treated the topic of split incentives, wherein the business case for investing in energy technologies falls apart when the owner of a building does not stand to benefit from improvements (costs are passed through to tenants) or where building occupants are not empowered to make decisions on energy investments. For residential customers, this problem typically manifests in multi-family situations where utility expenses are the responsibility of the tenant and thermal energy use based on fuel oil is the responsibility of the landlord. This removes any incentive on the landlord's part to improve the energy technologies installed on the property that are fueled by the utilities. For commercial and industrial customers, the split incentive problem is much the same; rental properties do not incent investment on the tenant's part. Commercial and industrial customers may be subject to additional contractual stipulations, making energy projects more complex and difficult to undertake. A business development organization explained that many commercial rental properties occupied by corporate clients have no organization or funding for undertaking energy projects beyond the decision of a building to occupy.

One manager of multifamily residential properties explained that providing incentives (subsidies) to landlords to undertake energy investments is, to him, an important way to remedy the split incentive problem. Some property managers installed electric baseboard heating or air source heat pumps as a means of passing through energy expenses to tenants (shifting from master-metered oil or gas to tenant-metered electricity for thermal energy). Particularly in instances where a tenant's rent is subsidized, opportunities exist for subsidies to extend to energy capital improvements in multi-family properties or public housing projects.

17 Stephen Wierzbicki

18 Only building owners were included in the interview sample. It would be helpful to interview tenants in future research.

The energy efficiency project manager for a public school district described another manifestation of the split incentive problem that arises in institutional settings. Large institutions often have separate budgets for capital expenses and operating expenses, which can make energy investments complicated to plan. (RTTs require capital expenses to install but generate savings in operational budgets.) Furthermore, competition for limited funds amongst departments in the same organization can create barriers to getting energy investments approved.

Climate Strategies and Plans

Climate strategies and plans on state, governmental, and company levels can present a driver to RTT deployment, to the extent that RTTs represent a substantial reduction in carbon emissions relative to fossil fuel technologies. In general, climate strategies and plans that mandate reductions in carbon emissions will create demand for abatement, which RTTs can provide. An overview of current Connecticut regulations and incentives related to RTTs can be found in Appendix 1.

As discussed above, RTTs are not explicitly included in Connecticut's current state-level energy policy, although some resources may be considered for Class II RECs. As it stands, the prospect of satisfying RPS needs using other technologies is likely crowding out RTTs. Similarly, the lack of a carbon tax or other means to internalize the social cost of carbon has the effect of inhibiting demand for RTTs. No directly applicable policy at the US Federal level, beyond the investment tax credits,[19] exists to incentivize these technologies.

Customers in all classes—residential, commercial, and industrial—expressed concern over the future availability of subsidies, net metering, and REC programs that incentivize energy technology investments. Installers described "stop and start" effects in the markets for solar hot water and ground source heat pumps in Connecticut, as a result of grant programs that were phased out and reinstated. This creates uncertainty in the investment process and exposes customers to potentially large changes to the long-run business case they establish for investment. Furthermore, regulatory stability is a prerequisite for installers wanting to pursue business models on RTTs; certainty about long-term availability and solvency of incentive programs makes it easier for installers and customers to justify long-term investments.

Connecticut's Comprehensive Energy Strategy is an important document giving direction to the market. The Green Bank, as a quasi-public institution responsible for facilitating the realization of parts of this strategy, was described as making possible favorable financing terms that allowed customers to overcome high upfront investment costs. All classes of customers described the role of the Connecticut Green Bank in providing financing for RTT investments as an important driver of investment decisions.

19 Of the RTTs, only solar thermal will be applicable for ITCs from 2017

Several projects of the customers interviewed were funded by a mix of state and utility grants in combination with Green Bank loans.

City and local governments can act as drivers of RTT installations, particularly in district energy applications. The research team interviewed several stakeholders involved in a district energy project in Bridgeport, Connecticut. In this case, the city government acted as a facilitator of the project, providing approvals for district energy infrastructure installations and financing through tax-exempt municipal bonds. The project developer described the city government's partnership as crucial to moving the project forward. A local university is negotiating a long-term contract as an anchor customer for this district energy system, providing assurance the private developer needed of a credit-worthy off taker. The same is the case for the city as an owner of property. Hence planning for district energy systems needs the involvement of local governments, which have regulatory authority to move district energy projects forward.

Policies and standards created at more specific and localized levels exert strong influence on the selection of energy technologies. Broadly, LEED, Energy Star, and other building certification programs are drivers of RTT deployment; these programs create demand for RTTs, as they mandate certain energy consumption profiles or require the installation of particular technologies to meet established criteria. Variations of such standards are also implemented at the firm-level. A public school district interviewed informed us that they created an in-house certification system and set of criteria for building energy efficiency, which constitutes the principal criteria against which potential energy investments are evaluated. Establishing and disseminating building certification criteria, or even building codes relevant to RTTs, will drive demand for these technologies. Firms also establish long-term sustainability plans that influence the selection of energy technologies. Such policies can mandate goals for carbon emissions, set benchmarks for renewable energy consumption, and set building efficiency standards, among other possible goals. Two universities interviewed described these institutional strategies as key drivers of technology selection, including one university that is piloting a program to place a price on carbon emissions.

With climate and long-term energy plans in mind, it is nonetheless important to note limitations to the role these plans play as drivers of investment. A local university explained: Environmental values or academic value [of energy investments] are the "icing on the cake", and energy investments have to provide savings from day one. We cannot afford to pay extra for environmental value, and the project has to be 'Zero out of pocket'," calling attention to the financial concerns that drive these decisions.[20]

20 Anastasi, Chris. Interviewed by Amir Mehr. In-person. Bridgeport, CT, 11 March 2016.

RTT's Added Incremental Service and Value

A consistent theme of using RTTs to deliver new, incremental services was encountered in customer interviews. The opportunity of using RTTs to do more than simply replace a fossil fuel system emerged as a driver of deployment. Customers want to feel as if they are "getting something more" in return for their investment in RTTs. Importantly, the benefits of incremental services work to alleviate the salience deficit that RTTs tend to face: new services give customers a tangible gain that they can see and feel. This drives investment.

Residential customers who undertook investments in geothermal systems often did so in order to add air conditioning services in addition to replacing existing (oil fired) heating services. This additional value served to improve the case for investment, in terms of both thermal comfort and financial savings. One customer expressed that the cost of upgrading an oil boiler in need of replacement *and* installing a central air conditioning system was roughly equivalent to the cost of a geothermal system, which made it easier to justify this RTT option:

> *Our house didn't have an air conditioning unit, which improved the case for geothermal. [When considering the cost of an] Air conditioning unit and oil, geothermal makes financial sense.*[21]

A similar story was told for air source heat pumps. In many cases, customers were able to add heating or cooling to a portion of their homes. The incremental value added of air source heat pumps, however, extends further: these technologies allow for the expansion of heated and/or cooled area within a home. Since these technologies are relatively inexpensive to install and require minimal ductwork or outdoor footprint, we encountered customers who considered them a viable way to heat or cool an additional room.

Commercial customers expressed a similar desire to gain additional value from RTT systems, but also introduced resiliency as a value that RTTs are capable of delivering. A public university explained that ongoing negotiation to connect to a local district heating grid is motivated, in part, by a desire to gain access to a more reliable energy source than its local (oil-fired) heat plant. The co-benefits that RTTs can deliver to customers may be an important driver in investment decisions.

Co-benefits of installing RTTs exist in further contexts. A university described its decision to connect to a district energy grid as partly motivated by a desire to be a "living lab" for energy technologies. Such a project provided academic value to the institution. Similarly, the municipality involved in the same project described the installation of a thermal grid as a tool for differentiating the city as a low-cost location for building operations.

21 Daniel Radmanovic

Financing

As with any investment in energy technology, RTTs constitute a large upfront capital investment. This is often project-financed to restrict upfront equity contribution to a tolerable amount and to provide a reasonable rate of return on the investment in the long run. Notions of making RTT investments both *possible* (i.e. upfront capital cost is financeable) and *cash-flow positive* (i.e. the savings of the investment offsets debt service) were necessities for all classes of customers.

Our interview with the Connecticut Green Bank surfaced several critical success factors for making RTTs viable, from a financing perspective. The bank found success in making the value (or savings) of energy investments available to customers immediately, meaning that the all-in financed monthly cost of the system (thermal or electric) would provide immediate savings in comparison to the customer's existing cost of fossil fuel. This aspect of providing net-positive cash flow to customers—in all classes—was, in many cases, a prerequisite for investment. Lease products are particularly well-suited to provide these savings. In the case of these products, the all-in monthly lease cost of the system is intended to provide a margin of savings to the customer. In the opinion of the bank, it is more convincing to present customers with the prospect of additional free cash flows rather than additional energy savings. Designing financial products that provide such free cash flows, along with a tolerable upfront equity contribution (if there is any at all) are prerequisites for widespread deployment of RTTs in Connecticut. As with all financial products, their viability is predicated on interest rates low enough to allow for an attractive payback period and rate of return.

The subtle ways that customers are engaged in the financing process, as it relates to the availability of incentives, the net upfront cost of installation, and the long-run cash flow of operation, surfaced as important in several interviews. A geothermal installer noted:

> *Upfront cost hides actual cost-effectiveness.*[22]

This may be particularly true for geothermal technologies, which require a substantial upfront investment for completion. More generally, the manager of an energy efficiency program for a local utility remarked that in his experience:

> *People love a deal. This is common in car sales - something like 0 percent financing is attractive to customers, even if the premium is in the car.*[23]

The way that investments, incentives, and financing packages are presented matters and has a strong influencing effect on the customer's final decision.

22 Duffy, Chris. Interviewed by Philip Picotte. Telephone. New Haven, CT, 5 May 2016.

23 McDonnell, Patrick. Interviewed by Philip Picotte. In-person. Orange, CT, 8 March 2016.

Generally, loan and lease products are the primary means of financing RTTs today. Loans have the advantage of providing customers with full equity ownership of all accrued benefits and savings; leases free customers of up-front capital contributions but do not impart permanent ownership of the system. RTTs are disadvantaged relative to renewable electrical technologies in that incentives have not been established to the same extent for thermal energy. RTTs can provide savings, but do not, in the absence of Renewable Energy Certificates or net metering, provide direct revenue. The revenue that electrical technologies can provide fueled the growth of the solar power purchase agreement (PPA), which facilitates installation of energy systems with no equity contribution from the customer, in exchange for a long-term contract for power provision. A "thermal PPA" may be possible, but such an arrangement would be predicated on creating demand for RTTs in the market, or otherwise placing a standardized value on a unit of thermal energy. Arrangements of third-party ownership can be other means of financing RTTs.

The timing of RTT installations presented itself as a significant barrier or driver, depending on the particulars of the situation. Several residential customers explained that they saw an opportunity to undertake a disruptive upgrade of their energy systems in the interim period between buying a home and the start of occupancy. These circumstances allowed the customers to go without heating or cooling for an extended period of time, but were predicated on access to sufficient capital to facilitate the prolonged period of living outside the home. Furthermore, seizing this opportunity required access to the cash flows necessary to finance all upfront installation costs coincident with the purchase of a new home. This is a high bar for customers to meet.

Commercial and industrial customers described financing as an essential driver of RTT investments. These customers emphasized that energy is not their primary business competency, and as such they were hesitant to evaluate, make, and manage large and complicated energy investments. Hence, they viewed access to inexpensive capital as an important means of both obtaining low-cost capital and removing risk from the investment process. These firms had no desire to make energy investments a significant part of their balance sheets. Installers, however, encountered administrative difficulties in coordinating financing—some installers described an inordinate amount of time required to facilitate loan application approval and funding. A large private university explained the emergence of the ESCO business model to remediate challenges of internal capacity and decision processes. Before ESCOs existed, the university needed to coordinate and organize engineering feasibility studies and construction project management in-house, using their own capital. This increased costs for the institution, and subjected energy investments to many levels of internal scrutiny. ESCOs were able to integrate these services and provide capital for financing, which streamlines projects for the university, allowed the institution to benefit from the ESCO's industry expertise, and reduced overall risks and project implementation complexity.

The measurability of RTT investments presented itself as a persistent challenge among many stakeholders interviewed.Thermal energy, like electrical energy, is measurable. However, the measurability of thermal energy is often less obvious than electrical energy, in part because thermal energy is often itself treated as a final energy service, whereas electricity is a secondary energy source. It is straightforward to measure the number of kilowatt-hours of energy consumed; quantifying thermal comfort is less obvious. Nonetheless, the secondary energy generation of RTTs can be quantified and measured, typically in terms of British Thermal Units (BTUs) or Joules (J). Further complexity comes from the decision of where the point of metering should occur in RTT implementations, and how the size of the system relates to its performance. Measurability, when effective, can act as a driver to deployment. Thermal meters however, are generally characterized as being less accurate and costlier than electric meters, which presents barriers for RTTs. This may be particularly important for enabling alternative, service-oriented business models (e.g. pay by the BTU). Difficulty in metering early RTT projects was cited as a barrier to creating accurate valuations of the benefits these investments provided, making future financing efforts more difficult.

Functional Limitations and Local Opportunities

Existing building performance is a determinant of RTT economic and physical feasibility. The ability for RTTs to provide thermal comfort, for instance, can be dependent on the quality of a building's envelope. Similarly, the availability of infrastructure and, where applicable, fuel, are another determinant of RTT feasibility. For example, proximity to a heat source determines the feasibility of connecting to a district energy system, and the quality of insolation influences the ability of a solar hot water system to perform. The choice, combination, and scale of RTTs will to some extent be defined by existing infrastructure, both within and around the building under consideration. Stakeholders in a district energy project described the confluence of both a source of waste heat for the thermal grid and the presence of off-takers as essential prerequisites for project viability. Similarly, a large university ruled out biomass as a source of thermal energy based on a short supply of local feedstocks and a lack of sufficient storage space at the point of consumption. Individual building characteristics also function as barriers or drivers of energy investments. A commercial customer explained that asbestos remediation was a barrier to undertaking investments in energy efficiency or thermal energy supply systems. However, such investments can also be serendipitous in their timing. To take the example of asbestos remediation, once the fixed cost of removing drywall is realized for remediation purposes, it is easier to justify upgrades to insulation or ductwork.

To be viable, district energy projects require a confluence of enabling factors. A developer of a local district energy project listed several attributes that must be in place as prerequisites for investment:

> *Population density, source of waste heat, high credit customers, strong legislative support, green bank line of credit to complete feasibility studies, and buy-in and support from the [heat source] owner and others who got involved.*[24]

Alignment is required both in terms of the physical attributes of the installation and in terms of financing and customer availability.

24 Donovan, Daniel. Interviewed by Joseph Schiavo. In-person. Bridgeport, CT, 25 March 2016.

Current Financing Models for RTTs

Given high capital costs, decisions to undertake energy projects are typically facilitated using some form of financing. In general, the goals of these financial products include overcoming high upfront cash requirements, delivering monthly cost savings to customers, and otherwise making capital-intensive projects affordable. Importantly, the characteristics of financial products used to finance energy investments influence the value proposition of the investment itself. Beyond providing access to otherwise unaffordable technologies, energy financing is frequently sold as a business model in which measurable savings are passed on to the customer. Consideration of appropriate financing mechanisms for RTTs requires a twofold assessment of both the ability of these products to provide positive net present value and the business value that these products can provide.

With some exceptions, RTTs can be financed using similar products available for other renewable energy technologies and energy efficiency. Leventis et. al. (LBNL, 2016) offer a typology of financing products for efficiency financing and an evaluation of these financing products' impact on market barriers. The overview of different financing models is based on this typology.

GRANTS AND TAX REBATES – Direct cash awards or rebates used to subsidize the cost of project

ADVANTAGES	DISADVANTAGES
• Provide immediate cash benefits that reduce upfront costs of installation • Shorten payback periods • Lower cash flow barriers to entry • Enable lower monthly payments (where applicable) • Generate attention • Generate trust when provided by a trusted source	• Costly; requires taxpayer or utility funding • Not considered scalable • Create disincentive for installers to reduce costs and find efficiencies

LOANS; SECURED OR UNSECURED – Loan financing for all or parts of the project cost. Either backed (secured) or not (unsecured) by collateral

ADVANTAGES	DISADVANTAGES
• Facilitate outright ownership by customers • Alleviate problem of high upfront cash requirements • In some cases, subsidized or below-market interest rates • Facilitate syndication and securitization, for market expansion	• Require verification of creditworthiness • Payments are fixed and do not vary with project performance • Where applicable, subsidies and interest rate buy-downs require public funding • Interest rate risk

LEASES; CAPITAL OR OPERATIONAL[25] – Project equipment leases; capital lease involving a purchase of the leased equipment, or operating lease involving no purchase at the outset

ADVANTAGES	DISADVANTAGES
• Typically require little to no upfront cash payments • Payments can be right-sized to provide a margin of savings to the customer on the energy bills • Facilitate the replacement of equipment at the end of term	• Equity does not accrue to property owner • Financing institution must accurately project depreciation • Lifetime project cost savings decreased relative to loan financing. Higher monthly payments

PROPERTY-ASSESSED CLEAN ENERGY (PACE) – Financing secured by an assessment on property taxes. Generally available only to commercial and industrial customers, with limited residential use

ADVANTAGES	DISADVANTAGES
• Strong security for lenders • Lowers cost of capital • Simplicity in payments and collection • Makes the investment cash-flow positive • Transfers to a new occupant, which reduces barriers related to occupancy time horizon	• Requires explicit policy in place at local levels • Unless the value of the asset financed by PACE is reflected in the property sales price, the PACE liability may impact negatively on the property value

ON-BILL FINANCING AND REPAYMENT – Financing provided directly by, or through, servicing utilities. Financing charges appear as line items on monthly energy bills

ADVANTAGES	DISADVANTAGES
• Associates financing charges with borrower's credit history, via utility bill • Historically high payment and collection rates • Lowers cost of capital • Can make the investment cash-flow positive • Access to financing for more people • Transfers to a new occupant, which reduces barriers related to occupancy time horizon	• Requires alignment and coordination with servicing utilities • Success of transfer balance to new occupant in case of bankruptcy or foreclosure is untested • Unless the value of the asset financed on-bill is reflected in the property sales price, the liability may impact negatively on the property value

25 Project equipment leases; capital lease involving a purchase of the leased equipment, or operating lease involving no purchase at the outset

SAVINGS-BACKED OR PERFORMANCE BASED ARRANGEMENTS – Financing provided directly by, or through, servicing utilities. Financing charges appear as line items on monthly energy bills

ADVANTAGES	DISADVANTAGES
• Generally, overcomes the high upfront costs barrier to entry • Delivers tangible energy services to customers • All installation, maintenance, and logistics handled by ESCO • Creates a market for energy services • Frees customers from the need to own and manage energy assets	• Requires an ESCO with access to capital, expertise, and scale

Leventis et. al. (LBNL 2016) have evaluated the barriers to energy efficiency that are addressed by the specific financing products that they discussed. This is shown by Table 1.

BARRIER	UNSECURED LOAN	SECURED LOAN	LEASING	ON-BILL	PACE	SAVINGS-BACKED ARRANGEMENTS
Access to capital	○	○	○	●	○	○
Cash flow	○	●	○	○	●	●
Application process	●		●	●		
Split incentives				○	○	
Occupancy duration				●	●	
Customer debt limits				○	○	○

Table 1 | Barriers addressed by financing products. Source: Leventis et. al. (LBNL 2016). Note: Filled-in circles suggest that a particular barrier may be largely addressed by a financing product, while empty circles suggest that the product has medium potential to address the barrier.

As can be seen from Table 1 , financing products can address several barriers, but not all. Stimulating the market requires a mix of market interventions, including regulatory mechanisms and financing products. Appendix 1 provides an overview of current regulations and financial incentives in the RTT field in Connecticut.

Conclusions and Recommendations

Connecticut's 2050 greenhouse gas reduction target is ambitious. A new fossil fuel boiler will normally be in operation for at least 20 years, locking the customer into fossil fuel for a long time, regardless of energy efficiency measures taken. Instituting measures that guide customers away from these path-dependent decisions for heating and cooling purposes will be an important driver of the success of Connecticut's GHG reduction policy. RTTs represent low-emitting solutions for heating and cooling.

This study reveals a set of factors that influence customers' RTT investment decisions at different stages of the value chain, as shown by Figure 2.

	UPSTREAM	Heating and cooling market	DOWNSTREAM
BARRIERS	• Fuel availability • Price volatility	• Competence and experience of experts • Unclear potentials due to lack of performance data (prior to and after RTT) • Nascent industry with unproven business models	• High upfront costs • Access to capital • Unfavorable economics compared to alternatives • Awareness of RTTs and its applicability • Physical constraints
DRIVERS	• Local resources that offer opportunities (e.g. waste heat from processes and buildings, wood chips from local industry, favorable ground conditions)	• Diligent stakeholders • Local governments as facilitators • Green Bank funding and investment support opens doors to other funding	• Long term plans and strategies • Grants and rebates • Value proposition; classification schemes, revenue streams • Being in a decision mode • Financing products

Figure 2 | Barriers and drivers across the value chain for RTTs.

For RTTs to be deployed at scale, they must become the preferred choice for customers. To be preferred, the technologies have to be recognized, trusted, and competitive, in terms of price, delivered comfort, and performance. We suggest a set of initiatives that will address the barriers and benefit from market drivers at different stages of the value chain. Broadly, these recommendations are grouped into four categories.

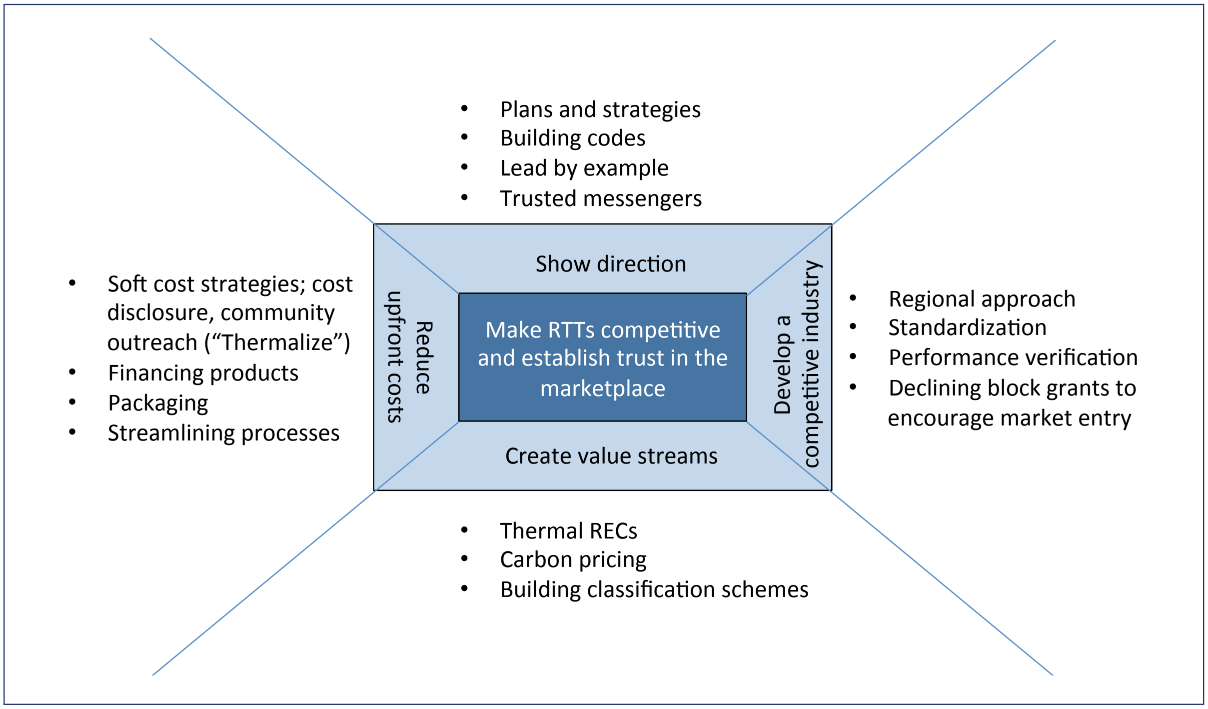

Figure 3 | Recommendations to address barriers and drivers for RTTs.

The first, "**Show direction,**" addresses low awareness and aims to create demand for RTTs through institutional means—that is, measures that governments can take to encourage the uptake of RTTs. The second, "**Reduce upfront costs**," addresses unfavorable project economics and high capital outlays (caused by high installation costs) compared to conventional thermal technologies. We propose creating financial products and strategies to both improve the value proposition of RTT investments and create conditions where the financing of RTTs can achieve scale. "**Develop a competent and competitive regional industry**," describes the need for a well-supported and trustworthy base of installers and experts focused on the RTT industry. Installers and experts are critical to RTT adoption because they are at the front line of customer decisions; their expertise directly influences a project's performance. The final category, "**Create value streams**," addresses unfavorable operational project economics and an unclear business case in short and long term. These recommendations support finding and promoting the additional value streams that RTTs can provide, both in terms of incremental energy services and an active market for renewable thermal energy.

The companion report on market potential (Grønli et. al. 2017), supplements the recommendations below by suggesting specific market interventions influencing on the competitiveness of RTTs.

Show Direction

A low-emission future requires long-term perspectives on the development and interaction of buildings and energy infrastructures like the electricity grid, the natural gas grid, and the thermal grid. The largest challenge may be related to the extent to which a low-emission future requires changes in this infrastructure. Influencing adoption of RTTs provides a leverage point for lowering emissions. Governments, in particular, can provide important signals about the long-term direction of the energy markets and its infrastructure, both through plans and action.

GOVERNMENTAL STRATEGIES AND PLANS

Governmental strategies and plans communicate the direction of policies and action, both on a national and local level. The Comprehensive Energy Strategy for Connecticut that is soon to be published will send important signals to the RTT market.

Local governments have a role with regards to land use planning and regulation. These can be used to include the perspective of thermal grids and possible industrial parks, utilizing synergies of exchange of surplus thermal energy between buildings and processes. Energy and climate roadmaps for cities may increase awareness of the local governments' roles as owners of buildings, planners, regulators, and providers of infrastructure.

Thermal grids provide flexibility to utilize several low-cost energy sources such as waste heat from waste incineration, surplus heat from data centers, surplus electricity from variable generation, and surplus heat from solar thermal installations. Additionally, easy access to a thermal grid facilitates a higher rate of fuel shifting. Thermal grids may be instrumental to achieving Net Zero Energy Districts (NZED).

The field study found that interest exists from both developers and potential customers in thermal grids; however, there is risk in a lack of institutional support for these complicated investments. If governments act to create a favorable environment for collaboration—through facilitating heat density maps, feasibility studies (including own buildings), and data initiatives—complexity and risk can be reduced for private actors.

THE BUILDING CODE

The building code can be used to show direction for building standards and energy systems under construction today and slated for future construction. In addition to stricter requirements for the building envelope, which eventually will favor low-temperature solutions such as heat pumps, the code can signal which energy systems to install and which to avoid in new and existing buildings. Examples include required minimum levels of renewable energy, disallowing fossil fuel boilers, and minimum levels of flexibility and efficiency. Although the number of new buildings per year is limited, requirements offer a nascent RTT industry a market segment in which it can start developing salient business models; these, in turn, can spread and adapt to the existing building stock. We recommend evaluating the current building code in this respect.

LEAD BY EXAMPLE

Public institutions, such as governments, municipalities, and educational organizations, can lead by example. Choosing RTTs for heating and cooling does not only create credibility for other customer groups, but it also helps to establish a nascent industry given the public sector is often a large property holder and energy user.

Public institutions also work on long time horizons, allowing them to establish leadership in investments and long-term energy service contracts. As large users of energy for heating and cooling, with a considerable purchasing power, public institutions may be more likely to see a favorable benefit cost analysis for RTTs as well. (Grønli et. al. 2017).

There can be several ownership models for RTTs, whether for stand-alone units or whole infrastructure projects, like thermal grids. As a large customer, public institutions can be instrumental in the development of standardized models and contracts, allowing the most logical ownership model for each given situation to emerge. Templates for tendering processes and standardized contracts that ensure consistency with public procurement requirements will not only facilitate public entities' participation, but can serve as models for third party ownership across a broader spectrum of customers.

TRUSTED MESSENGER

Lenders who are unfamiliar with RTTs may require a higher risk premium or be reluctant to provide financing, and a trusted messenger may facilitate the financing process. Green Bank funding generally—and first-loss arrangements specifically—provides credibility and risk reduction to the technology and project; it may also secure better financing terms than customers would otherwise receive. Investment support through other program administrators such as utilities similarly advices the customer in choosing technology. For residential customers, this credibility is linked to the technologies included in a program. For larger customers and projects, credibility is created on a project-by-project basis.

Reduce Upfront Costs

In the field study, we consistently received the feedback that costs and long-term economic considerations were a primary consideration for prospective RTT installations. Although both installation and operational costs are important when a customer chooses which technology to use for heating and cooling, high upfront costs seem to represent a particularly important barrier. This barrier has two aspects to it: 1) high installation costs influence competitiveness when compared with conventional technologies, and 2) high upfront costs require considerable capital.

The installation costs related to installing RTTs vary depending on the type of technology, the state of the existing internal system and building envelope, thermal service to be delivered, and the overall size of the installations. Roughly, the costs can be categorized into heating-cooling unit, storage, drilling and digging, pipes, planning and permitting, retrofit of internal distribution or building envelope, financing, and installation. Figure 4 provides a taxonomy of project investment costs.

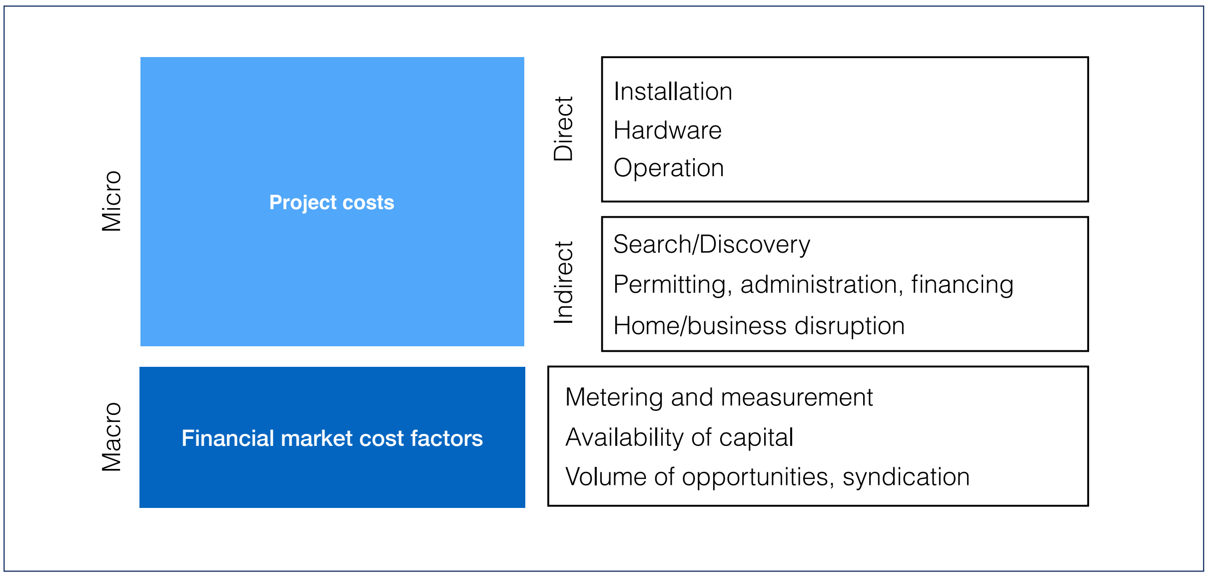

Figure 4 | Investment cost taxonomy

Although some customers are able to finance RTT investments without raising capital, many will have to find external sources of financing to make these investments possible. Financing has costs, and the higher the risk the financing institutions perceive, the more expensive capital tends to be.

In addition to direct costs related to the installation and operation of the thermal technology, there are indirect costs related to searching for information, evaluating options, applying for permits and grants, disturbing core business, and raising capital. These costs are less visible, but will influence the customer's decision making.

STRATEGIES TO REDUCE SOFT COSTS

Several studies support that technologies are expensive at the point of market introduction, but eventually become cheaper due to technological learning. This technological learning applies to both producing the equipment (hard costs) and the installation work (soft costs). To achieve technological learning, the market has to attain certain volumes and scale. As several RTTs can be categorized as technologically mature in a nascent East coast market, the effect of technological learning is expected to be highest with regard to soft costs. **Strategies to reduce soft costs** will contribute to lower installation costs.

The Connecticut Green Bank's "Solarize"[26] campaign was highly effective in both raising awareness of solar PV technologies and reducing customer acquisition and soft costs. Pilots such as HeatSmart[27] Thomson of New York indicate that a similar campaign ("Thermalize") for renewable thermal technologies could have similar outcomes.

FINANCING PRODUCTS

Financing products can be designed to address several aspects of high upfront costs, access to capital, and the cash flow over the life of the asset. According to Leventis et. al. (LNBL, 2016), on-bill financing is the most advantageous to address the challenge of access to capital. While any financing product may offer cash-flow-positive terms to customers depending on the scope of the project, Leventis et. al. suggest that secured loans, PACE, and savings-backed products are preferable. Their argument is that the security associated with secured loans and PACE tends to allow for longer terms and lower rates without credit enhancement, which can facilitate more positive cash flow arrangements. Savings-backed arrangements, such as Thermal Service Contracts or Energy Performance Contracts, tend to be structured so as to be cash-flow positive.

RTTs represent a range of technologies with different features; they can scale in size from serving residential customers to district energy and industrial purposes. Financing products should take this into consideration as the importance of the barriers and drivers may vary between RTTs. Mass-market strategies can be applied to some RTTs, while tailored products may be necessary for others.

Furthermore, some RTTs would benefit from applying different financing products to different parts of the installation. Thermal grids and ground source loops are installations with considerable technical lifetimes, but the costs are sunk should the asset be left idle. Boilers and heat pumps have shorter technical lifetimes, but are to a larger extent movable. These characteristics may allow for designing different financing products and business models.

26 Solarize CT is a community-based program that leverages social interaction to promote the adoption of solar through a group-pricing scheme intended to reduce soft costs. See http://solarizect.com/

27 See http://www.solartompkins.org/

PACKAGES OF MEASURES AND FINANCING PRODUCT

Preparing packages of measures and financing products may make it easier for the customers to realize cost benefits and inspire the customers to do more renovation at one time. The reasons why customers opt for thermal technologies may vary, and the packages can target each decision-making situation; an oil boiler breaking down in the middle of the winter may demand a different financing package than the retrofit of an internal heat distribution system.

Bundling RTTs with solar PV and energy efficiency measures was identified as a driver of deployment in the field study, not to mention the co-benefits these installations can provide.

STREAMLINING

If not streamlined as much as possible, the process from when a customer decides to install RTT to the point of final installation can be time-consuming and full of hurdles. Examples of steps that may benefit from streamlining and standardization are:

- Harmonization of permitting processes across cities and states
- Coordination between governmental offices
- Coordination of work, e.g. digging of trenches for infrastructure
- One-stop-shop for financial products and incentives
- Standard contracts for “thermal service agreements”, templates for tendering and public procurement processes
- Ownership and business models
- Installation processes and systems designs
- Certifications

Cultivate a Competent and Competitive Regional Industry

A pool of qualified RTT experts and suppliers is a prerequisite for a well-functioning RTT market. To be attractive, the market should promise a certain volume, have low barriers to entry, and be predictable over time. Both the mainstream market and the market for customized solutions would benefit from a professionalized RTT industry with long-term business models including services related to maintenance and correction. Conditions supportive of RTTs contribute to the attractiveness of the market.

Being mature technologies in a nascent market, RTTs may seem riskier to customers and lenders than they actually are. Measures to reduce the risk will increase confidence in the technologies.

REGIONAL APPROACH

A regional approach to address barriers and drivers of RTT deployment is recommended, as both installers and customers benefit from a regional market. Unless rules for certification, taxes, incentives, and permissions vary extensively across states, the installers of RTTs are not limited to operation in one state. However, if there are large differences in interstate business environments, this will serve as a barrier to entry. Standardization of contracts and procedures, along with harmonization of rebate programs and qualifying criteria, installer certification, data definitions, permission processes, and financing models are examples of possible areas for coordination and shared experience.

STANDARDIZATION

Standardization of contracts, tendering and public procurement processes, financing models, verification methods, certification, and ownership models may make it easier to raise private capital for RTTs. Standardization helps the industry develop salient business models based on common and trusted reference for doing business.

PERFORMANCE VERIFICATION

Performance verification, either through metering or other accepted monitoring methods, will not only reduce the risk for the customer, but it will increase lender confidence in the project performance, which is an important driver according to IMT (2016). Performance verification provides customers information on the quality of the installation and potential malfunctions during its lifetime. Proving performance will create customer trust in the solutions. Performance verification will also facilitate new revenue streams and business models, such as Thermal Renewable Energy Certificates, third-party ownership, green bonds, and Energy Performance Contracts. The level of required accuracy will influence the additional cost. We recommend evaluating various methods for performance verification with respect to the purpose it will serve for various customer segments and the related costs and benefits.

DECLINING BLOCK GRANTS

Incentives supporting RTTs provide valuable information to the customer and function as a marketing campaign. Incentives may range from grants to cheap loans and leasing products. To avoid “start and stop” market effects, it is important to be clear about the duration and potential ramping down of grants and rebates. Declining block grants with an announced profile will encourage entry to the market and help to create momentum with efforts like the proposed “Thermalize” campaign.

Create Value Streams

RTTs can utilize resources that would otherwise be wasted. These include waste heat from industrial processes (thermal electricity generation, data centers, and waste heat incineration) and waste products that can be transformed into fuel for heating (biogas and wood chips from old building materials). The promotion of additional value streams not only makes RTTs more favorable economically, but it allows for new financing products and business models supporting RTTs.

THERMAL RENEWABLE ENERGY CREDITS

Include Thermal Renewable Energy Credits (TRECs) in the Renewable Portfolio Standard (RPS) to establish revenue streams on renewable thermal energy.. Given the limited availability of RECs for thermal energy, renewable resources such as biogas may not be used where they add the most value when they are awarded credits for only one of several possible applications (electricity generation.) Including thermal energy in the RPS incentivizes project developers to optimize the use of energy sources to a larger extent than they otherwise would. As a market for RECs has already been established for renewable electricity, adding thermal energy could be done with relatively low effort.

Thermal RECs, which depend on technologies that afford performance verification with some degree of certainty, can be instrumental in funding both large installations and small projects in aggregate. However, high costs related to heat meters and performance verification may imply that participating in TREC trading is worth the effort mostly for larger installations.

CARBON PRICING

Carbon pricing would internalize the social costs of carbon in customers' investment decisions. This would increase the operational costs of conventional alternatives and improve the project economics of RTTs. Visualizing the costs of carbon on the profit and loss statement may appear as an important driver to low-carbon solutions of companies, increasing the awareness of RTTs.

BUILDING CERTIFICATION SCHEMES

To promote investments in RTTs regardless of a customer's time horizon requires the perception that the investment will generate value regardless of occupancy period. Building certification schemes make it possible for the customer to separate high-quality buildings from low-quality buildings; this quality difference would be reflected in the property value and rents, creating additional value to the RTT investment. Building certification may, further, diminish the split incentive issue inherent in rental properties. LEED, Living Building Challenge, and Energy Star are examples of existing voluntary classification schemes.

Open access to all aspects of building performance data makes energy projects more attractive from an investor's point of view (Energy Efficiency Financial Institutions Group, 2015). High-performance buildings are well suited to low temperature heating and high temperature cooling sources that several RTTs provide. Developers of high-performance buildings in cities are focusing increasingly on classification schemes such as LEED (Kolstad, 2016). Several studies support that "green buildings" achieve higher rents. [28]

RATE MECHANISMS

Explore rate mechanisms that recognize the value of RTTs in reducing demand for natural gas and electricity. RTTs can effectively help alleviate peaks in Connecticut's energy demand by diversifying the pool of energy supply and delivering services balanced throughout the day and night. However, it is necessary to be aware of the features of the different RTTs compared to conventional alternatives. RTTs have different impacts on electricity and gas loads depending on their drive energy, efficiency over the year, and which energy source they replace. We recommend evaluating the rate structure in this respect.

28 The publication "Green Building and Property Value. A Primer for Building Owners and Developers" by IMT and the Appraisal Institute refers to several studies trying to quantify the higher rents achieved by "green buildings".

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Appendices

Appendix 1 – Connecticut Incentives

REGULATIONS			Upstream	Mid Stream	Downstream
			Above-market-level incentives. Applies to the distribution and wholesale businesses	*Infrastructure-level incentives. Applies to district energy and other infrastrutures*	*Project-level implementation incentives (all customer classes)*
State	Upfront	CO2			
State	Upfront	Quota	CT renewable portfolio standard Contractor licensing	CT renewable portfolio standard Contractor licensing	CT renewable portfolio standard CT Building Code Contractor licensing Zoning Permitting
State	Performance based	CO2			
State	Performance based	Quota	Energy efficiency requirements for state government		
Federal	Upfront	CO2			
Federal	Upfront	Quota	Energy goals and standards for Federal Government Green power purchasing goal for Federal Government		
Federal	Performance based	CO2			
Federal	Performance based	Quota			

INCENTIVES			Upstream	Mid Stream	Downstream
			Above-market-level incentives. Applies to the distribution and wholesale businesses	*Infrastructure-level incentives. Applies to district energy and other infrastrutures*	*Project-level implementation incentives (all customer classes)*
State	Upfront	Tax incentives		Sales and use taxes for items used in renewable energy industries	Sales and use tax exemption for solar and geothermal systems Property tax exemption for renewable energy systems
State	Upfront	Subsidies		Eversource and UI energy efficiency programs	Eversource and UI energy efficiency programs Home energy solutions rebate program Ground source heat pump subsidy
State	Upfront	Finance		Municipal (infrastructure) bonds for district energy Qualified Energy Conservation Bonds (QECBs)	Smart- E Loans Energize CT heating loan program Energy conservation loan program Geothermal Heat Pump rebates C-PACE Clean energy on-bill financing Small business energy advantage loan program Local option - Residential sustainable energy program
State	Performance based	Tax incentives			Production tax credit for commercial geothermal and closed-loop biomass
State	Performance based	Subsidies			
State	Performance based	Finance	RECs (class III)		Lead by Example – Energy savings performance contracting program (state and municipal)
Federal	Upfront	Tax incentives		Credit for home builders Investment Tax Credit for solar thermal (ITC)	Modified Accelerated Cost-Recovery System (MACRS) Residential energy efficiency tax credit Energy-efficient new homes tax
Federal	Upfront	Subsidies			USDA - Rural Energy for America Program (REAP) Grants Weatherization Assistance Program (WAP) USDA - High energy cost grant program
Federal	Upfront	Finance	Clean renewable energy bonds U.S. Department of Energy - Loan guarantee program	Clean renewable energy bonds U.S. Department of Energy - loan guarantee program	Energy-efficient mortgages USDA - Rural Energy for America Program (REAP) loan guarantees
Federal	Performance based	Tax incentives			
Federal	Performance based	Subsidies			
Federal	Performance based	Finance			Energy Efficiency Fund (Electric and Gas) - Residential energy efficiency financing

Appendix 2 – Interview Guides

INTERVIEW GUIDE – GOVERNMENT AGENCIES

INTRODUCTION

This interview is part of the project "Feasibility of renewable thermal technologies in Connecticut", which is a cooperation between Yale University, the Yale Center for Business and the Environment, the Connecticut Department of Energy and Environmental Protection, the Connecticut Green Bank, Eversource, and United Illuminating. The purpose of the project is to determine a realistic contribution from renewable thermal technologies to achieve Connecticut's overall target of reducing greenhouse gases, and what factors make the customers invest or not invest.

Renewable thermal technologies (RTTs) are technologies that use renewable energy resources to provide heating and cooling. RTTs can deliver domestic hot water, process heating, space heating and space cooling. These needs are normally served by petroleum, natural gas or electricity today. For the purpose of this project, the following RTTs are included:

- Air Source Heat Pumps and Ground Source Heat Pumps
- Devices burning biomass such as wood chips and wood pellets
- Biofuels such as biogas and biodiesel
- Solar thermal such as solar water heaters
- Waste heat recovery technologies

The purpose of this interview is to gain deeper insight into what makes customers decide whether to invest in these technologies. The project covers residential, commercial and industrial customers. **[Focus for Government Agencies: How do Governmental Agencies view RTTs role in the future, and what regulatory mechanisms do they consider important to develop these markets?]**

The interview is estimated to last 45 to 60 minutes. Is it OK if we record the interview? The audiotape will be destroyed after the study is finalized.

The answers will be treated as confidential, and we will seek your approval for any quotations we wish to publish. You are free to end the interview at any time.

MUNICIPALITIES

[Role as regulator]

1. Describe the number and profile of buildings owned and operated by the municipality.
   [Clues if needed: Square feet, type of buildings, owner vs renter, age of building]
   [This question should be sent out in advance]

2. How does your town heat and cool its buildings today?
   [This question should be sent out in advance]

3. How would you describe the technologies for heating and cooling that you are aware of?
   [If necessary, mention the alternatives]

4. Has the municipality prepared a master energy plan that guides the choice of thermal technologies in the municipality? If yes, describe the main elements of this plan.
   [Refer to project name if known: BGreen 2020, Stamford 2030 District.... If examples of choices are needed: Choice of energy source at municipal new building, choice of energy source at retrofit of existing buildings, land use regulations, permits...]
   [Consult List no 1 - thermal technologies]

5. Please describe the energy projects that have recently been undertaken in your municipality. We are interested in both projects for municipality-owned buildings, and those by residents or businesses in the municipality.
   [Request experience - good or bad]

6. Describe the regulatory measures that would apply to renewable thermal energy projects in the municipality.

7. Describe the municipal permitting / approval process for thermal technologies for (1) residential customers and (2) commercial/industrial customers.
   [Differentiate by type of RTT: Heat pump, bioenergy, solar water heaters, district energy]

8. What do you regard as critical success factors in order for district energy systems to be realized in your municipality
   [If clues are needed: Consult List no 2 – Barriers and Drivers]
   [If the answer is positive – follow up by asking how the municipality would facilitate district energy]

9. From your perspective, what are the most important factors restricting investments in Renewable Thermal Technologies in your municipality?
[For the municipality to switch to RTTs, and for the city's residential and commercial buildings to switch]

10. From your perspective, what factors have to be in place in order for Renewable Thermal Technologies to be a preferred choice of the municipality in the future?
[Generally, and for different RTTs in particular: Air Source Heat Pumps, Ground Source Heat Pumps, Solar Hot Water, Bioenergy, District Energy]

11. Other issues that the interviewee finds relevant

CT STATE GOVERNMENT

1. How would you describe the technologies for heating and cooling that you are aware of?
[If necessary, mention the alternatives]

2. CT has established a thriving Solar PV market. In your opinion, what are the most important factors that influenced that success, and which might be applied to Renewable Thermal Technologies?

3. In your opinion, what were the most important challenges the State had to overcome in developing the Solar PV market? To what extent can this help inform a strategy for Renewable Thermal Technologies?

4. From your perspective, what are the most important incentives and regulations for promoting Renewable Thermal Technologies

    1. Existing today?
    2. To be put in place for the future?
    [Request the rational for future incentives and regulations – which problems would they solve?]

5. Mention the five most important policy changes that you see coming to achieve Connecticut's energy and climate ambitions

6. What does this imply for Renewable Thermal Technologies?

7. What conflicts might exist between the expansion of Renewable Thermal Technologies and other technologies?
   [Examples if needed: More efficient natural gas boilers vs RTTs, energy efficiency vs RTTs. If examples have to be given – ask the interviewee to elaborate and evaluate]

8. Other issues that the interviewee finds relevant

INTERVIEW GUIDE – FINANCIAL INSTITUTIONS

INTRODUCTION

This interview is part of the project "Feasibility of renewable thermal technologies in Connecticut", which is a cooperation between Yale University, Yale Center for Business and the Environment, the Connecticut Department of Energy and Environmental Protection, the Connecticut Green Bank, Eversource and United Illuminating. The purpose of the project is to determine a realistic contribution from renewable thermal technologies to achieve Connecticut's overall target of reducing greenhouse gases, and what factors make the customers invest or not invest.

Renewable thermal technologies (RTTs) are technologies that use renewable energy resources to provide heating and cooling. RTTs can deliver domestic hot water, process heating, space heating and space cooling. These needs are normally served by petroleum, natural gas or electricity today. For the purpose of this project, the following RTTs are included:

- Air Source Heat Pumps and Ground Source Heat Pumps
- Devices burning biomass such as wood chips and wood pellets
- Biofuels such as biogas and biodiesel
- Solar thermal such as solar water heaters
- Waste heat recovery technologies

The purpose of this interview is to get a deeper insight into what makes customers decide to invest in these technologies or not. The project covers residential, commercial and industrial customers. **[Focus for Financial Institutions: How do Financial Institutions view RTTs role in the future, and what barriers exist to enhance the role of RTTs?]**

The interview is estimated to last 45 to 60 minutes. Is it OK for you if we record the interview? The audiotape will be destroyed after the study is finalized.

The answers will be treated as confidential, and we will seek your approval for any quotations we wish to publish. You may choose to end the interview at any time.

GREEN BANKS

1. How many projects involving Renewable Thermal Technologies have your organization helped financing the last five years?
   [Differentiated by residential, commercial, industrial as well as per RTT]

2. Give examples of best practices that you have observed in successful financing projects for Renewable Thermal Technologies?
   [Request examples for both residential, commercial and industrial customers. Ask the interviewee to mention why he/she considers the project(s) to be successful]

3. Comment on projects that have been problematic to finance or execute.
   [Request examples for both residential, commercial and industrial customers. Ask the interviewee to mention why the project(s) were difficult to finance or execute]

4. What do you regard as critical success factors in order for district energy systems to be realized (as contrasted with distributed energy technologies)?

5. From your perspective, what are the most important factors restricting investments in Renewable Thermal Technologies?
   [Generally, and for different RTTs in particular: Air Source Heat Pumps, Ground Source Heat Pumps, Solar Hot Water, Bioenergy, District Energy]

6. From your perspective, what factors have to be in place in order for Renewable Thermal Technologies to be the preferred choice for customers in the future?
   [Generally, and for different RTTs in particular: Air Source Heat Pumps, Ground Source Heat Pumps, Solar Hot Water, Bioenergy, District Energy]

7. What market barriers are your support programs for Renewable Thermal Technologies designed to overcome?
   [Consult List 2 if examples are needed]

8. Describe the successes and failures of programs like SmartE and C-PACE. What are considerations for making these programs successful in the CT market?

9. What role can your organization play in deploying Renewable Thermal Technologies?

10. Mention the five most important policy changes that you see coming to achieve Connecticut's energy and climate ambitions

11. What does this imply for Renewable Thermal Technologies?

12. Other issues that the interviewee finds relevant

UTILITIES

1. What are the lessons learned about the Connecticut market through the energy efficiency programs your organization promotes?

2. How many projects involving Renewable Thermal Technologies have your organization helped financing the last five years?
[Repeat the list of renewable thermal technologies before asking this question. Answer should be differentiated by residential, commercial, industrial as well as per RTT]

3. What methods of financing could be made available to Renewable Thermal Technologies through your organization?
[Mention examples if necessary: On-bill finance, system charge, grant]

4. Give examples of best practices that you have observed in successful financing projects for Renewable Thermal Technologies?
[Request examples for both residential, commercial and industrial customers. Ask the interviewee to mention why he/she considers the project(s) to be successful]

5. Comment on projects that have been problematic to finance or execute.
[Request examples for both residential, commercial and industrial customers. Ask the interviewee to mention why the project(s) were difficult to finance or execute]

6. Describe the successes and failures of programs like SmartE and C-PACE. What are considerations for making these programs successful in the CT market?

7. From your perspective, what factors have to be in place in order for Renewable Thermal Technologies to be the preferred choice for customers in the future?
[Generally, and for different RTTs in particular: Air Source Heat Pumps, Ground Source Heat Pumps, Solar Hot Water, Bioenergy, District Energy]

8. From your perspective, what are the most important factors restricting investments in Renewable Thermal Technologies?
[Consult List 2 if necessary. Request the interviewees' view on general basis as well as for different RTTs in particular: Air Source Heat Pumps, Ground Source Heat Pumps, Solar Hot Water, Bioenergy, District Energy]

9. What do you regard as critical success factors in order for district energy systems to be realized (as contrasted with distributed energy technologies)?

10. Other issues that the interviewee finds relevant

INTERVIEW GUIDE – CUSTOMERS

INTRODUCTION

This interview is part of the project "Feasibility of renewable thermal technologies in Connecticut", which is a cooperation between Yale University, Yale Center for Business and the Environment, the Connecticut Department of Energy and Environmental Protection, the Connecticut Green Bank, Eversource and United Illuminating. The purpose of the project is to determine a realistic contribution from renewable thermal technologies to achieve Connecticut's overall target of reducing greenhouse gases, and what factors make the customers invest or not invest.

Renewable thermal technologies (RTTs) are technologies that use renewable energy resources to provide heating and cooling. RTTs can deliver domestic hot water, process heating, space heating and space cooling. These needs are normally served by petroleum, natural gas or electricity today. For the purpose of this project, the following RTTs are included:

- Air Source Heat Pumps and Ground Source Heat Pumps
- Devices burning biomass such as wood chips and wood pellets
- Biofuels such as biogas and biodiesel
- Solar thermal such as solar water heaters
- Waste heat recovery technologies

The purpose of this interview is to get a deeper insight into what makes customers decide to invest in these technologies or not. The project covers residential, commercial and industrial customers.**[Focus for customers: To what extent do the customers know RTTs and what are the factors influencing on investment decisions in heating and cooling technologies?]**

The interview is estimated to last 45 to 60 minutes. Is it OK for you if we record the interview? The audiotape will be destroyed after the study is finalized.

The answers will be treated as confidential, and we will seek your approval for any quotations we wish to publish. You are free to end the interview at any time.

RESIDENTIAL

1. Are you the owner of your current residence? How long have you lived in your current residence?

2. Would you be responsible for any decisions on investments in energy technologies at your residence? If not, who would have to agree?
   [Clues: Landlord, homeowners' association]

3. **Tell us about your household's current energy consumption for space heating and cooling, hot water?**
[List examples of heating and cooling – consult List 1]
[Clues to guide direction: Describe how you use heat and air conditioning in a typical year? What temperatures are comfortable to you? Age of heating device? Distribution system? Number of residents? Annual energy costs / consumption?]

4. **How would you describe the technologies for heating and cooling that you are aware of?**
[If necessary, mention the alternatives in List 1]

5. **In** [insert the relevant year] **you received a rebate / Smart E loan from the Connecticut Green Bank for financing a** [insert the relevant RTT]. **Tell us about your reasons for investing in this device**
[Clues: Economic reasons and which, environmental reasons, retrofitting the house, advice from peers, grant. Consult List 2 and ask the interviewee to elaborate if necessary]

6. **Describe the process leading up to the point of contacting the CT Green Bank**
[Clues: What initiated the process? Where did you search information? Referrals? What caught interest? What made you decide?]

7. **What was your experience from installing and financing this device?**
[Clues: Easy to find information, ease to orient her/himself in the market, available installers, competent installers, financing, costs as expected, need for adaptations of building or heating system. Consult List 2 and ask the interviewee to elaborate if necessary]

8. **What is your experience from operating this device?**
[Clues: Ease of use, energy costs, response from others, availability of fuel. Consult List 2 and ask the interviewee to elaborate if necessary]

9. **Suppose that your** [use reference to question on current energy devices] **is old and has to be replaced. What are the considerations that you would make when you explore replacing it?**
[Clues: Investment costs, operational costs, limitations of existing building, ease of use, financing, competent installers .. Consult List 2 if necessary]

How would you go about to replace it with a new one?
[Clues: Who would you contact? Where would you seek information? Who's opinion would be important for your decision? How would you finance it?...]

10. What would be the three most important factors making you decide in favor of a renewable thermal technology?
   - **A.** Guaranteed cost savings
   - **B.** Good for the environment
   - **C.** 100 percent upfront financing
   - **D.** Expert advice
   - **E.** Fast recovery of investment through lower annual energy bills
   - **F.** Comfort
   - **G.** Increased property value
   - **H.** Easy to use and low maintenance

   [Have the interviewee elaborate his / her choices]

11. What would be your considerations if you were to choose between changing your heating and cooling source as compared to changing windows and insulating your house?

12. Other issues that the interviewee finds relevant

COMMERCIAL

[For customers having received Green Bank support: 8 – 11 are important. For customers not having received Green Bank support: Ask if they have changed their heating or cooling device the last years, and then continue with questions 9 – 11.]

1. Does your company / organization own the building you occupy, or do you rent?

1. Describe your business and its need for heating and cooling.

2. What do you use to meet those heating and cooling needs today?
   [Consult List 1 if necessary]

3. Describe the internal decision making process of energy related projects at your company / organization.
   [Who would be involved? Who would make the decision? Budget or operational expenses? Priority compared to other investment projects?]

4. How would you describe the technologies for heating and cooling that you are aware of?
   [If necessary, mention the alternatives]

5. Suppose that the energy infrastructure of your company's building(s) is old and has to be replaced. What would be the most important considerations to make for your company?
   [Clue from question 3]
   [Clues: Investment costs, operational costs, limitations of existing building, ease of use, financing .. Consult List 2]

6. Which of these technologies would you consider when you have to replace your existing thermal energy solution and why?
   - **A.** Air Source Heat Pumps
   - **B.** Ground Source Heat Pumps
   - **C.** Solar Hot Water
   - **D.** Bioenergy such as wood pellets
   - **E.** District Energy
   - **F.** Natural Gas
   - **G.** Fuel oil/heating oil/propane

7. In [insert the relevant year] your organization received a rebate / loan from the Connecticut Green Bank for financing a [insert the relevant RTT]. Tell us about your reasons for investing in this device
   [Clues: Economic reasons and which, environmental reasons, retrofitting the house, advice from peers, grant. Consult List 2 and ask the interviewee to elaborate if necessary]

8. Describe the process leading up to the point of contacting the CT Green Bank
   [Clues: What initiated the process? Where did you search information? Referrals? What caught interest? What made you decide?]

9. What was your experience from investing and installing this device?
   [Clues: Easy to find information, ease to orient her/himself in the market, available installers, competent installers, financing, costs as expected, need for adaptations of building or heating system. Consult List 2 and ask the interviewee to elaborate if necessary]

10. What is your experience from operating this device?
    [Clues: Ease of use, energy costs, response from others, availability of fuel. Consult List 2 and ask the interviewee to elaborate if necessary]

11. What would be the three most important factors making you decide in favor of a renewable thermal technology?
    - **A.** Guaranteed cost savings
    - **B.** Good for the environment
    - **C.** 100 percent upfront financing
    - **D.** Expert advice
    - **E.** Fast recovery of investment through lower annual energy bills
    - **F.** Comfort
    - **G.** Increased property value
    - **H.** Easy to use and low maintenance

    [Have the interviewee elaborate his / her choices]

12. What would be your considerations if you were to choose between changing the heating and cooling source as compared to changing windows and insulating your building?

13. Describe your organization's ability to access capital for these types of projects.

14. Other issues that the interviewee finds relevant

INDUSTRIAL

1. Describe the particular needs for thermal energy of your business. Specify if process heating and cooling is required.

2. What are the current energy sources for thermal purposes?

3. Describe your company's internal decision making process for energy-related projects.
   [Who would be involved? Who would make the decision? Budget or operational expenses? Priority compared to other investment projects?]

4. Suppose that the energy infrastructure of you company is old and has to be replaced. What would be the most important considerations to make for your company?
   [Clues: Investment costs, operational costs, limitations of existing building, ease of use, financing .. Consult List 2]

5. Which of these technologies would you consider when you have to replace your existing thermal energy solution and why?
   - **A.** Air Source Heat Pumps
   - **B.** Ground Source Heat Pumps
   - **C.** Solar Hot Water
   - **D.** Bioenergy such as wood pellets
   - **E.** Biogas
   - **F.** District Energy
   - **G.** Natural Gas
   - **H.** Fuel oil/heating oil/propane

6. Have you been involved in a Renewable Thermal Technology project before? Tell us about it.
   [Clues: Type of project, e.g., replacing furnace, renovate heating system, facilitating for the utilization of waste heat, energy efficiency measures for thermal purposes]

7. Describe the process leading up to the point of investing in the technology?
   [Clues: What initiated the process? Where did you search information? Referrals? What caught interest? What made you decide?]

8. What was your experience from investing and installing this device?
   [Clues: Easy to find information, ease to orient her/himself in the market, available installers, competent installers, financing, costs as expected, need for adaptations of building or heating system. Consult List 2 and ask the interviewee to elaborate if necessary]

9. What is your experience from operating this device?
   [Clues: Ease of use, energy costs, response from others, availability of fuel. Consult List 2 and ask the interviewee to elaborate if necessary]

10. What is most important to your organization when considering an energy technology investment?
    [Clues: Guaranteed cost savings, 100 % upfront financing, expert advice, high internal rate of return, low operational costs, fast recovery of investment through lower annual energy bills]

11. Describe your organization’s ability to access capital for these types of projects.

12. Other issues that the interviewee finds relevant

INTERVIEW GUIDE – INSTALLERS

INTRODUCTION

This interview is part of the project "Feasibility of renewable thermal technologies in Connecticut", which is a cooperation between Yale University, Yale Center for Business and the Environment, the Connecticut Department of Energy and Environmental Protection, the Connecticut Green Bank, Eversource and United Illuminating. The purpose of the project is to determine a realistic contribution from renewable thermal technologies to achieve Connecticut's overall target of reducing greenhouse gases, and what factors make customers invest or not invest.

Renewable thermal technologies (RTTs) are technologies that use renewable energy resources to provide heating and cooling. RTTs can deliver domestic hot water, process heating, space heating and space cooling. These needs are normally served by petroleum, natural gas or electricity today. For the purpose of this project, the following RTTs are included:

- Air Source Heat Pumps and Ground Source Heat Pumps
- Devices burning biomass such as wood chips and wood pellets
- Biofuels such as biogas and biodiesel
- Solar thermal such as solar water heaters
- Waste heat recovery technologies

The purpose of this interview is to get a deeper insight into what makes customers decide to invest in these technologies or not. The project covers residential, commercial and industrial customers. **[Focus for installers: What do installers experience as the most important factors influencing on customer decisions investing in thermal technologies or not?]**

The interview is estimated to last 45 to 60 minutes. Is it OK for you if we record the interview? The audiotape will be destroyed after the study is finalized.

The answers will be treated as confidential, and we will seek your approval for any quotations we wish to publish. You are free to end the interview at any time.

QUESTIONS

1. What types of thermal technologies does your company install?

2. How many projects did your company have the 1) last year, 2) last 5 years?
   - **A.** Air Source Heat Pumps
   - **B.** Ground Source Heat Pumps
   - **C.** Solar Hot Water
   - **D.** Bioenergy such as wood pellets
   - **E.** District energy
   - **F.** Natural Gas
   - **G.** Fuel oil/heating oil/propane

3. What kind of customers do you serve?
   [Clues: Residential, Commercial, Industrial. Type of buildings. Public vs private]

4. Are there particular challenges you see in delivering Renewable Thermal Technology to each of these groups?
   [Clues: Lack of awareness, prejudices, physical limitations of buildings, capital restraints, alternative source is cheaper. Consult List 2 for more]

5. Describe the trends you see in the industry.
   [Clues: Which technologies are currently thriving/struggling? What do you experience as being important to your customers? Competition in the industry? Quality of work?)

6. What do you think about the reputation and position of Renewable Thermal Technologies in the renewable energy sector?
   [Considered environmentally friendly? Easy to use? Comfortable? Low energy costs? Energy savings? Innovative and modern?]

7. How would you describe these technologies when you advise your customers who need to replace their existing boiler?
   - **A.** Air Source Heat Pumps
   - **B.** Ground Source Heat Pumps
   - **C.** Solar Hot Water
   - **D.** Bioenergy such as wood pellets
   - **E.** District energy
   - **F.** Natural Gas
   - **G.** Fuel oil/heating oil/propane

8. What is your process on advising customers on heating and cooling solutions?
   [Clues: What types of questions do you ask and what are the main considerations for advising one technology over another?]

9. What are the most important factors that make your customers wishing to install Renewable Thermal Technologies?
   [Consult List 2 for examples if necessary]

10. What are the most important factors that make your customers hesitant to install Renewable Thermal Technologies?
    [Consult List 2 for examples if necessary]

11. Are there credit or incentive programs that your firm is offering to customers? Is financing an option? Which of these programs work well? Which don't work well?

12. Describe how you train your staff to install new Renewable Thermal Technologies

13. Other issues that the interviewee finds relevant

INTERVIEW GUIDE – INDUSTRY ASSOCIATIONS

INTRODUCTION

This interview is part of the project "Feasibility of renewable thermal technologies in Connecticut", which is a cooperation between Yale University, Yale Center for Business and the Environment, the Connecticut Department of Energy and Environmental Protection, the Connecticut Green Bank, Eversource and United Illuminating. The purpose of the project is to determine a realistic contribution from renewable thermal technologies to achieve Connecticut's overall target of reducing greenhouse gases, and what factors make the customers invest or not invest.

Renewable thermal technologies (RTTs) are technologies that use renewable energy resources to provide heating and cooling. RTTs can deliver domestic hot water, process heating, space heating and space cooling. These needs are normally served by petroleum, natural gas or electricity today. For the purpose of this project, the following RTTs are included:

- Air Source Heat Pumps and Ground Source Heat Pumps
- Devices burning biomass such as wood chips and wood pellets
- Biofuels such as biogas and biodiesel
- Solar thermal such as solar water heaters
- Waste heat recovery technologies

The purpose of this interview is to get a deeper insight into what makes customers decide to invest in these technologies or not. The project covers residential, commercial and industrial customers. **[Focus for Industry Associations: What does the industry generally experience as barriers and drivers to RTTs?]**

The interview is estimated to last 45 to 60 minutes. Is it OK for you if we record the interview? The audiotape will be destroyed after the study is finalized.

The answers will be treated as confidential, and we will seek your approval for any quotations we wish to publish. You are free to end the interview at any time.

1. How would you describe the technologies for heating and cooling that you are aware of?
   [If necessary, mention the alternatives]

2. From your perspective, what are the most important factors restricting investments in Renewable Thermal Technologies?
   [Ask the interviewee to answer both for RTTs generally, and for the technology he/she represents specifically. Consult List 2 if necessary to give examples]

3. From your perspective, what factors have to be in place in order for Renewable Thermal Technologies to be the preferred choice of customers in the future?
[Follow up: Are these factors different for the technology you represent compared to other renewable energy technologies? Consult List 2 if necessary to give examples]

4. What do you regard as the advantages and disadvantages of district energy systems vs distributed energy technologies?

5. What do you regard as critical success factors in order for district energy systems to be realized (as contrasted with distributed energy technologies)?

6. How do you forecast the overall market size for the technology you represents?

7. How well do customers (residential, commercial, industrial) understand Renewable Thermal Technologies and recognize these technologies as viable options when making decisions?

8. In your opinion, what are the most important challenges facing the industry you represent?
[Clues: Competence of installers, regulations, costs, awareness of customers. Consult List 2 for more examples if necessary]

9. Which companies, in terms of manufacturers, distributors, and installers, are the main players in [the technology represented by the interviewee] ? How were they able to differentiate themselves?

10. What makes [the technology represented by the interviewee] attractive relative to other technologies, such as natural gas?

11. How easy is it for customers to access information on Renewable Thermal Technologies? Where do you send customers who are looking for information?

12. Other issues that the interviewee finds relevant

Appendix 3 – Stakeholders Participating in the Study

TYPE OF STAKEHOLDER	# INTERVIEWED	DESCRIPTION OF EACH INTERVIEWEE
Residential customer	5	• Environmentally conscious single family renovating their recently bought home. Unfamiliar with oil. Simultaneous measures: energy efficiency, ground source heat pumps (GSHP), solar thermal, and PV. Received incentives • Single family renovating their recently bought home. Unfamiliar with oil. Simultaneous measures: energy efficiency, GSHP, solar PV, ductwork. Received incentives • Single family considering different renewable energy options, particularly solar PV, and air source heat pump (ASHP). Considering selling their house in the near future, and expecting increased salability with cooling. No incentives • Single family having done measures over 18 years. Received incentives for solar PV and solar hot water. Replaced the oil boiler with a gas boiler connected to the grid • Multi-family with GSHP installed when the apartment building was being built. Received incentives
Commercial customer	6	• University close to a waste heat source • University with own energy provision, both electricity and thermal. Sources from natural gas, thermal grid, GSHP, and solar thermal • Municipality with several unexploited waste heat sources available and long-term sustainability plan • Museum having installed GSHP with incentives. Several sources covering different parts of the building. • Public School. Department investing in new schools and refurbishments, leaning toward LEED. • City with coordinated energy efficiency effort across commercial customers
Industrial customer	2	• Industrial customer utilizing jacket water rand exhaust and turning it into space heating, space and process cooling • Industrial customer owned by private equity

Installers	5	• Installer of geothermal systems based on an ESCO model. Focus on district energy • Regional installer of bioenergy installations primarily in residential buildings. Does also install oil and gas boilers • Installer of solar thermal, mostly hot water, but also cooling and dehumidification. Both residential and commercial customers • Installer of solar thermal, mainly in residential buildings. Has also done installations for low-income buildings and an industrial customer • Installer of solar thermal water heating, geothermal, ASHP, and ductless ASHP
Financing institutions	3	• Public and private companies providing financial incentives for selected RTTs in Connecticut
Other stakeholders	4	• Regulator • Project developer of district energy based on waste heat • Industry association • Manufacturer of pellets and wood chip boilers

Appendix 4 – Summary of the Workshop

RTT BARRIERS AND DRIVERS SOLUTIONS WORKSHOP: SYNTHESIZED FINDINGS

Problem Statement 1: RTT financing should be a profitable investment for both customers and lenders, and should be scalable and repeatable.

Problem Statement 2: The RTT market should allow customers and installers to discover RTTs as an energy option, and make the value RTTs can provide obvious to all stakeholders.

MARKET-LEVEL SOLUTIONS

- Metering technology and reporting processes should be standardized to facilitate transparency in system performance and comparability across installations (all RTTs)
- To alleviate the policy risk of incentives disappearing after a large capital investment, customers should have assurance that earlier adopters will be grandfathered in the event incentives are phased out
- Bundling energy efficiency and other investments with RTT investments maximizes co-benefits and improves the financial viabiltiy of projects
- A Thermal Renewable Energy Credit (T-REC) should be instituted to provide positive cashflow for financing, and to make RTT benefits salient

CUSTOMER CLASS-SPECIFIC SOLUTIONS

Residential

- Simple, readily-available financing packages, standard offers
- RTT financing should consist of lease and loan products
- Dealer and installer education and support programs
- Awareness campaign: RTT education and technology discovery
- Streamlined, integrated marketing materials on Energize CT website
- Partner with suppliers: Home Depot/Lowes, contractor networks to increase availablity of RTT technologies and expertise
- Integrate RTT system sizing/suitability analysis into HES audits

Commercial

- Promote performance-based contracts with installers/manufacturers
- Compile and publish best practices and case studies
- Bundle off-the-shelf equipment, financing, and incentives
- Developed standardized installation and financing contracts

Industrial

- State-level tax credits linked to CAPEX
- Compile and publish best practices and case studies
- C-PACE financing
- Develop industrially-focused marketing campaign
- Tailor financing and technology bundles to subsets of industry, to account for heterogeneity across energy demands
- Make RTT available through ESCOs to increase visibility and profliferation
- Pilot projects for new classes of industrial customers

RTT BARRIERS AND DRIVERS SOLUTIONS WORKSHOP: MAPPING TO BARRIERS AND DRIVERS

MAIN BARRIERS

BARRIER	RECOMMENDATIONS
High upfront costs RTTs require significant upfront capital investments to install, while the benefits they provide accrue over the long-term life of the technology	• Simple, readily-available financing packages, standard offers • RTT financing should consist of lease and loan products • State-level tax credits linked to CAPEX • To alleviate the policy risk of incentives disappearing after a large capital investment, customers should have assurance that earlier adopters will be grandfathered in the event incentives are phased out • A Thermal Renewable Energy Credit (T-REC) should be instituted to provide positive cashflow for financing, and to make RTT benefits salient • C-PACE financing • Tailor financing and technology bundles to subsets of industry, to account for heterogeneity across energy demands • Create financial mechanism to smooth cash flows of large capital investments (e.g. allow for realization of ITC before tax filing)
Lack of knowledge The economic and technical advantages RTTs can provide are not salient and obvious to customers. The performance of a RTT system is not immediately tangible to customers. RTTs are disadvantaged from a general market-awareness perspective.	• Metering technology and reporting processes should be standardized to facilitate transparency in system performance and comparabiity across installations (all RTTs) • Integrate RTT system sizing/suitability analysis into HES audits • Streamlined, integrated marketing materials on Energize CT website • Develop cross-channel marketing campaigns tailored to customer segments • Bundling energy efficiency and other investments with RTT investments maximizes co-benefits and improves the financial viability of projects • Awareness campaign: RTT education and technology discovery for uninformed customers new to the energy space

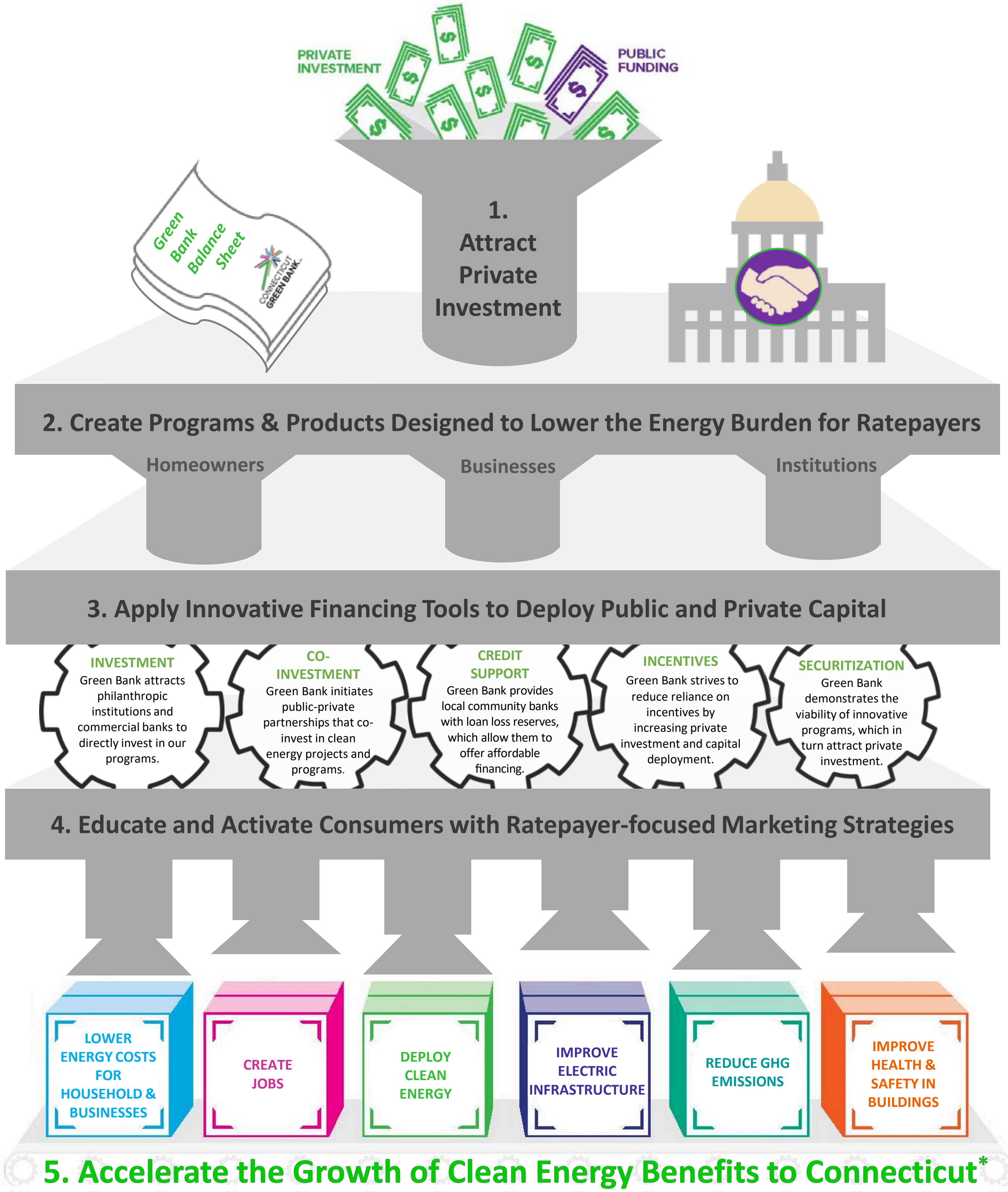
BARRIER	RECOMMENDATIONS
Installer business models not supported for RTT growth Installers in the RTT space are disadvantaged relative to competing energy technologies. Current business models favor fossil energy technologies and create limited opportunities for customers to discover RTTs and installers skilled in their installation.	• Dealer and installer education and support programs • Promote performance-based contracts with installers/manufacturers • Compile and publish best practices and case studies • Develop standardized installation and financing contracts • Make RTT available through ESCOs to increase visibility and proliferation • Pilot projects for new classes of industrial customers • Bundle off-the-shelf equipment, financing, and incentives • Partner with suppliers: Home Depot/Lowes, contractor networks to increase availablity of RTT technologies and expertise • Continue utility programs of subsidizing energy efficient or RTT equipment upstream
Split incentives hinder logical investments in RTT Split incentives render irrelevant business cases for RTTs that make financial sense. Residential, commercial, and industrial rental properties provide limited opportunities for investment benefits to accrue to energy users who stand to benefit.	• Create advertising platform/marketing materials for landlords to market energy-efficient apartments • Require disclosure of expected energy costs in lease signings/listings

MAIN DRIVERS

DRIVER	RECOMMENDATIONS
Climate policy Climate and environmental policies can create demand for renewable thermal technology implementations.	• Restructure CT Renewable Portfolio Standards to include RTTs
New services RTT installations are particularly successful when they provide new incremental services to the customer (e.g. geothermal provides cooling to a residential customer previously without air conditioning)	• Target customers that stand to make incremental gains from the installation of RTTs (e.g. target customers without air conditioning for geothermal installations) • Bundle RTTs or sell as part of packaged solutions to maximize value provided • Market the ability RTTs have to provide improved thermal comfort (residential customers) or low-cost incremental heating and cooling (air source heat pumps)
Financial Structures Tax code-based subsidies encourage investment in RTTs by reducing high upfront capital costs.	• The Federal Investment Tax Credit should be extended to cover geothermal heat pumps at the same level of support given to Solar PV and Solar Hot Water • State-level tax credits can make up for gaps in RTT subsidies absent in current ITC • Informational resources should be created to help business and customers discover available incentives and simplify the process of getting them • Production-based subsidies: T-RECs or similar to Production Tax Credit • Promote performance-based contracts with installers/manufacturers • Financial products: loans, leases, C-PACE financing • Subsidies for geothermal??

Connecticut Green Bank

Economic Development Engine



*Benefits since the creation of the Connecticut Green Bank in 2011

CONNECTICUT
GREEN BANK℠

Key Performance Proof Points

By the time the Connecticut Green Bank celebrated its **5** year anniversary, it:

- **mobilized** over **$1 billion of investment** by
- achieving a **10:1 leverage ratio** in Connecticut's clean energy economy, that
- created nearly **13,000 direct, indirect, and induced jobs,** which
- **reduced the energy burden on over 20,000 households and businesses**.
- **Deployed over 200 MW of renewable energy,** that
- **reduced over 2.5 million metric tons of CO2 emissions** over the life of the projects.