ENERGY STAR® Products Partner Meeting 2020

Appliances | Electronics | Electric Vehicle Chargers | HVAC | Lighting | Smart Home Energy Management Systems | Smart Thermostats | Water Heaters

Heat Pump Technology Enables Most Efficient Water Heaters and Clothes Dryers

October 29, 2020

Speakers

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Navitas Partners

Moderator

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Heat Pump Dryers

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Business Development Manager - Utility Sector

Heat Pump Water Heaters

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Heat Pump Technology

Thank You ------ Q&A

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Heat Pump Dryers

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Heat Pump Water Heaters

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Heat Pump Water Heaters

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Heat Pump Technology Potential

Kyle Gluesenkamp, PhD
Senior R&D Scientist
Oak Ridge National Laboratory

Presented to ENERGY STAR Product Partners Meeting
Heat Pump Technology Enables Most Efficient Water Heaters and Clothes Dryers session
October, 2020

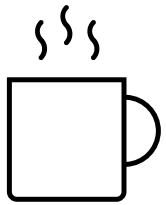
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

What is a heat pump?

- The "pump" analogy:

Water	Heat
High things fall (gravity)	Hot things cool (dispersion of kinetic energy)
Pumping water uphill takes work	Pumping heat to higher temperature takes work
More height diff. = more lift	More temp. diff. = more lift
Work = (amount of water)*(lift) Work = m*g*Δh	Work = (amount of heat)*(lift)/(temp) Work = Q*ΔT/T



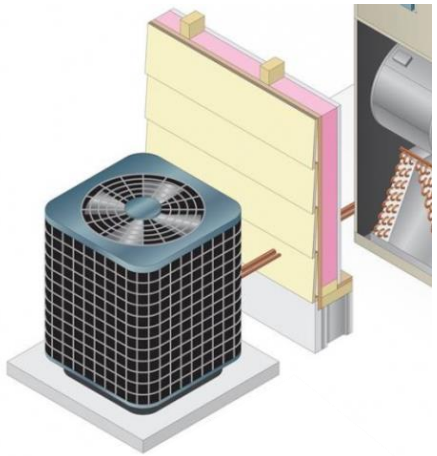
What is a heat pump?

In common usage in the US:

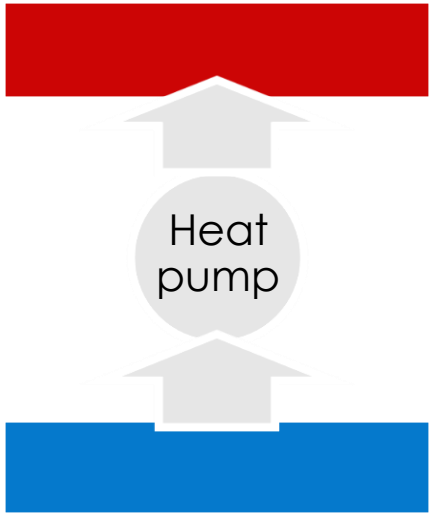
A vapor compression system that provides space heating or water heating

In a more universal sense:

A device that moves heat from low to high temperature



- Heat pump applications:
  - AC, fridge, space heating, water heater, dryer, dishwasher, etc.
- Heat pump types:
  - vapor compression
  - non-vapor compression



Potential and Limits

- Limits of heat pump efficiency:
  - Some well defined by thermodynamics
  - Some open research areas

- Potential heat pump applications:
  - Infinite creativity possible
    - New cycles
    - New applications

My goals for my talk today:

- **Educate** our ESTAR community about heat pumps

- **Inspire** creative thinking about the future of heat pumps

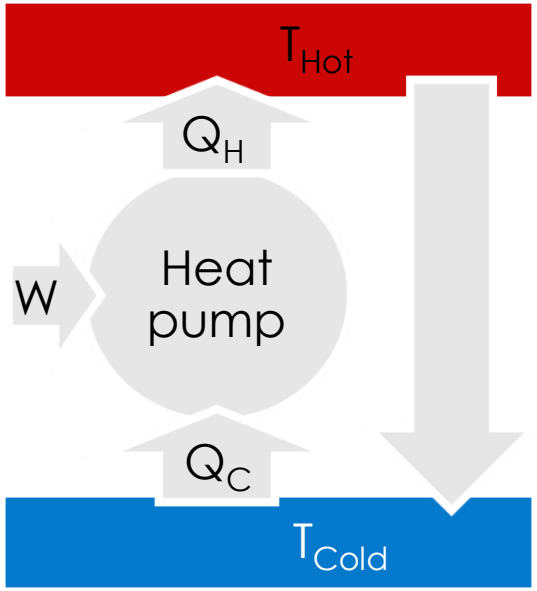
Carnot limits

Coefficient of performance

- COP = Q/W
- Carnot limit:

$$COP_{H,Carnot} = \frac{T_{Hot}}{T_{Hot} - T_{Cold}}$$

$$COP_{C,Carnot} = \frac{T_{Cold}}{T_{Hot} - T_{Cold}}$$



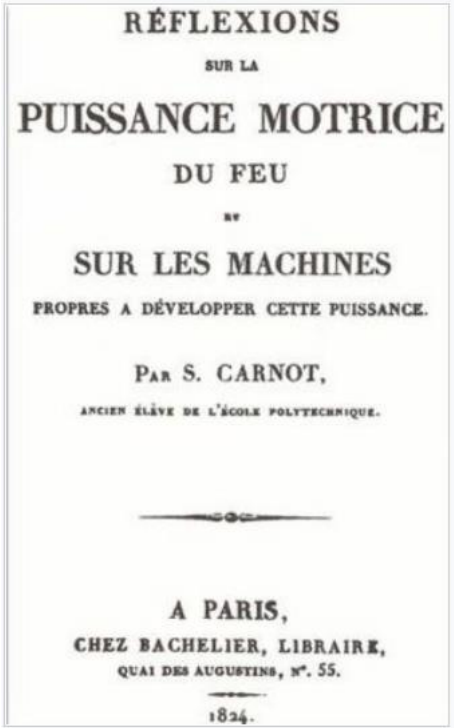
- Takeaway: the math confirms: "less lift, more efficiency"

Sadi Carnot

Nicolas Léonard Sadi Carnot in 1813 at age of 17 in the traditional uniform of a student of the École Polytechnique

Born	1 June 1796 Palais du Petit-Luxembourg, Paris, France
Died	24 August 1832 (aged 36) Paris, France
Nationality	France
Alma mater	École Polytechnique École Royale du Génie University of Paris Collège de France
Known for	Carnot cycle Carnot efficiency Carnot theorem Carnot heat engine

Reflections on the Motive Power of Fire



RÉFLEXIONS
SUR LA
PUISSANCE MOTRICE
DU FEU
ET
SUR LES MACHINES
PROPRES A DÉVELOPPER CETTE PUISSANCE.

PAR S. CARNOT,
ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE.

A PARIS,
CHEZ BACHELIER, LIBRAIRE,
QUAI DES AUGUSTINS, N°. 55.
1824.

How efficient?

- Carnot limit is generally very high
- For some applications, the Carnot limit is clear

	Cold, hot Temperatures	Carnot limit COP	Typical mass market products
Space heating	32, 100°F[1]	8.2	COP = 2.5 (HSPF of 8.5)
Heating water	67.5, 125°F	10.2	COP = 4.2 (UEF of 4.0; 5% losses)
Space heating	-30, 90°F[1]	4.6	COP = 1.8 (prototype[2])
Space cooling	50, 95°F[3]	11.3	COP = 3.7 (EER of 12.5)

General rule of thumb (historical experience):
30-50% of Carnot limit is achievable by mass market devices

1. Supply duct temperature is used instead of indoor temperature
2. Shen, 2017 https://www.energy.gov/sites/prod/files/2017/04/f34/2_32219_Shen_031417-0900.pdf
3. Here a dewpoint of 50°F is used for T_C. The limit is 26.7 for a 75°F dry bulb.

Carnot limits

- For many product classes, Carnot has not been established!

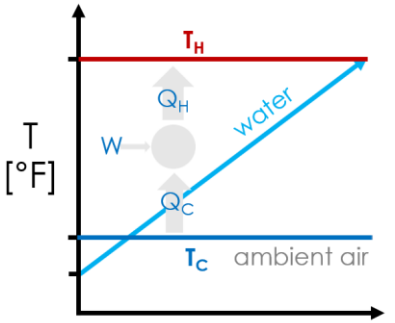
	Cold, hot T	Carnot limit	Notes
Clothes drying	?	(next 3 slides)	Mass market products: CEF = 5 to 8 (implied COP of 0.8 to 1.4)
Dishwasher drying	?	?	Performance not established for drying
Water heating, accounting for glide	67.5, 96°F	(next slide)	Existing products use vapor compression, which cannot take advantage of the glide
Space cooling with separate sensible and latent processes	?	?	30% improvement reported in literature compared to traditional AC

HPWH Efficiency Limit

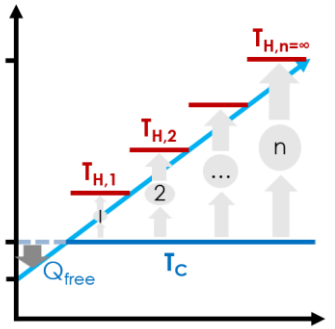
For 67.5°F ambient air, 125°F water:

- 4.0 = UEF on market in 2020
- 10.2 = COP limit for a Carnot heat pump[1]
- 22.9 = COP limit for an infinite number of Carnot heat pumps, heating water from 58°F to 125°F[2]
- ?? = COP limit for solar thermal, integrating with with AC, drain water heat recovery, and other "outside the box" approaches

Simple Carnot



Infinite Carnot

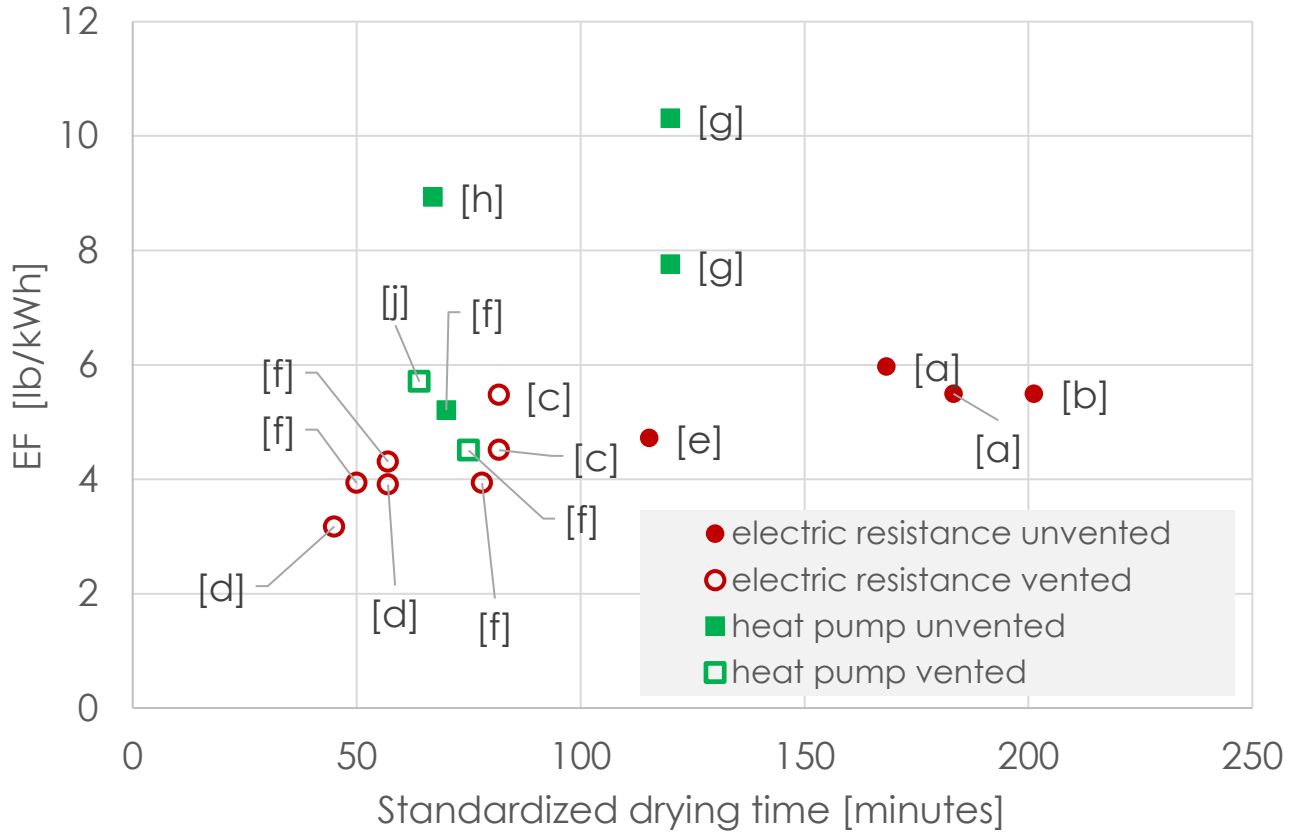


[1] assumes Carnot heat pump operating between 67.5 and 125°F

[2] assumes zero work from 58 to 67.5°F, then Carnot heat pumping from 67.5 to 125°F, operating between 67.5°F and the entropic average temperature ($\Delta h/\Delta s$) of 95.8°F

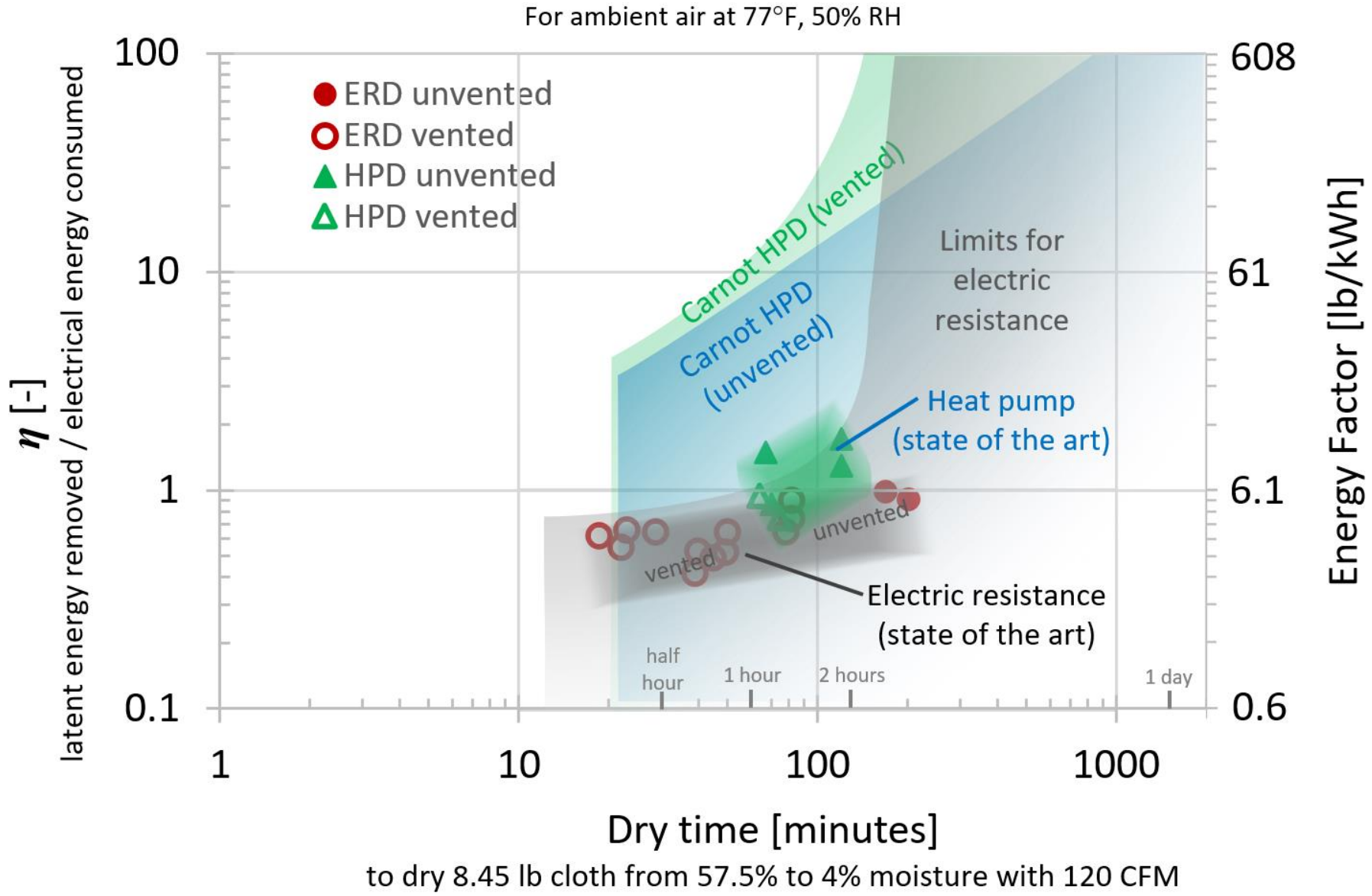
Dryers state of the art

ENERGY STAR-rated commercialized and prototype systems in the literature



[a]	Jian et al. 2019
[b]	Jian and Zhao 2017
[c]	Jian and Luo 2018
[d]	Stawreberg and Nilsson 2013
[e]	Zhao et al. 2018
[f]	ENERGY STAR qualified products July 2020
[g]	Cao et al. 2014
[h]	Bengtsson et al. 2014
[i]	Novak et al. 2019
[j]	TeGrotenhuis et al. 2017

Fundamental Limits and State of the Art

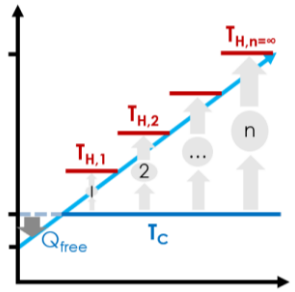


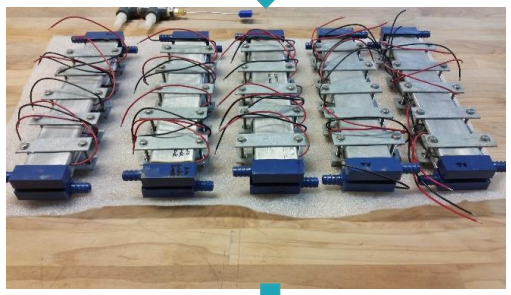
- Duration and efficiency are linked
- ERD: close to limits
- HPD: far from limits

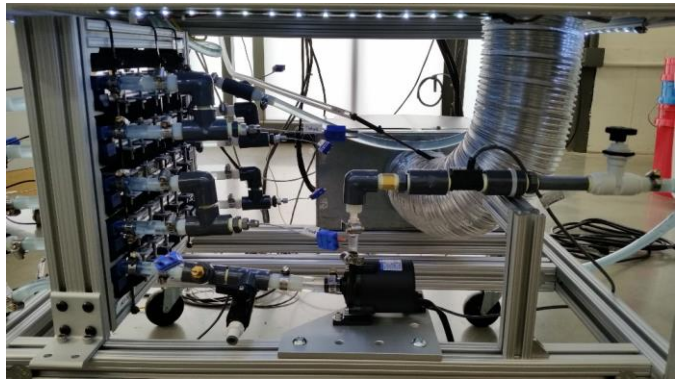
For more thorough treatment, see:
Gluesenkamp, Kyle R.; Viral K. Patel, Ayyoub M. Momen (2020). "Efficiency limits of evaporative fabric drying methods," ***Drying Technology*** (accepted for publication).

ORNL's Prototype Thermoelectric Dryer (TED)

- CRADA project with Samsung
- Thermoelectric heat pump
  - No refrigerant
  - Solid state
  - Modularity leveraged: some TEs have small lift (relevant limit is "infinite Carnot")

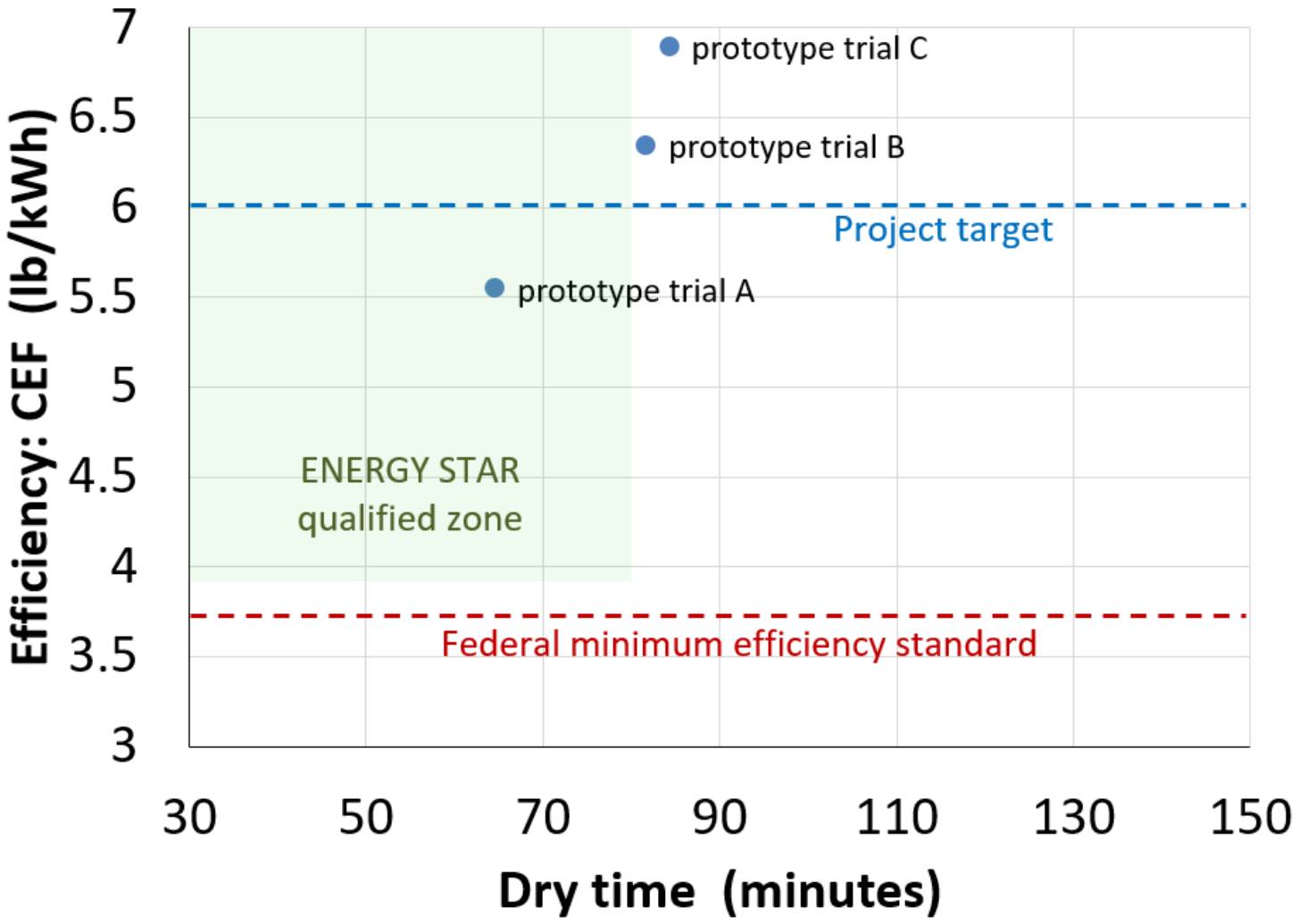






ORNL's Prototype Thermoelectric Dryer (TED)

- CEF of 6.89 achieved with dry time of 84 minutes
- CEF of 5.55 with dry time of 65 minutes



Beyond vapor compression (a big heat pump family)

Heat pump technologies include:

- Electro/mechanically-driven
  - Reverse Rankine (vapor compression)
  - Thermoelectric
  - Magnetocaloric
  - Elastocaloric
  - Electrocaloric
  - Maisotsenko
  - Reverse Brayton
  - …
- Thermally-driven
  - Vapor sorption (absorption and adsorption)
  - Ejector
  - Evaporative liquid desiccant
  - Vuilleumier/duplex Stirling
  - Thermoacoustic
  - …

Goetzler et al. (2014). "Energy Savings Potential and RD&D Opportunities for Non Vapor-Compression HVAC Technologies" https://www.energy.gov/sites/prod/files/2014/03/f12/Non-Vapor%20Compression%20HVAC%20Report.pdf

Beyond efficiency: other consumer benefits

- Enhanced functionality and non-energy benefits of heat pumps can include:
  - Faster dish drying, avoid steam ejection from appliance
  - Ventless operation
  - Water recovery: condense water vapor
  - Grid interactive capabilities, storage, and waste heat recovery
  - Fun technology
  - Multiple functions: e.g. dehumidification of basement as byproduct of water heating
- For non-vapor compression technologies:
  - Solid state, silent operation
  - Refrigerant-free

References

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- Goetzler et al. (2014). "Energy Savings Potential and RD&D Opportunities for Non Vapor-Compression HVAC Technologies" https://www.energy.gov/sites/prod/files/2014/03/f12/Non-Vapor%20Compression%20HVAC%20Report.pdf
- Patel, Viral; Kyle R. Gluesenkamp, Dakota Goodman, Anthony Gehl (2018). "Experimental evaluation and thermodynamic system modeling of thermoelectric heat pump clothes dryer," ***Applied Energy***, v. 217, 221-232. (May 2018) https://doi.org/10.1016/j.apenergy.2018.02.055
- Shen, Bo (2017). "High Efficiency Cold Climate Heat Pump". DOE Building Technologies Office 5th **Annual Peer Review**, March 13–16, 2017, Arlington, Virginia. available at https://www.energy.gov/sites/prod/files/2017/04/f34/2_32219_Shen_031417-0900.pdf
- Stewart, Susan W.; Sam V. Shelton (2004). "The usefulness of entropic average temperatures." Proceedings of 2004 **ASME IMECE** International Mechanical Engineering Congress and Exposition, November 13-20, 2004, Anaheim, California USA.

Acknowledgements

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- The author would also like to acknowledge Mr. Antonio Bouza, Technology Manager – HVAC&R, Water Heating, and Appliance, U.S. Department of Energy Building Technologies Office.

Discussion

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Heat Pump Dryers

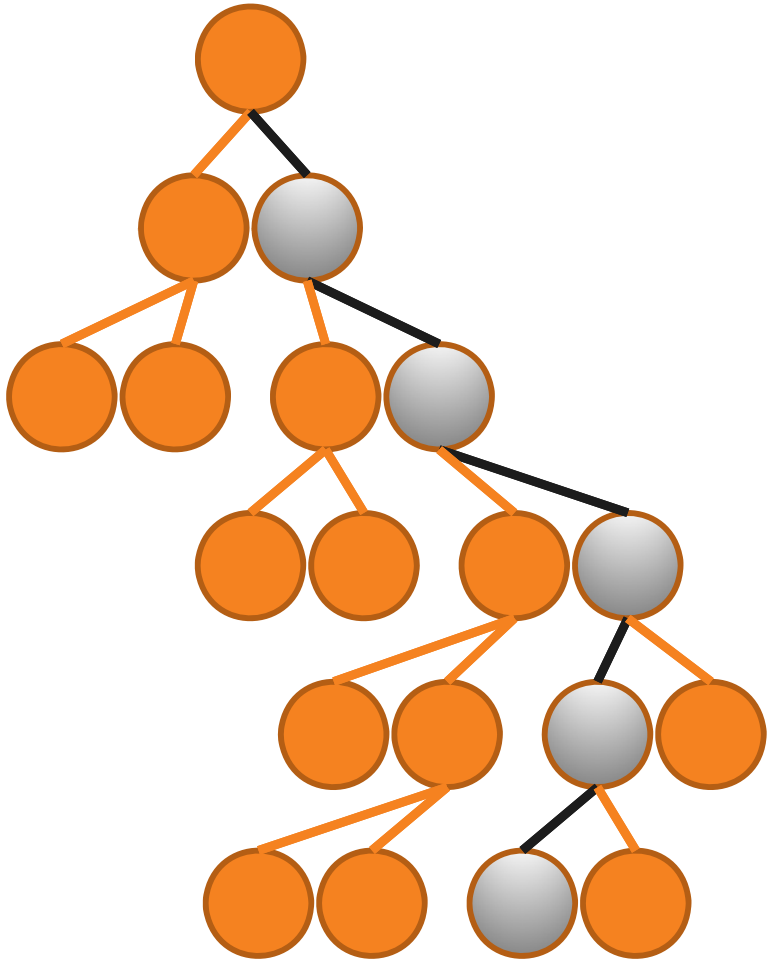
Heat Pump Dryers

Whirlpool WHD560CHW 7.4 cu. ft. 240 Volt Stackable White Electric Ventless Dryer with Intuitive Touch Controls, ENERGY STAR

Samsung DV22N6800HW 4.0 cu. ft. Capacity White 24 Stackable Electric Ventless Heat Pump Dryer ENERGY STAR Certified

Heat Pump Technology as a Feature

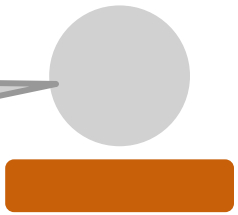
- Pair or stand alone?
- Gas or electric?
- Standard or compact?
- Brand preference?
- Price?
- Color/finish?
- Stackable or side by side?
- Drum capacity?
- Steam function?
- Energy Star?
- Vented or ventless?



Heat Pump Dryer Reviews

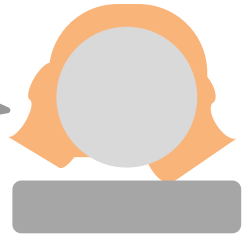
We have had it for a few months now and only one time did it not fully dry on the first cycle and that load was full of towels. The story of non vented dryers being subpar is a myth now.

It is the worst dryer experience ever. It doesn't heat and I have spent hours waiting for my laundry to dry.

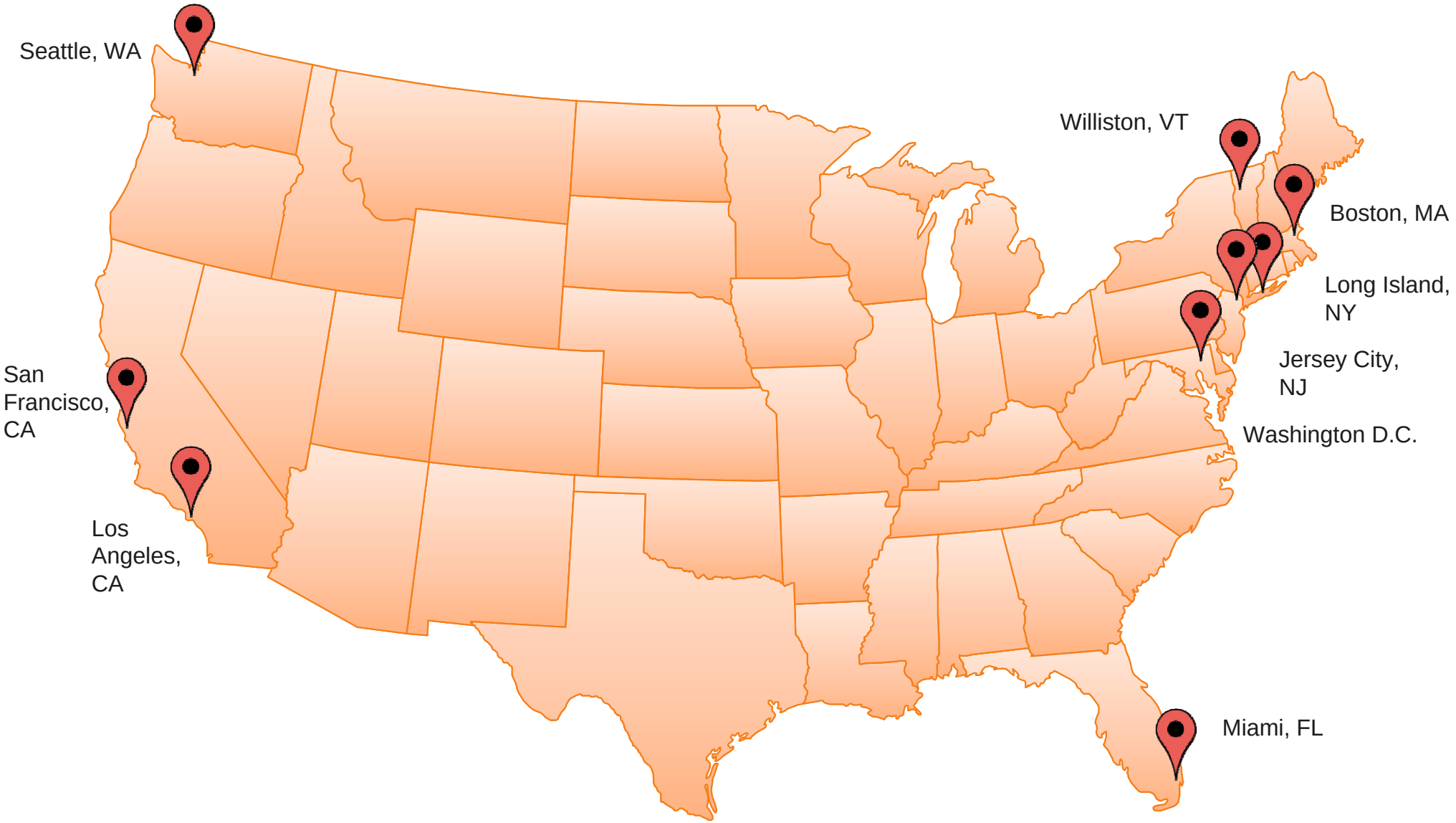


It works great and it's quiet. It does takes twice as long to dry an average load of laundry. However, we have no venting options, so the ventless feature is great.

So far very happy. Heard mixed reviews. Not having issues with clothes not drying. They take longer, but needed a ventless dryer for first floor laundry, so I don't mind



Heat Pump Dryer Activity



Heat Pump Dryer Market

- Heat pump dryer market still VERY niche
  - Customer demand still very low, but is growing
  - Ventless feature is largest driver
  - Drying time is biggest barrier
  - Urban markets are best due to size and venting

What can be done to bring growth forward?

PG&E Key Findings

- Sales data from PG&E's participation in the ENERGY STAR Retail Products Platform underscore price and availability barriers to heat pump dryers.
- Very low market penetration in 2019 prompted PG&E to more than double the incentive rates to $550 in the 2020 program year.
- Within four months, 2020 program sales volume has already exceeded all 2019 PG&E heat pump dryer sales by over 70%.

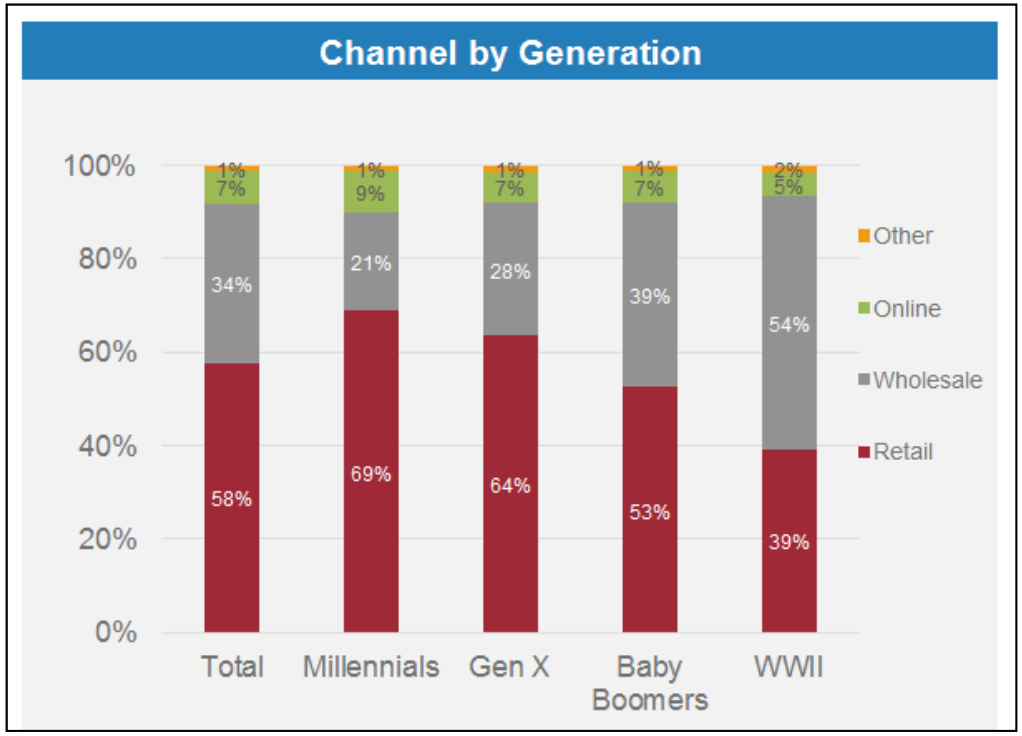
Learning from Heat Pump Water Heaters

- Similar challenges exist:
  - Fuel type – electrification could help shift the market
  - Unit size – improves with technology advancements
  - Dry time, recovery time – improves with technology advancements
  - Customer perception – the narrative needs to change
  - Price – utility rebate programs can offer assistance
  - Limited options – improves with technology and customer demand

Demand Creation for Heat Pump Water Heaters

October 2020

Create Market Demand For Both Retail and Wholesale Channels



Source: KeyStat water heater purchases YE4Q18 sample size n=5,310

Retail > 50% water heater market…

…Especially among younger generations

- ❑ **Offer instant rebate programs where consumers shop**

Instant Rebate Program Design Options

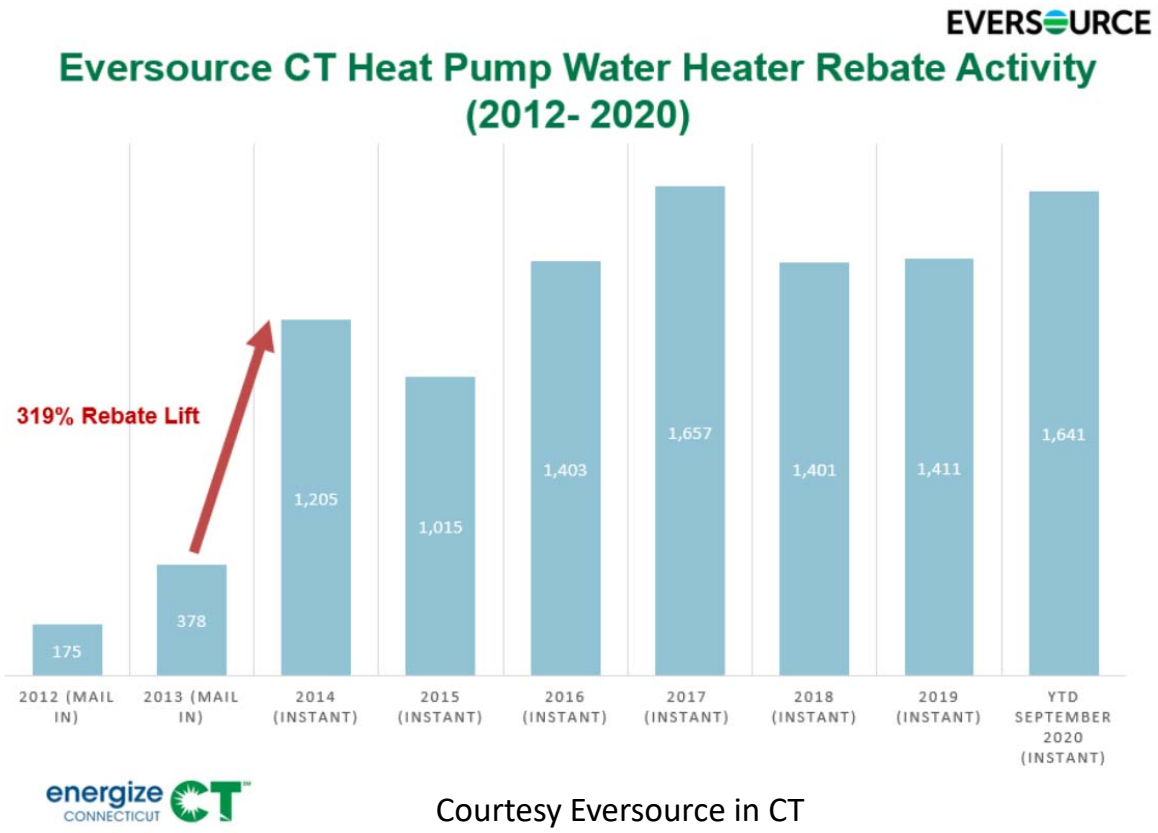
Markdown

- ❑ Pros: Immediate reduction of price; Low program admin costs
- ❑ Cons: No end-user Data

Validated Instant

- ❑ Pros: End-user data with digitization
- ❑ Cons: Program costs; possibly less effective

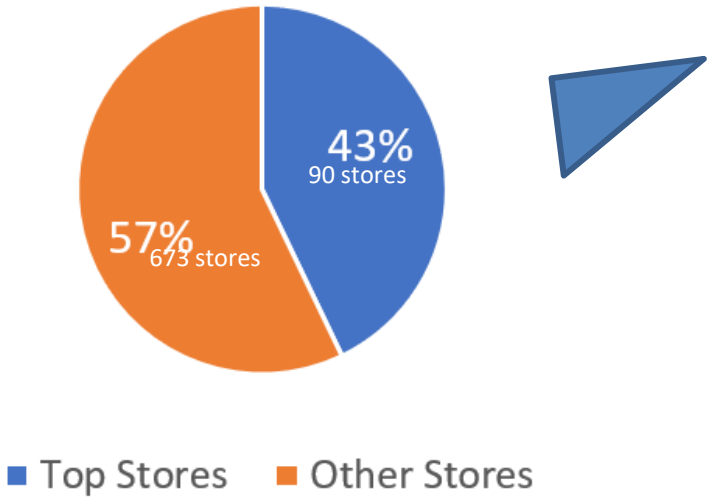
Energize CT Instant Rebate Success

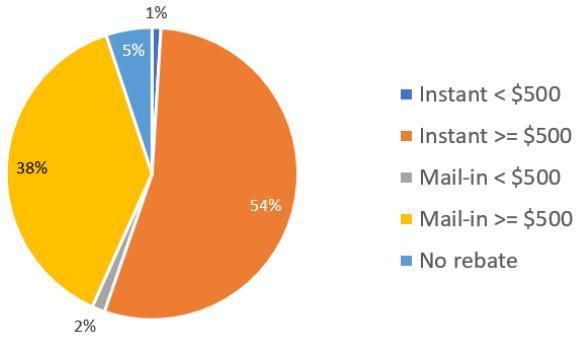


Courtesy Eversource in CT

Top Performing HPWH Stores at Lowe's

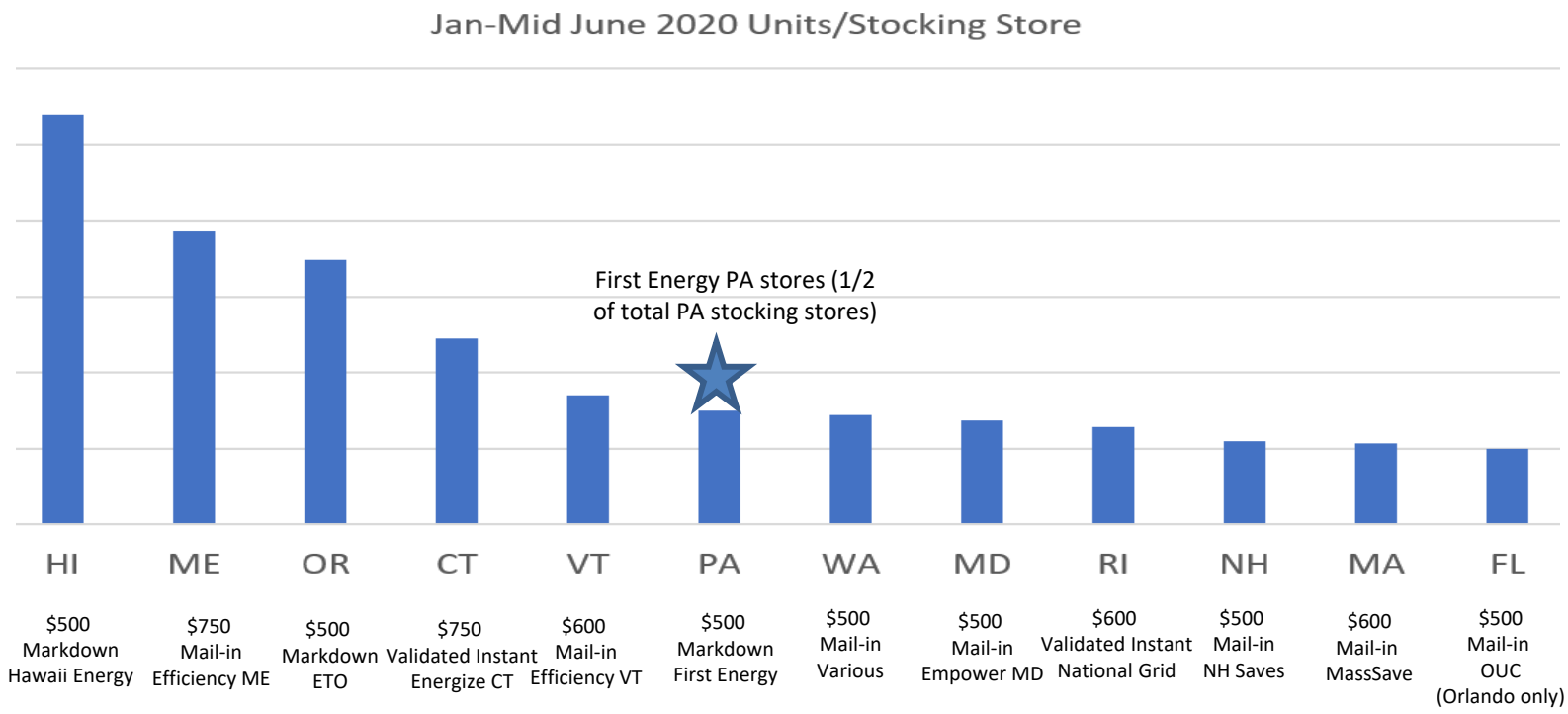
January to Mid-June 2020 HPWH Unit Sales at Lowe's





- 12% of stocking stores account for 43% of HP volume
- **The overwhelming majority of the top performing stores are in markets with Utility rebates >= $500**

Top Performing HPWH States at Lowe's



Instant Rebates >= $500 produce superior results

Drive Scale and Simplification with Regional Programs

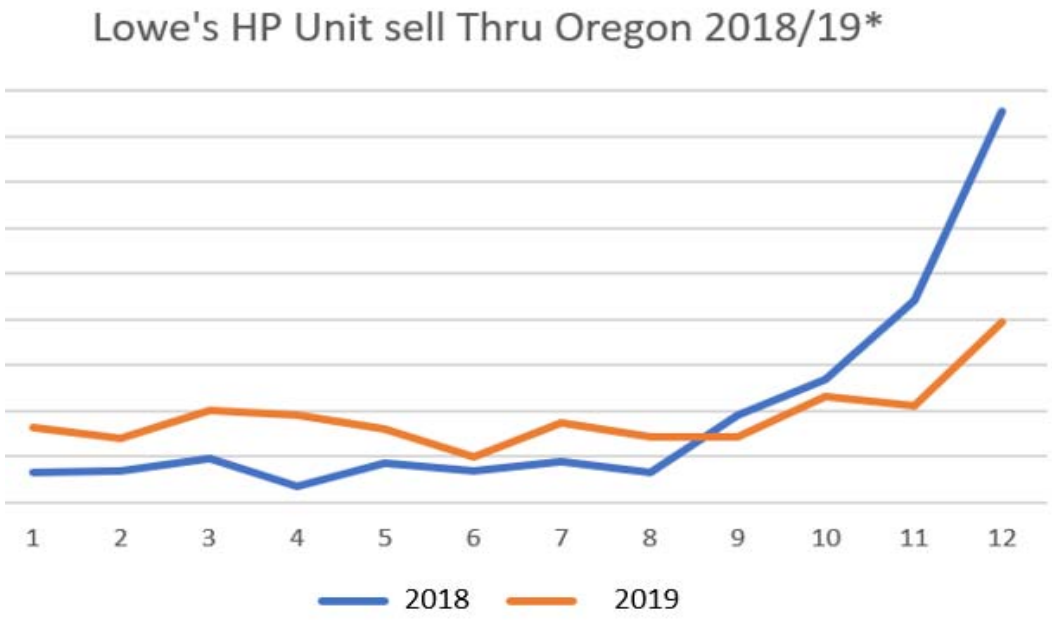
Northwest Puget Sound

Same instant rebate amount and program structure offered by PSE, Snohomish PUD and Tacoma Power

New York NYS Clean Heat

Similar instant rebate amounts and same program structure offered by National Grid, RGE, NYSEG, O&R, Central Hudson and ConEdison

Consumer Demand Responds to Instant Rebates and Advertising – Lowe's in OR



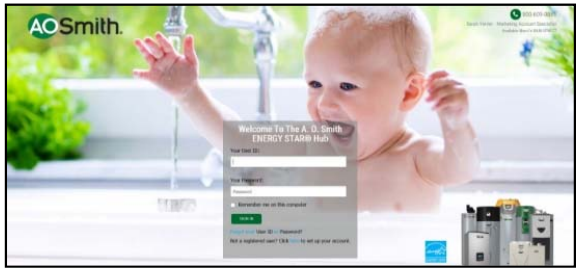
$700 Instant Rebate in Fall + 200K Mailers

$500 Instant Rebate all year + 200K Mailers in Fall

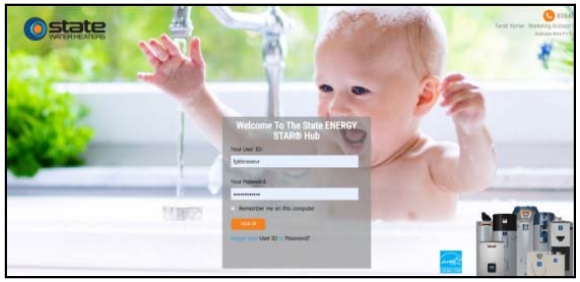
Best HPWH advertising performance instant rebate > $500 + Mailers

*13 Lowe's stores. Excludes the Eugene, OR store

Promote to Installers with A. O. Smith and State ENERGY STAR® Hubs



https://aosmith.mymarketingbench.com/

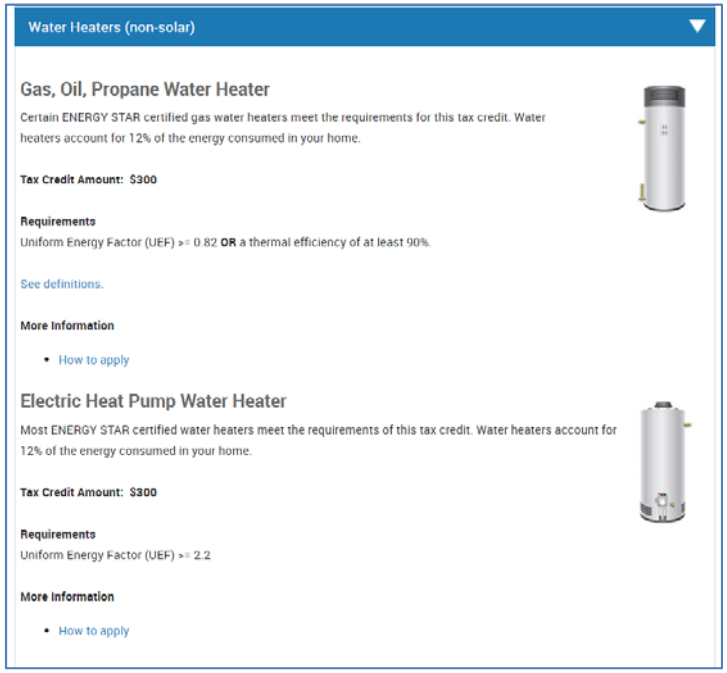


https://state.mymarketingbench.com/

- ❑Dedicated to ENERGY STAR certified products
- ❑Central repository of Spec. sheets, brochures, videos, promotional tools for Distributors and Contractors
- ❑**Help Manufacturers co-fund ad campaigns for the Installers**

This Fall….Advertise the $300 Federal Tax Credit

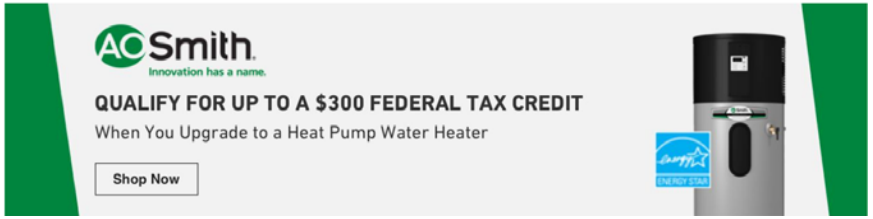
$300 Federal Tax Credit



https://www.energystar.gov/about/federal_tax_credits/non_business_energy_property_tax_credits

Store POP at Lowe's

Web banner on lowes.com



https://www.lowes.com/search?searchTerm=heat+pump+water+heaters

Load Control and Energy Storage

- CTA-2045, Wi-Fi and Bluetooth
- Free A. O. Smith app
  - Control temperature and mode
  - Monitor water heater status
  - Fault and Maintenance notifications
- California Title 24 – JA13 Compliant
  - Easily load utility Time of Use rates
  - Demand Response: OpenADR 2.0b VEN certified
- Factory Installed
  - Also available as an accessory kit. Backwards compatible on all series 130 heat pumps.

Take-Aways

- ❑ First Cost is the main barrier to market adoption.
- ❑ Offer HPWH instant rebates >= $500 at Retail and Wholesale.
- ❑ SIMPLE program design, Statewide or Regional Upstream programs whenever possible
- ❑ Help co-fund Consumer Advertising for Retailers and Contractors to generate proactive replacements
- ❑ This Fall….Promote the $300 Federal Tax Credit
- ❑ Offer incentives for Load Management