Fuel-Fired Heat Pumps

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Background

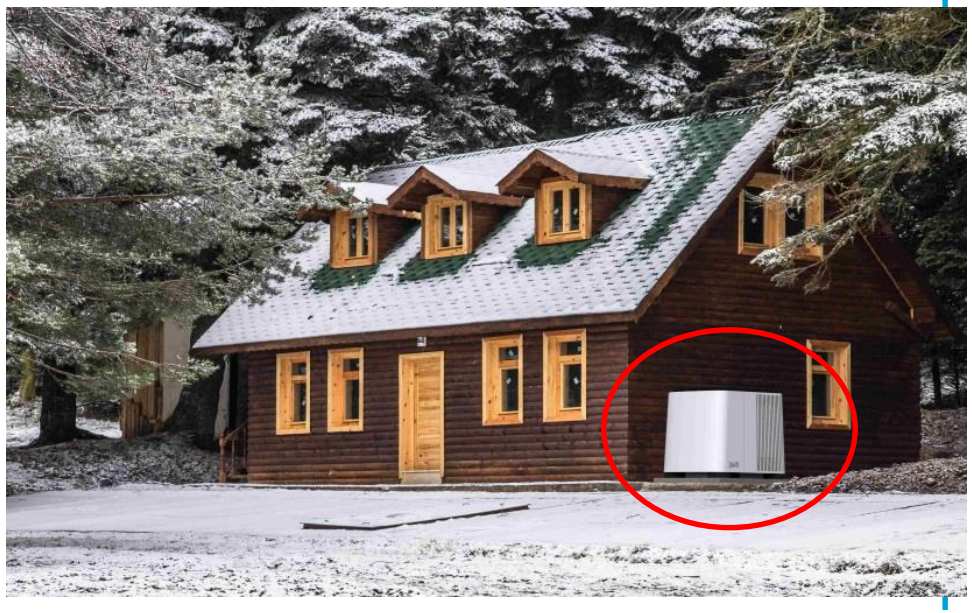
Under a NORA R&D contract – SMTI is developing a liquid fuel-fired version of their gas-fired ammonia water absorption heat pump.

Basic feasibility has been demonstrated.

Longer term combustion tests with a modulating air-atomized (Babington) burner are planned with No. 2 oil and biodiesel.

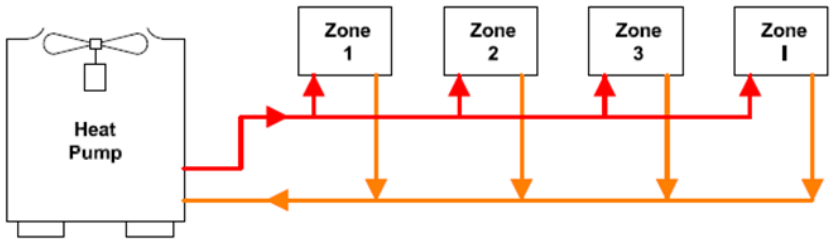
Thermally Driven Heat Pump (TDHP)

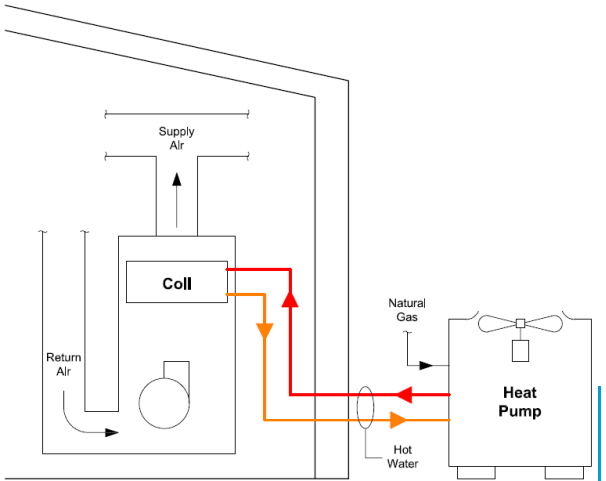
- **Warm Comfort:** useable in all heating system types
- **All Climates**: **perfect for cold weather!**
- **All Fuels:** natural gas, propane, **fuel-oil, bio-fuels**
- **Very High Fuel Efficiency**: 145% (COP)
- **Natural Refrigerant** (GWP = 0)



Many Uses:

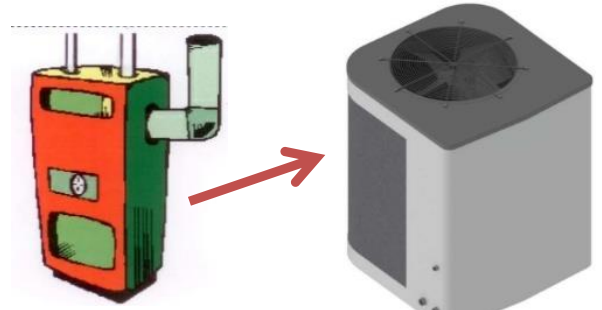
- ✓ *Residential Space Heating*
- ✓ *Residential Water-heating*
- ✓ *Commercial Water Heating*
- ✓ *Commercial Space-heating*
- ✓ *Pool Heating*





Why develop TDHPs?

- TDHPs can directly replace existing furnace or boiler, and water heater technologies; **(30-50% <u>cost</u> / <u>energy</u> / <u>emission</u> reduction)**
- EHP technology inefficient and/or struggles to heat in cool/cold climates.
- Economically superior to EHPs in heating applications.
- A more cost effective mass-scale method of achieving emission reduction goals in building heat, compared to EHPs.



SMTI Prototype Programs, 3rd Party Verification, Field Testing

10 kBth

20 kBth

80 kBth

140 kBth

gti

UTD Utilization Technology Development

U.S. DEPARTMENT OF ENERGY

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neea

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SMTI: a B2B Business Model

Thermal Compressor

Sell To

HVAC & WH OEMS

End Use Products

- ✓ Partners, not competitors
- ✓ Maximize existing brand & marketing power
- ✓ Least-cost, Fastest-to-market, Lowest-risk pathway to Product Differentiation

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Market Segments: Residential “Combi” Test - #1

- Single family home in Northeast Tennessee
- Operational since March 2016 (logged ~3500 hrs)
- “Combi” application (space-heat and hot water). Replaced a warm-air furnace & storage hot water tank
- No complaints from owner who “loves” the slow steady heat and almost endless hot water
- No issues during coldest nights (0°F)

Market Segments: Residential “Combi” Test - #2

- Single family home in West-Central Wisconsin
- Operational since March 2018 (logged ~1000 hrs)
- “Combi” application (space-heat and hot water). Replaced a warm-air furnace & storage hot water tank

Modeling Study - Technologies Investigated

- Standard Boiler – 78% efficient
- Condensing Furnace – 92% efficient
- Standard Electric Air Conditioner (EAC) – 14 SEER
- Standard Electric Heat Pump (EHP) – 14 SEER/8.2 HSPF
- Cold Climate Electric Heat Pump (CC-EHP) – 18 SEER/12 HSPF
- Resistance Heaters – 100% efficient

Note: Performance curves for EAC/EHPs taken from published data of commercially available systems

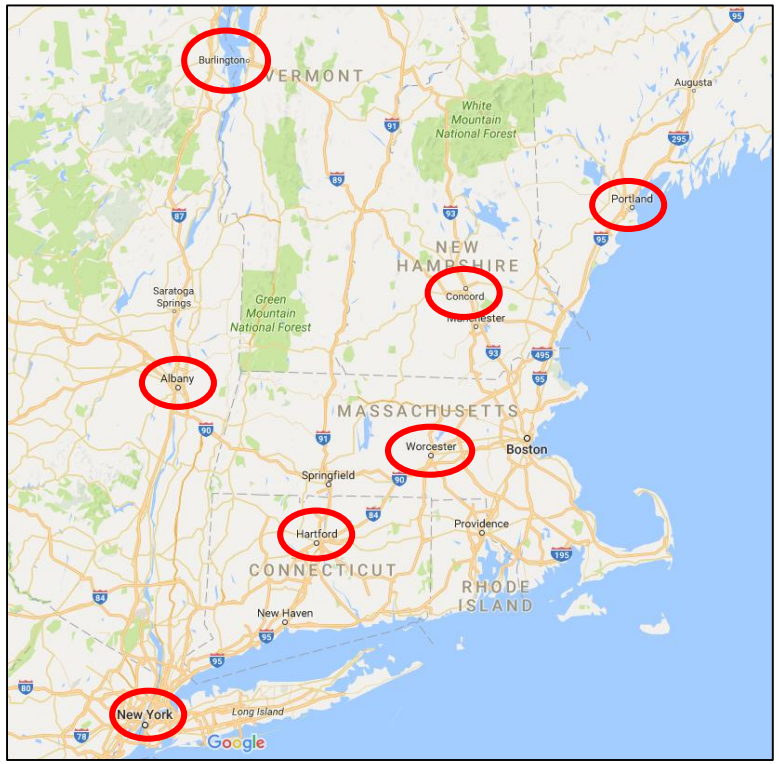
Configurations Investigated

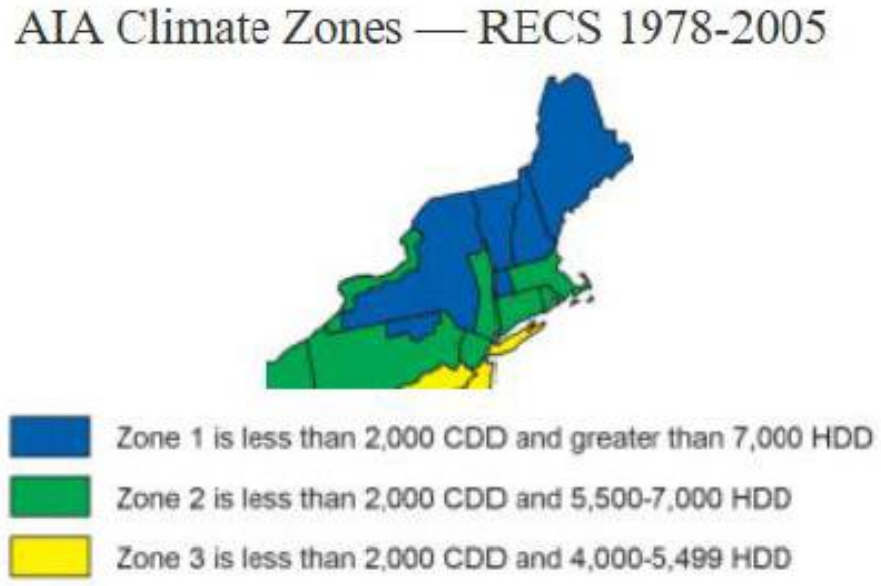
- 12 cases investigated (Combined heating and cooling systems)
  - 2 baseline configurations
  - 2 Reversible LF-AHP configurations
  - 2 Heating only LF-AHP configurations
  - 3 Standard EHPs configurations
  - 3 CC-EHPs configurations

Heating/cooling systems	Indoor heating/cooling equipment
Standard Boiler, 14 SEER AC	Radiator Coupled, mini-split
Condensing furnace, 14 SEER AC	Air Handler Coupled
Reversible LF-AHP	Radiator coupled, zoned fan coils
Reversible LF-AHP	Air Handler Coupled
Heating Only LF-AHP, 14 SEER AC	Air Handler Coupled
Heating Only LF-AHP, 14 SEER AC	Radiator coupled, mini-split
14 SEER/8.2 HSPF EHP with Boiler Back-up	Radiator Coupled, mini-split
14 SEER/8.2 HSPF EHP with Furnace Back-up	Air Handler Coupled
14 SEER/8.2 HSPF EHP with Resistance Back-up	Air Handler Coupled
18 SEER/12 HSPF CCEHP with Boiler Backup	Radiator Coupled, mini-split
18 SEER/12 HSPF CCEHP with Furnace Backup	Air Handler Coupled
18 SEER/12 HSPF CCEHP with Resistance Backup	Air Handler Coupled

Locations Investigated – Climate Zones

- Seven Cities Across the Northeast
- Represent the full range of climates in the Northeast
  - Zone 1 - Portland, ME; Concord, NH; Burlington, VT
  - Zone 2 - Hartford, CT;; Albany, NY; Worcester, MA
  - Zone 2/3 - New York City, NY





Locations Investigated – Utility Pricing and Building Information

- Small variation in the price of heating oil
  - $2.049 to 2.753/gallon
  - ±15% wrt $2.401/gal
- Significant Variation in the price of electricity
  - $0.0694 to 0.2321/kWh
  - ±54% wrt $0.151/kWh

Location	Heating Oil Price, $/Gal	Electricity price, $/kWh	AIA Climate Zone
Portland, Maine	2.049	0.0694	1
Hartford, Connecticut	2.482	0.1267	2
New York City, New York	2.753	0.2321	2/3
Albany, New York	2.462	0.1100	2
Concord, New Hampshire	2.231	0.1392	1
Burlington, Vermont	2.309	0.1558	1
Worcester, Massachusetts	2.390	0.1313	2

Note: Prices from 2016-2017 heating season

Results –Source Based Energy Savings, Boiler Baseline

- Heating Only LF-AHP with 14 SEER Minisplit configuration offers the highest annual source energy savings except for Hartford, CT (within 205 kWh)
- Reversible LF-AHP had lowest annual source based energy savings except for in Burlington, VT

Baseline Heating/ Cooling System	Radiator Based System with Standard Boiler, 14 SEER Minisplit AC			
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Minisplit	14 SEER Minisplit Heat Pump with Boiler Back-up	18 SEER 5 RT Cold Climate Heat pump with Boiler Backup
Location	**Annual Source-Based Energy Savings, kWh**			
Portland, ME	5,371	15,657	7,465	14,275
Hartford, CT	2,072	14,316	6,969	14,521
NYC, NY	-1,300	11,280	4,717	7,795
Albany, NY	4,759	16,357	6,941	14,865
Concord, NH	5,744	16,704	6,550	14,842
Burlington, VT	7,132	17,980	7,124	15,348
Worcester, MA	5,286	15,898	8,121	15,830

Results –Source Based Energy Savings, Furnace Baseline

- Heating Only LF-AHP with 14 SEER EAC configuration offers the highest annual source energy savings in all cases
- The Standard EHP with resistance back-up had lowest annual source based energy savings for all cases

Baseline Heating/ Cooling System	Forced Air System with Condensing Furnace, 14 SEER Central AC					
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Central AC	14 SEER Electric Heat Pump with Furnace Back-up	14 SEER Electric Heat Pump with Resistance Back-up	18 SEER 5 RT Cold Climate Heat pump with Furnace Backup	18 SEER 5 RT Cold Climate Heat pump with Resistance Backup
Location	**Annual Source-Based Energy Savings, kWh**					
Portland, ME	687	10,890	5,083	-25,013	8,703	975
Hartford, CT	-2,161	10,022	4,744	-21,348	9,185	4909
NYC, NY	-4,596	7,964	2,205	-18,743	3,409	2629
Albany, NY	-85	11,438	4,664	-28,937	8,651	4035
Concord, NH	707	11,567	4,509	-32,027	8,833	148
Burlington, VT	1,680	12,403	4,953	-35,684	9,173	-3658
Worcester, MA	608	11,162	5,515	-21,760	9,630	7566

Results – CO2e Savings, Boiler Baseline

- CC-EHP with Boiler Back-up offers highest savings for all cases when ULS Fuel is assumed
- Heating Only LF-AHP with 14 SEER Minisplit configuration offers second highest savings for all locations
- Reversible LF-AHP configuration is lowest for all locations

Baseline Heating/ Cooling System	Radiator Based System with Standard Boiler, 14 SEER Minisplit AC			
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Minisplit	14 SEER Minisplit Heat Pump with Boiler Back-up	18 SEER 5 RT Cold Climate Heat pump with Boiler Backup
Location	**Annual CO2e Savings (ULS Fuel + Non-Baseload Electricity), lbm**			
Portland, ME	2,695	8,945	5,943	12,358
Hartford, CT	692	8,169	5,537	12,128
NYC, NY	-1,674	6,502	5,339	8,966
Albany, NY	2,322	9,292	5,323	12,477
Concord, NH	2,891	9,552	5,212	13,126
Burlington, VT	3,703	10,292	5,613	13,547
Worcester, MA	2,610	9,064	6,452	13,692

Results – CO2e Savings, Furnace Baseline

- CC-EHP with Furnace Back-up offers highest savings for all but one cases when ULS Fuel is assumed

Baseline Heating/ Cooling System	Forced Air System with Condensing Furnace, 14 SEER Central AC					
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Central AC	14 SEER Electric Heat Pump with Furnace Back-up	14 SEER Electric Heat Pump with Resistance Back-up	18 SEER 5 RT Cold Climate Heat pump with Furnace Backup	18 SEER 5 RT Cold Climate Heat pump with Resistance Backup
Location	**Annual CO2e Savings (ULS Fuel + Non-Baseload Electricity), lbm**					
Portland, ME	40	6,245	4,582	-1,967	9,233	13,884
Hartford, CT	-1,707	5,737	4,268	-1,407	9,138	8,205
NYC, NY	-3,557	4,608	3,908	-1,059	6,498	6,312
Albany, NY	-414	6,516	4,026	-5,451	9,002	7,699
Concord, NH	34	6,641	4,036	-3,918	9,756	7,861
Burlington, VT	609	7,130	4,361	-4,488	10,080	7,346
Worcester, MA	-39	6,383	4,968	-965	10,221	9,770

Results – CO2e Savings with B100 – Boiler Baseline

- Heating Only LF-AHP with 14 SEER EAC configuration offers the highest annual CO2e savings in all cases
- Standard EHP and CC-EHP cases have CO2 losses compared to a conventional boiler

Baseline Heating/ Cooling System	Radiator Based System with Standard Boiler, 14 SEER Minisplit AC			
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Minisplit	14 SEER Minisplit Heat Pump with Boiler Back-up	18 SEER 5 RT Cold Climate Heat pump with Boiler Backup
Location	***Annual CO2e Savings (B100 Fuel + Non-Baseload Electricity), lbm**			
Portland, ME	1,309	2,835	-161	-1,203
Hartford, CT	819	2,602	-140	-824
NYC, NY	420	2,042	-1,002	-1,758
Albany, NY	1,345	2,911	-565	-2,614
Concord, NH	1,392	3,017	-139	-1,501
Burlington, VT	1,626	3,238	-101	-1,528
Worcester, MA	1,327	2,896	-162	-1,323

*Note: CO_{2e} values assume base technology is also using B100

Results – CO2e Savings with B100 – Furnace Baseline

- Heating Only LF-AHP with 14 SEER EAC configuration offers the highest annual CO2e savings in all cases
- Standard EHP and CC-EHP cases have CO2 losses compared to a condensing furnace

Baseline Heating/ Cooling System	Forced Air System with Condensing Furnace, 14 SEER Central AC					
Replacement Technology	Reversible LF-AHP	Heating only LF-AHP and 14 SEER Central AC	14 SEER Electric Heat Pump with Furnace Back-up	14 SEER Electric Heat Pump with Resistance Back-up	18 SEER 5 RT Cold Climate Heat pump with Furnace Backup	18 SEER 5 RT Cold Climate Heat pump with Resistance Backup
Location	**Annual CO2e Savings (B100 Fuel + Non-Baseload Electricity), lbm**					
Portland, ME	442	1,952	-592	-15,637	-2,264	-6124
Hartford, CT	34	1,805	-545	-13,591	-1,844	-3,979
NYC, NY	-189	1,429	-1,468	-10,294	-2,594	-2,922
Albany, NY	462	2,012	-966	-19,483	-3,792	-6,334
Concord, NH	462	2,066	-500	-18,761	-2,645	-6,982
Burlington, VT	621	2,206	-483	-20,792	-2,701	-8,958
Worcester, MA	459	2,016	-639	-14,276	-2,509	-3,540

*Note: CO_{2e} values assume base technology is also using B100

Installation Configurations Investigated

- Pricing determined based on several factors
  - Equipment pricing for Furnaces, Boilers, 14 SEER EHP, 18 SEER CC-EHP
  - Equipment pricing estimates for LF-AHP (including supply chain mark-ups)
  - Feedback from contractors in the Northeast
- For LF-AHP
  - Hybrid - LF-AHP and EAC integrated in same box (1 unit to be installed)
  - Separate – LF-AHP and EAC installed separately (2 units to be installed)

Installation Configurations Investigated

	Heating Equipment	Cooling Equipment	TOTAL Installed Cost, USD
Baseline Systems	Standard Boiler - Radiator	14 SEER EAC, Minisplit	$13,250
	Condensing Furnace	EAC, Forced Air	$10,350
Hybrid	LF-AHP, Radiator	14 SEER EAC, zoned	$13,800
	LF-AHP, Forced Air	14 SEER EAC, Forced Air	$12,600
Separate Systems	LF-AHP, Radiator	14 SEER EAC, Minisplit	$15,750
	LF-AHP, Forced Air	14 SEER EAC, Forced Air	$12,650
	12 HSPF CCEHP with Boiler backup	18 SEER EAC, Minisplit	$22,250
	12 HSPF CCEHP with Furnace backup	18 SEER EAC, Forced Air	$18,050
	12 HSPF CCEHP with Resistance backup	18 SEER EAC, Forced Air	$14,050

Results – Simple Payback

- LF-AHP configurations offer reasonable paybacks for both standard boiler and condensing furnace replacement
- CC-EHP does not offer a reasonable payback in almost all cases

Baseline Heating/ Cooling System	Radiator Based System with Standard Boiler, 14 SEER Minisplit AC			Forced Air System with Condensing Furnace, 14 SEER Central AC			
Replacement Technology	Hybrid LF-AHP/14 SEER AC	Heating only LF-AHP and 14 SEER AC	18SEER- 12 HSPF CCEHP with Boiler backup	Hybrid LF-AHP/14 SEER AC	Heating only LF-AHP and 14 SEER AC	18SEER-12 HSPF CCEHP with Furnace backup	18SEER-12 HSPF CCEHP with Resistance backup
Location	**Payback Period, Years**						
Portland, ME	0.8	3.6	8.6	4.7	4.8	9.5	5.0
Hartford, CT	0.7	3.4	9.8	4.3	4.4	12.0	7.6
NYC, NY	0.9	3.9	Never*	5.0	5.1	Never*	Never*
Albany, NY	0.6	2.9	7.8	3.8	3.8	9.3	5.2
Concord, NH	0.7	3.3	14.0	4.2	4.3	20.9	Never*
Burlington, VT	0.6	3.0	15.5	3.9	3.9	Never*	Never*
Worcester, MA	0.7	3.2	10.0	4.1	4.1	13.0	7.3

*Never indicates payback over 25 years

Conclusions

- The Heating only LF-AHP with EAC for cooling offered the highest source energy savings when replacing a standard boiler or furnace in all locations
- Local electricity costs determined whether the LF-AHP/EAC combination or the CCEHP with Fuel Fired Backup provided the lowest operating cost
- B100 offers the potential for LF-AHPs and baseline equipment to offer lower C02e emissions than CC-EHP technologies
- Hybrid and Separate LF-AHP system offered reasonable paybacks
- CCEHP could not offer reasonable paybacks and had higher 15 year total cost
- Reversible LF-AHP performance limited by Cooling COP

Full Study

Keinath, C., Butcher, T., and Garrabrant, M., *Energy, Cost and CO_{2e} Analyses of Reversible, Hybrid, and Heating-Only LF-AHP in the Northeast*, ASHRAE HO-18-C038, presented at ASHRAE Annual Meeting, Houston, June 2018.