Stone Mountain Technologies, Inc.

Next Generation Heating Innovation

Absorption Heat Pumps for Building Heat

Pathways to Decarbonization of Residential Heating

ACEEE Hot Water Forum 2019
Session 4D: Greenhouse Gas Reduction Strategies in the Water Heater Market

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Agenda

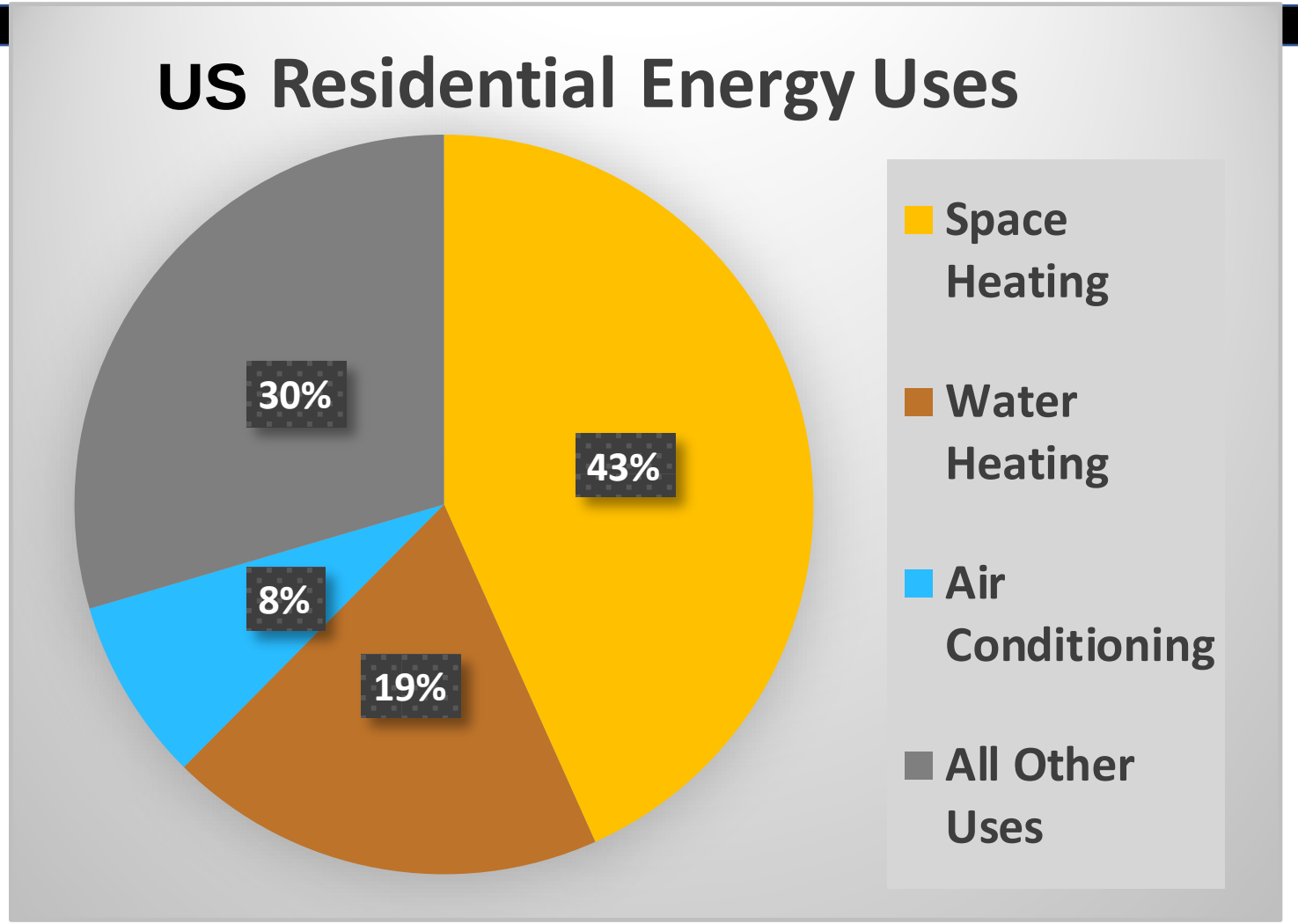
1. The Technology & Application – Residential Building Heat
2. Emissions
3. Economics
4. Decarbonization at Scale
5. Summary / Q&A

Technology & Application

Heating Energy used in US residences

- Space- & Water-heating:
  (62% of the total energy)
- 5.7 Quads / year (all heating)

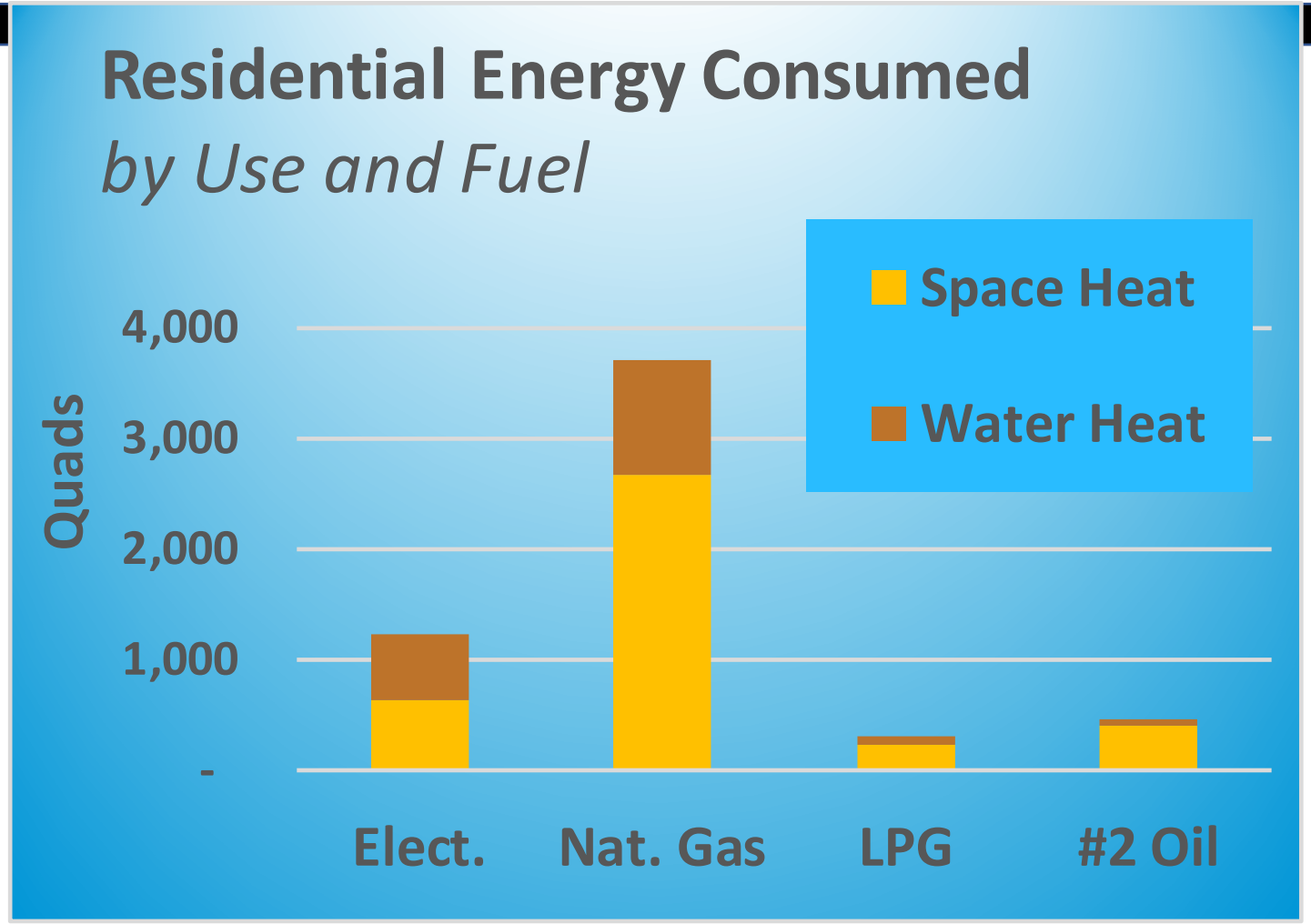
Carbon equivalents



Source: EIA RECS (2015), ce3.1

Fossil Fuel Sources Dominate Building-heat

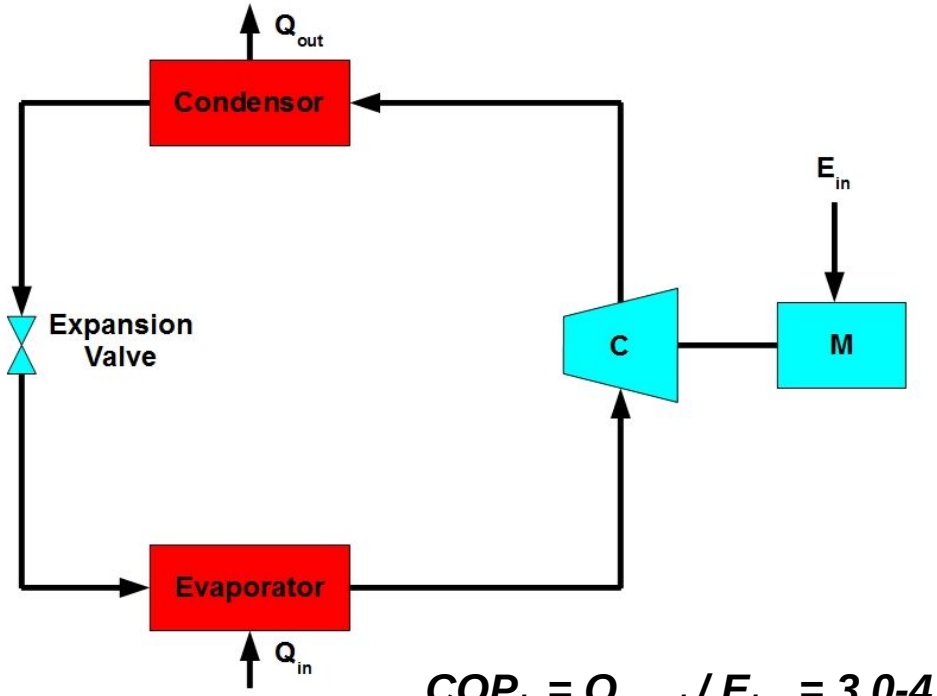
- Heating requires energy density for efficient delivery
- Reducing the greatest amount of GHGs means attacking the largest fuel sources
- More than 3/4 of all building heat is via fossil fuels



Source: EIA RECS (2015), ce4.1

Comparing Heat Pump Technology: **Vapor Compression & Gas Absorption**

Electric Vapor Compression Cycle



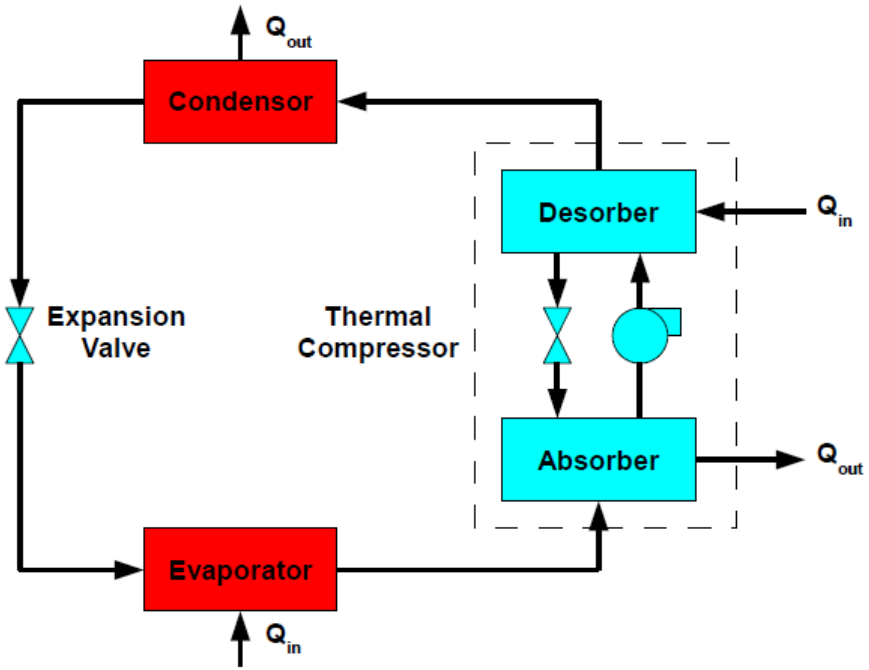
$COP_h = Q_{cond} / E_{in} = 3.0\text{-}4.0$

$Q_{heat} = \sim 1.1 \times Q_{cooling}$

$COP_{PE} = COP_E \times (0.91 / 3.15)$

$0.91 = PEF_{NG}$ $3.15 = PEF_E$ (US avg)

Gas Absorption Cycle



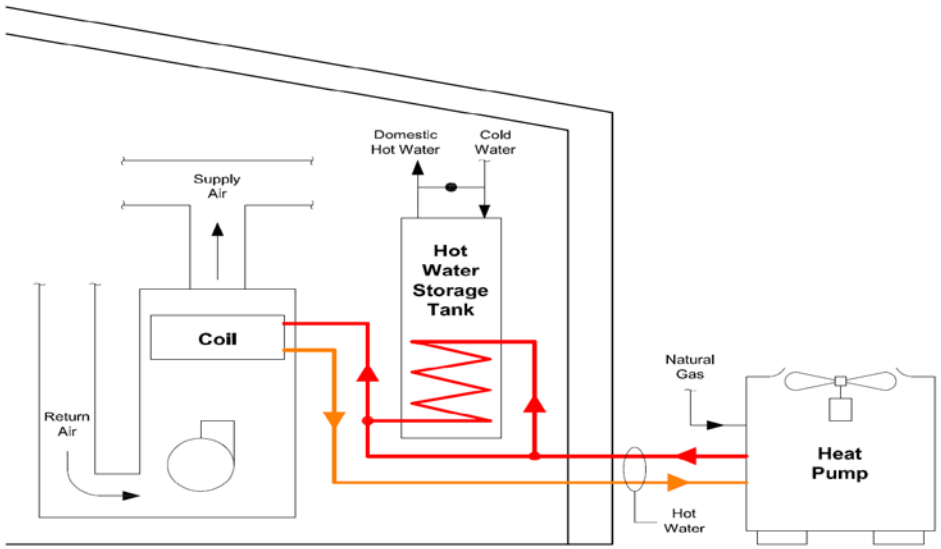
$COP_h = (Q_{cond} + Q_{abs}) / Q_{in} = 1.4\text{-}2.0$

$Q_{heat} = (Q_{cond} + Q_{abs}) \sim 2.5 \times Q_{evap}$

Gas Absorption Heat Pumps: Basic Technology

Gas Heat-Pump Water-Heater

- 65/80 gallon tank
- 10 kBTU/hr output
- UEF: 1.20
- In-market: ~2021

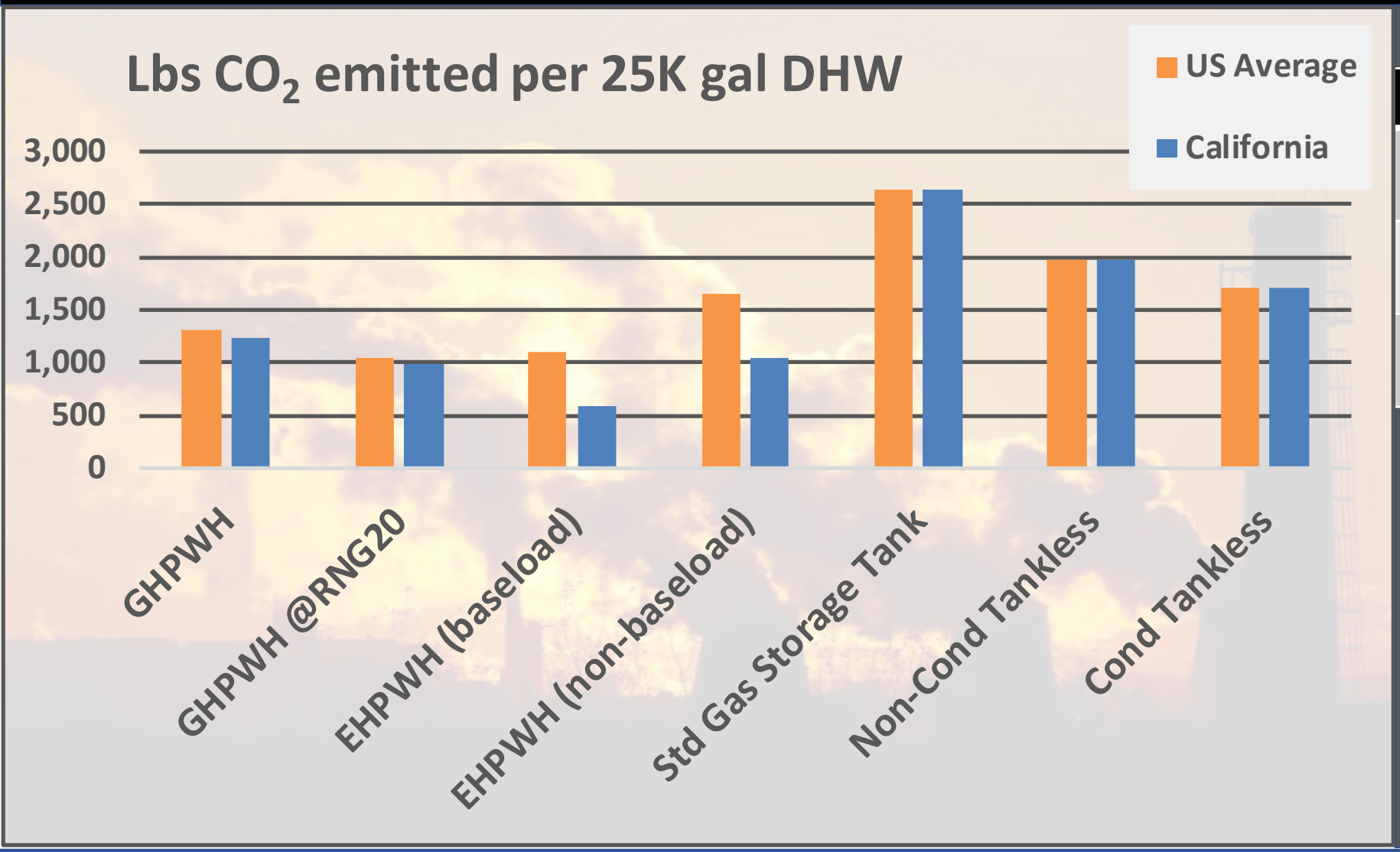


Gas Heat Pump Furnace / Boiler

- Space heating with DHW option
- 40-140 kBTU/hr output
- Warm-air Furnace or Hydronic application
- AFUE: 140%
- 4:1 modulation
- In-market: ~2021

Water Heating - Emissions

Water-heating Carbon Emissions by Technology



CO_2 Assumptions

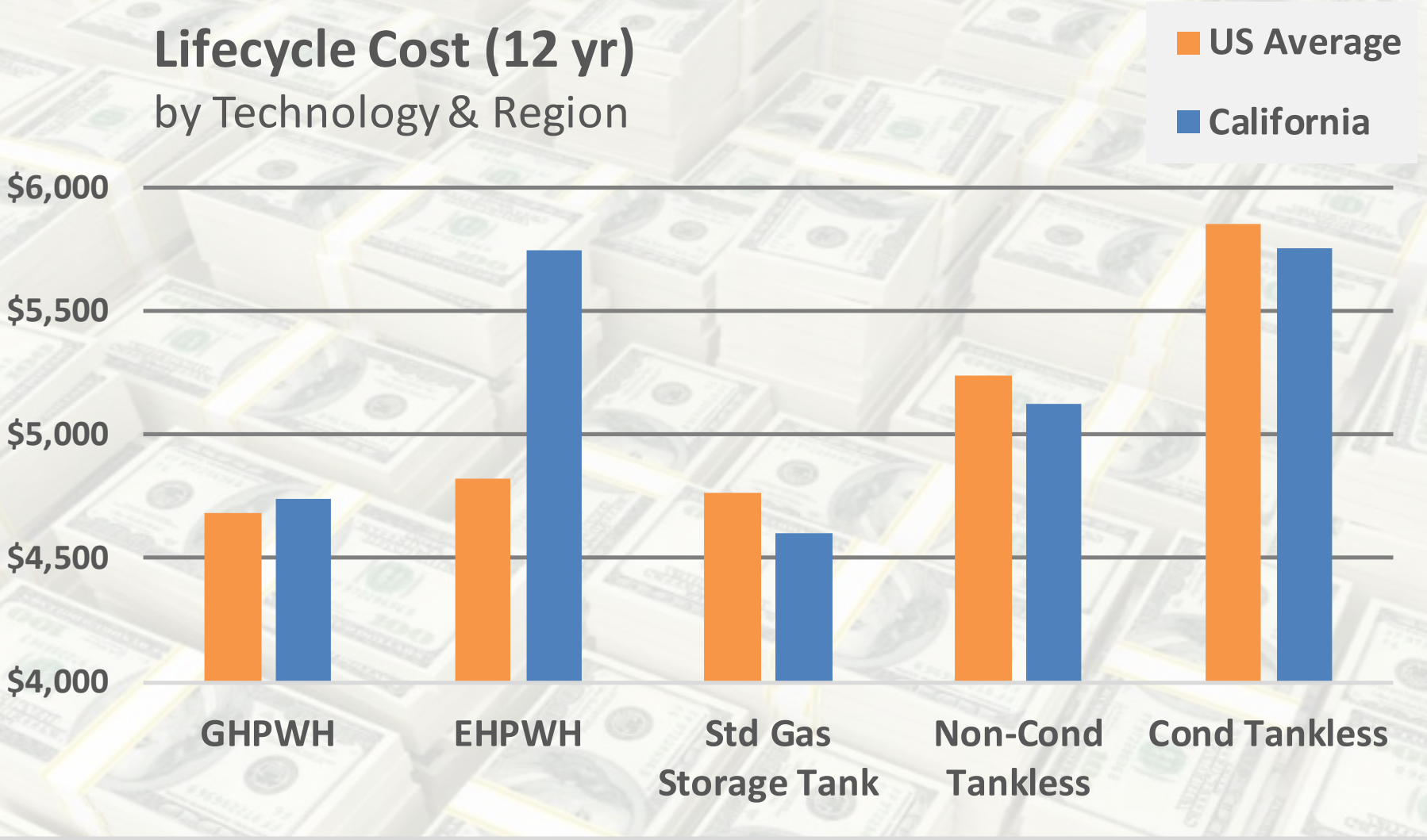
eGrid 2016	US Avg	Calif.
Nat. Gas (lbs / therm)	11.69	11.69
Elec. - All output (lbs / kWh)	0.99	0.53
Elec. - Non-Baseload (lbs / kWh)	1.50	0.94

Water Heating Assumptions

Residential Water-Heating Assumptions	*Unit*	GHPWH	Std Gas Storage Tank	Non-Cond Tankless	Cond Tankless	EHPWH
		gas				elec
Volume	*gal*	25,000				
Cold Temp	*F*	58				
Hot Temp	*F*	125				
Q_water	*btu*	13,952,750				
COP_avg		1.4	0.62	0.83	0.96	3.7
Gas_used	*therm*	100	225	168	145	
Q_hp	*bth*	10,000		199,999	199,999	
Run time	*hr*	1,395		84	73	
Power	*watts*	105		60	70	
Elect_used	*kWh*	147		5.0	5.1	1,105

Water Heating - Economics

Water Heater Technology Lifecycle Costs

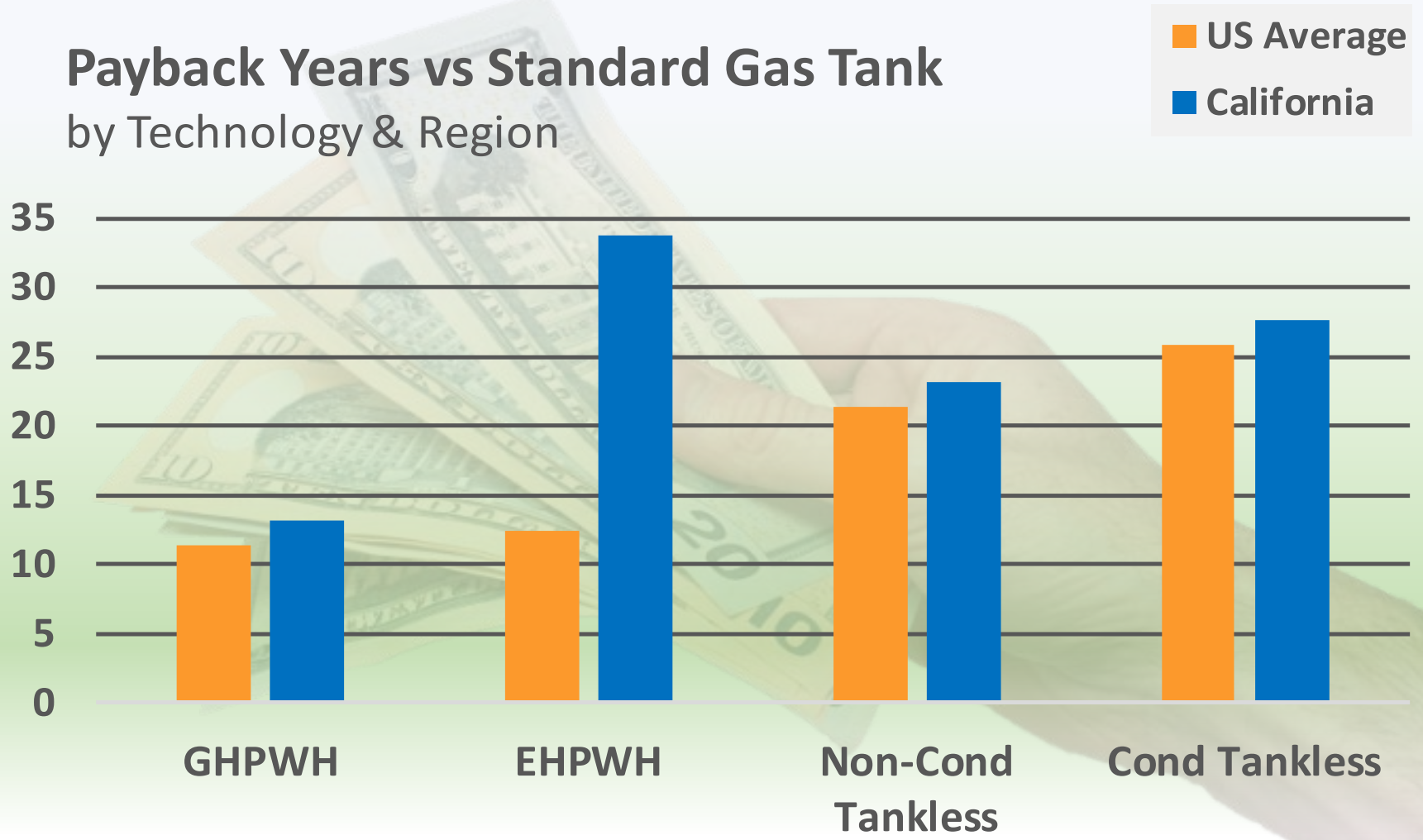


Water-heater Assumptions
(no incentives included)

Utility Costs	US Avg	Calif.
Nat. Gas ($ / therm)	$1.25	$1.19
Electricity ($ / kWh)	$0.12	$0.19

Technology	Typical Install Cost
GHPWH	$2,800
EHPWH	$3,050
Standard Gas Tank	$1,270
Tankless, Non-Cond.	$2,350
Tankless, Cond.	$3,300

Water Heater Technology Economic Paybacks



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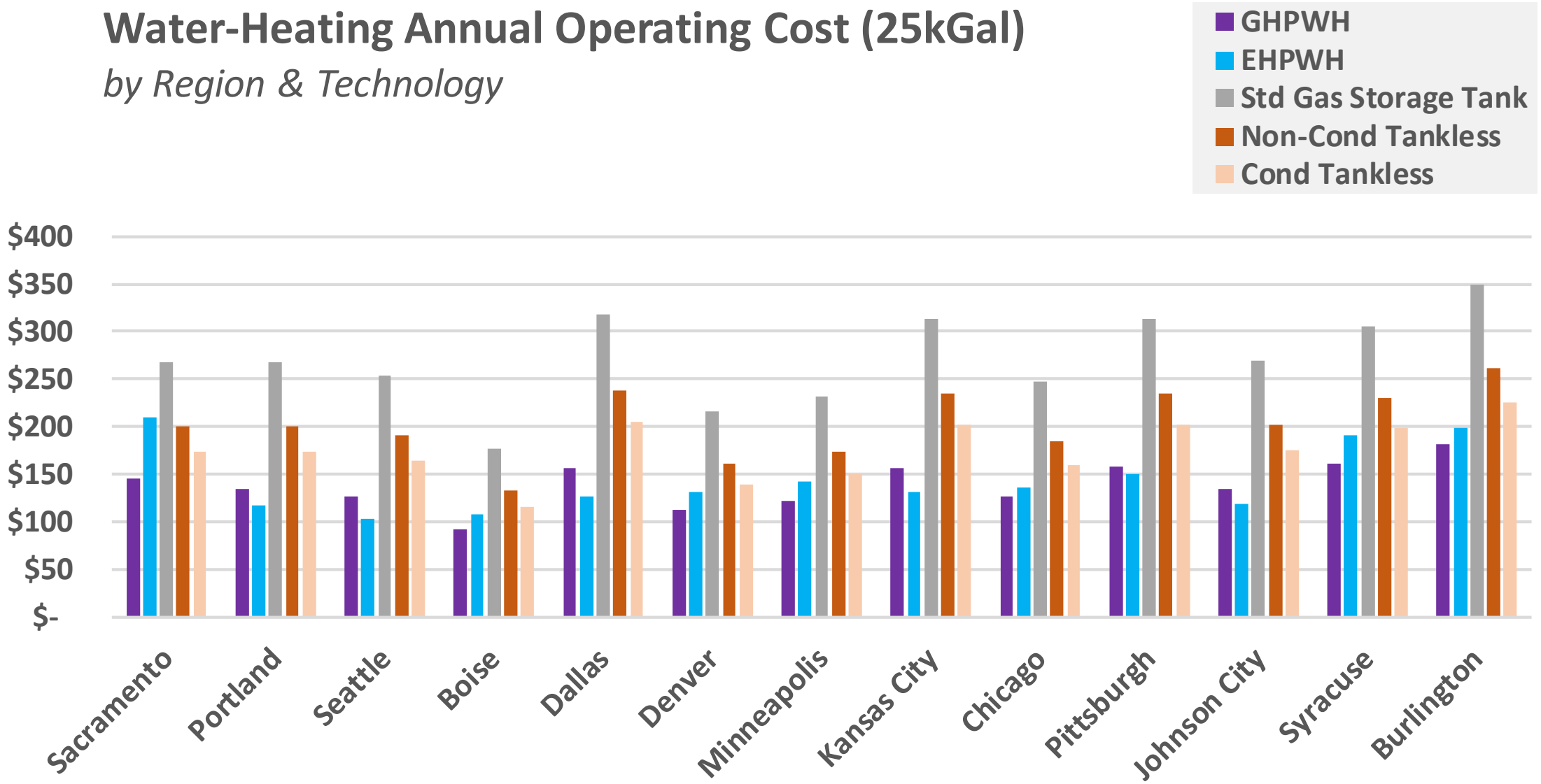
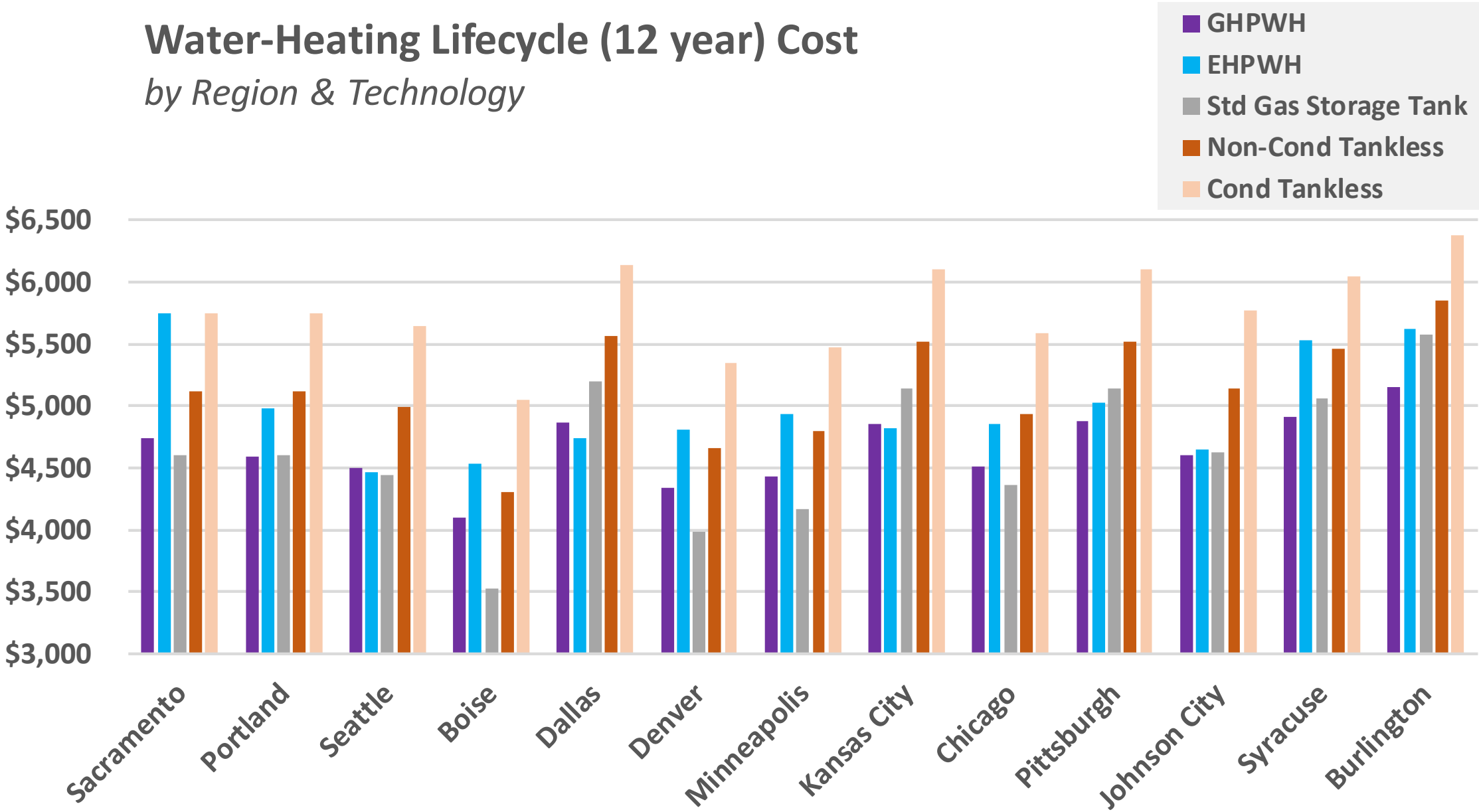
Water-Heating Annual Operating Cost (25kGal)

by Region & Technology



Water-Heating Lifecycle (12 year) Cost

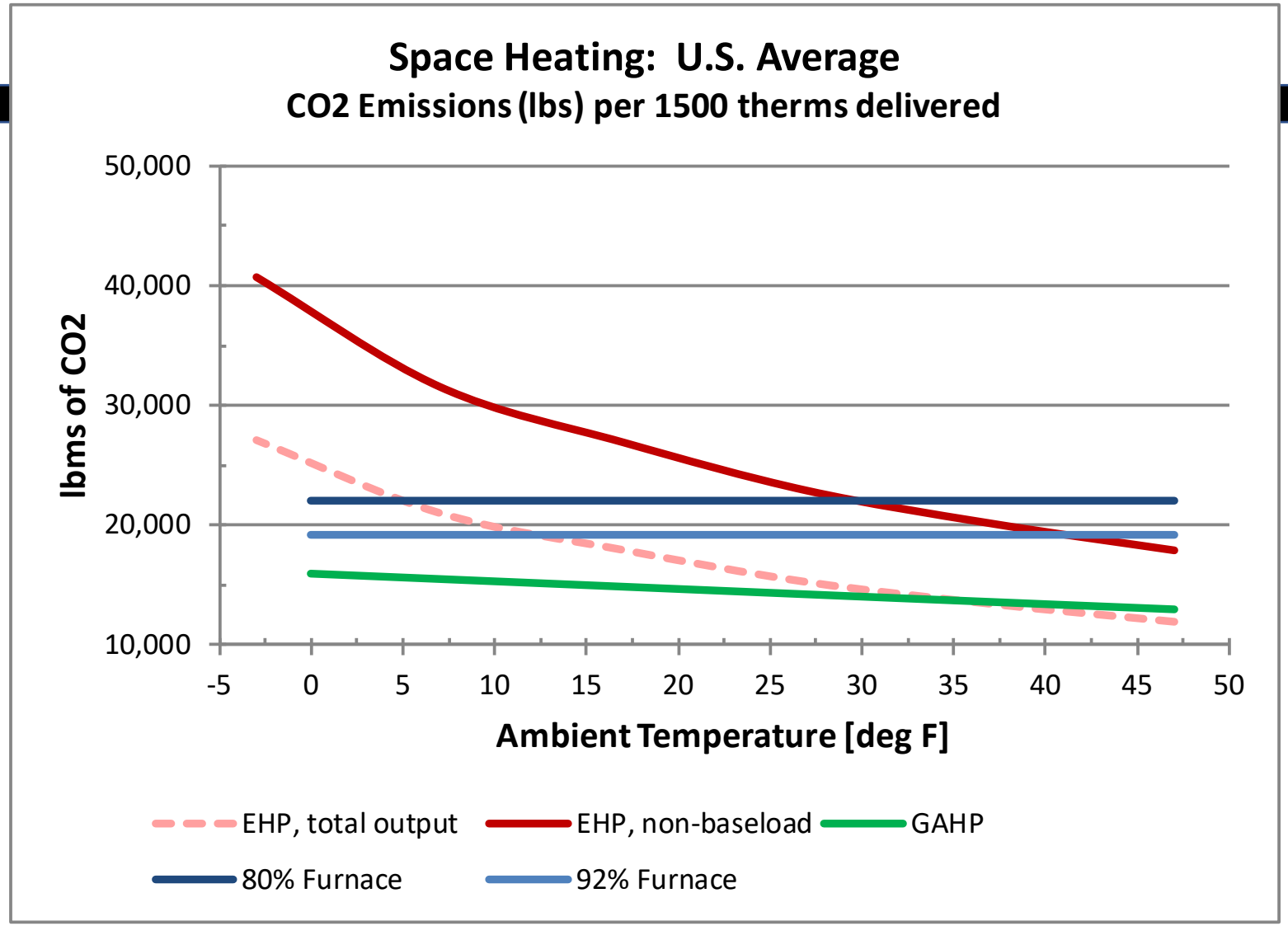
by Region & Technology



Space Heating - Emissions

Emissions Comparison US average

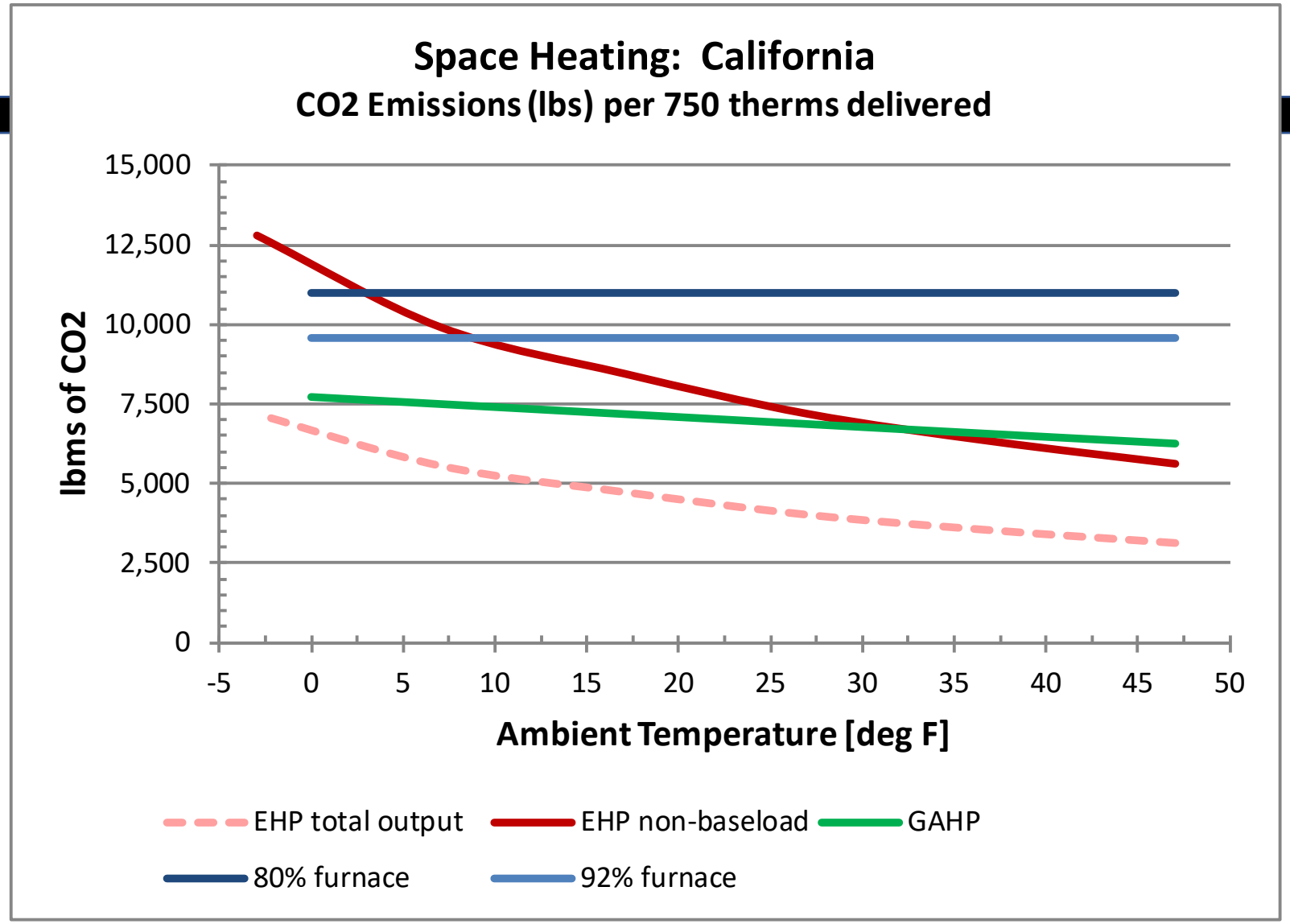
- GAHPs have the lowest carbon footprint in the coldest temperatures
- EHP carbon footprints are closer to non-baseload, not total output



eGRID 2016: US average CO_2 lbs / kWh is 1.501 (non-baseload) & 0.998 (total output)

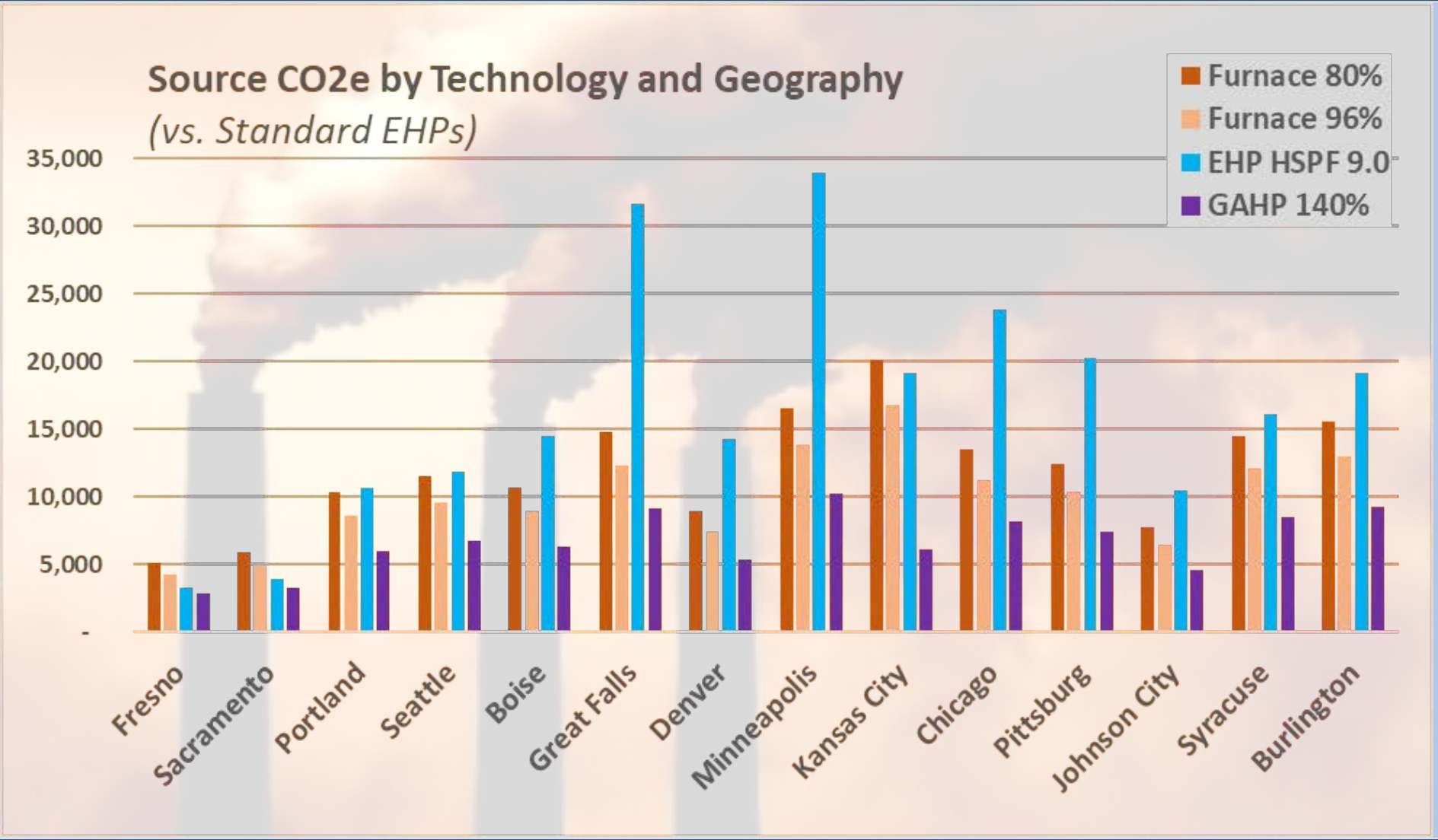
Emissions Comparison California

- Cleaner grids bring carbon foot prints closer together



eGRID 2016: CA average CO_2 lbs / kWh is 0.943 (non-baseload) & 0.528 (total output)

Emissions from Space Heating – Source CO_2e ("standard" EHPs)

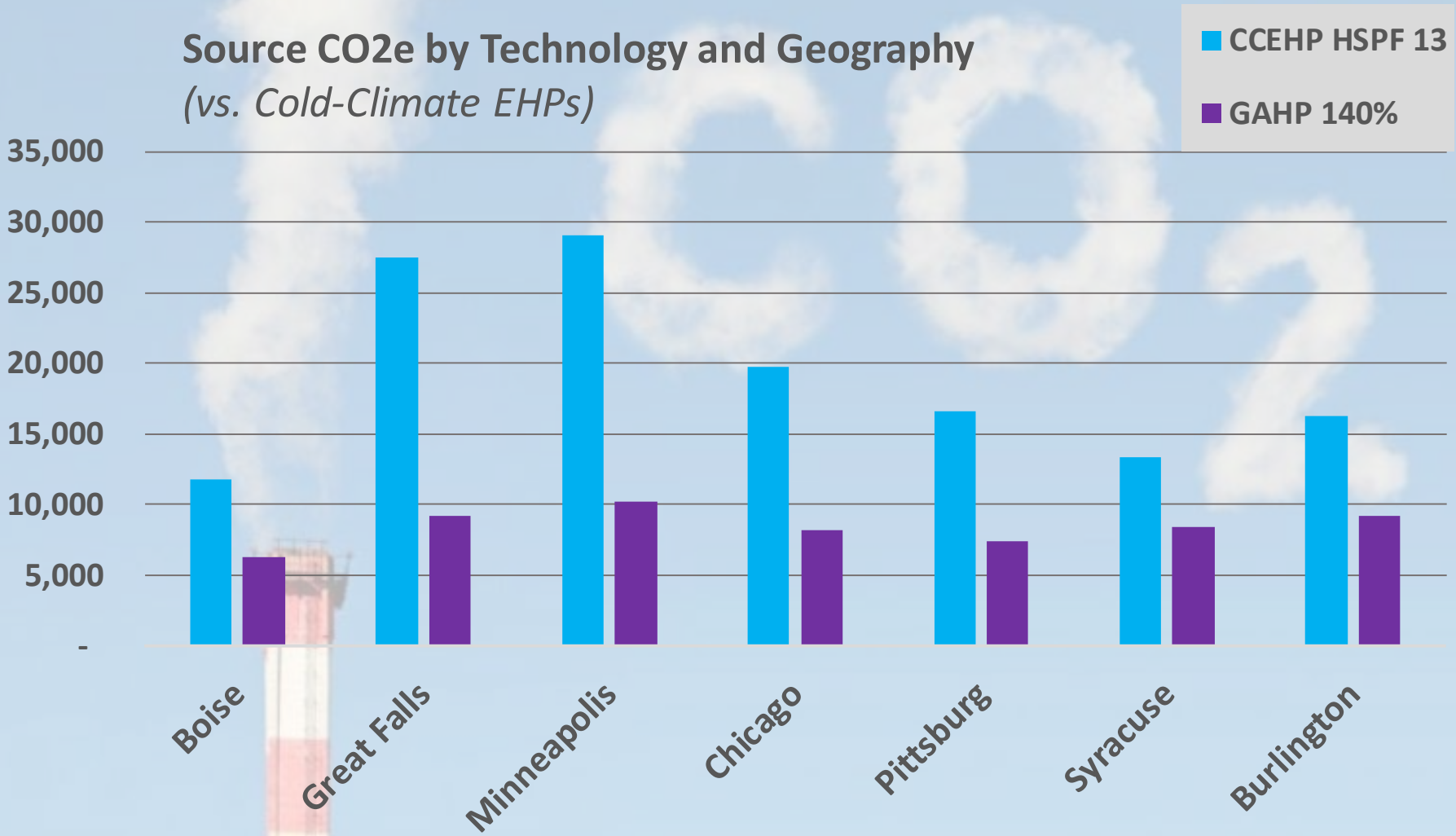


Method and Assumptions

- 2,700 sqft home
- 4 occupants
- Space-heating load only
- eGrid 2016
- Energy Planning Analysis Tool (GTI – based on EnergyPlus)
- Performance: mfr data except GAHP (prototype test data)

http://epat.gastechnology.org/

Emissions from Space Heating – Source CO_2e (Cold Climate EHPs)



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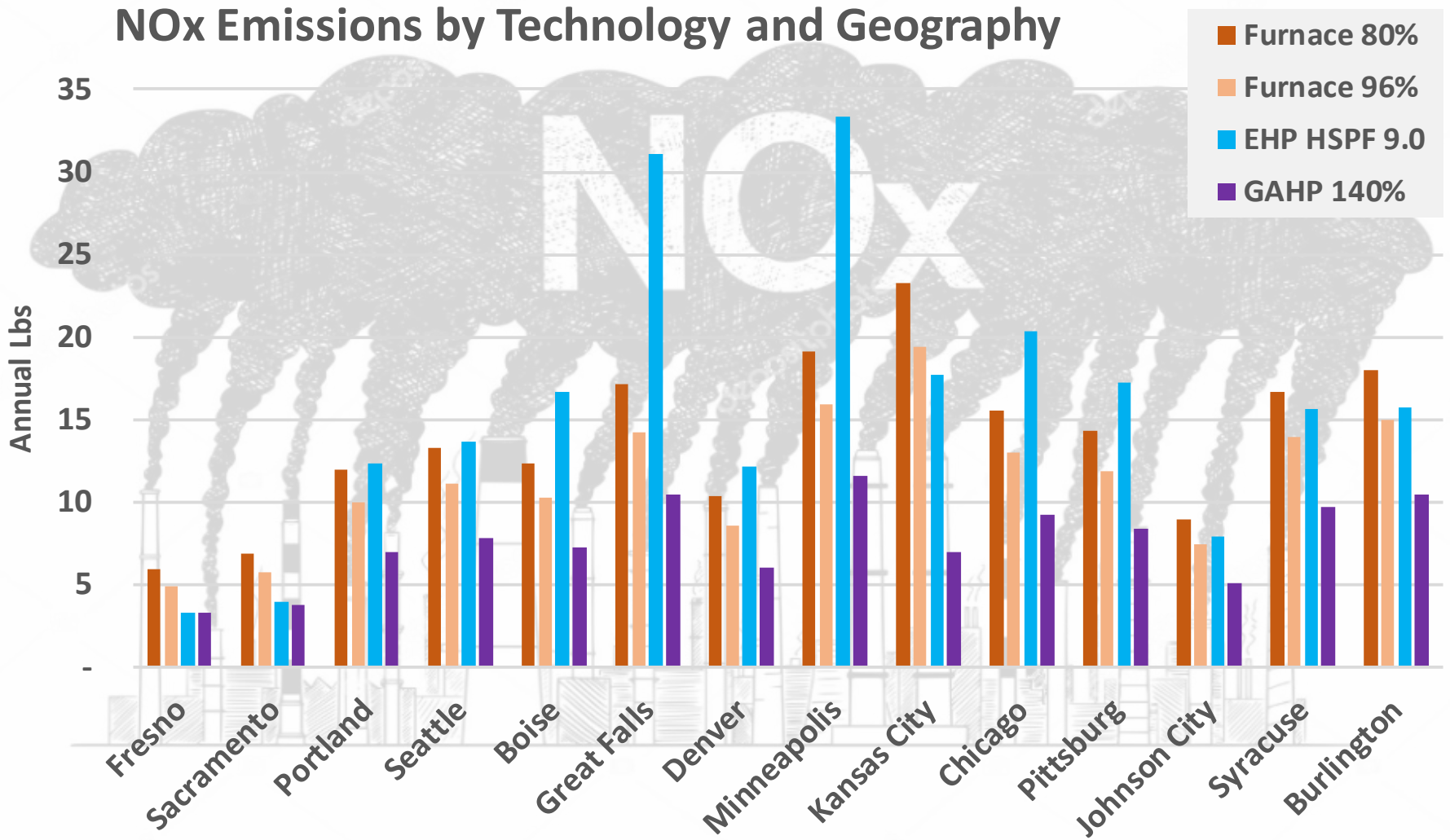
Emissions from Space Heating – NOx ("standard" EHPs)



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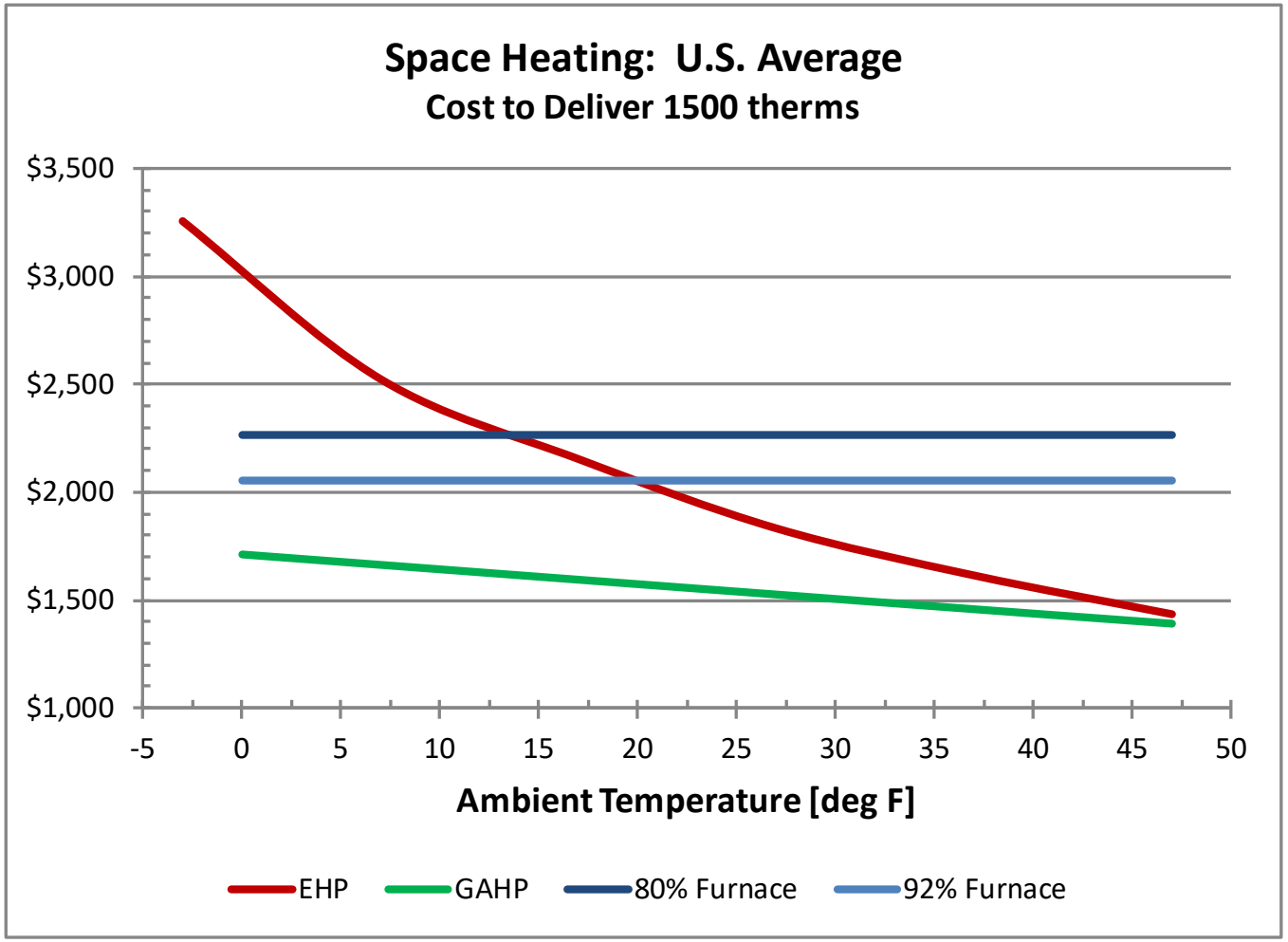
Space Heating - Economics

Cost per Delivered Unit of Heat

US Average

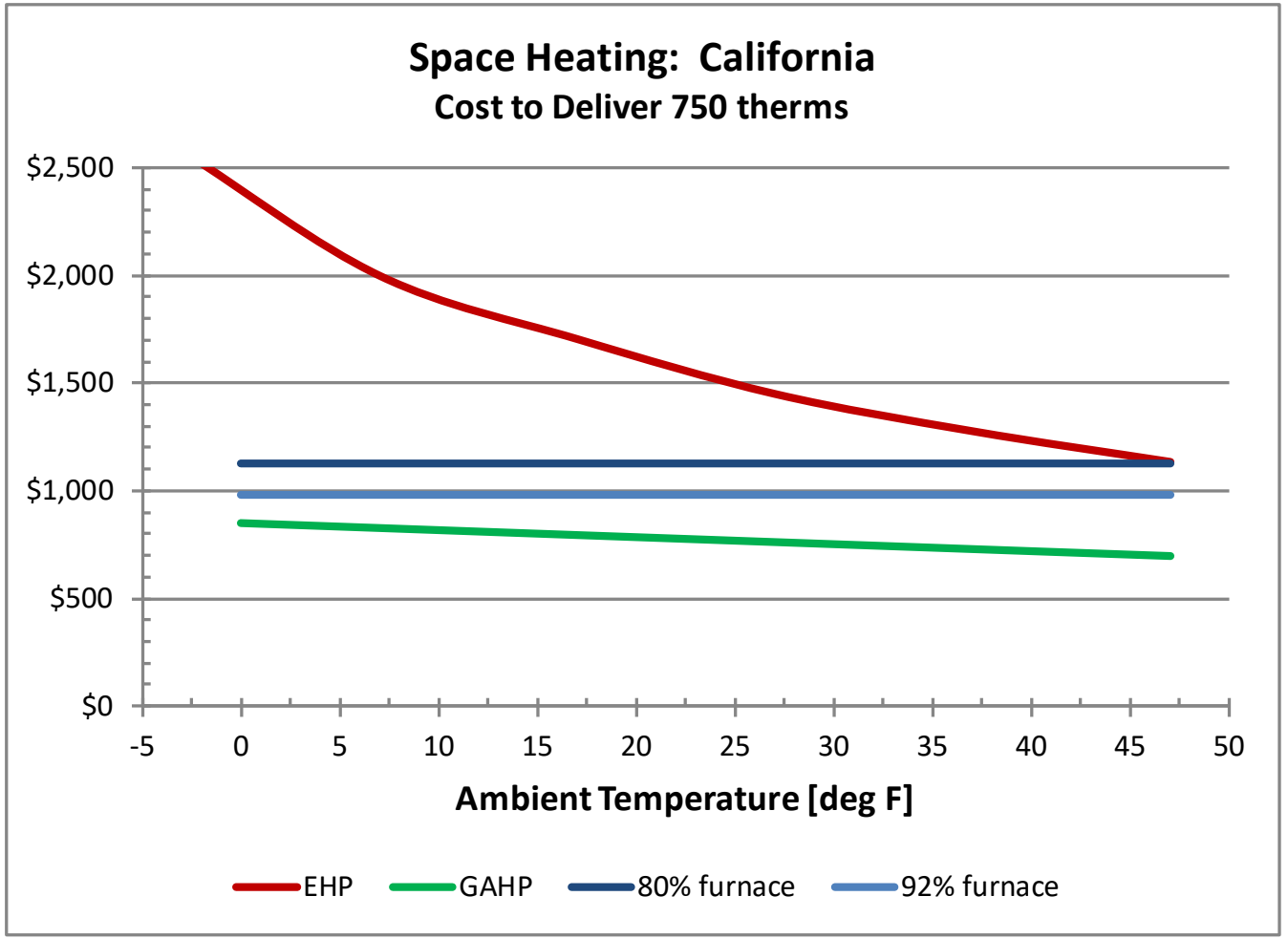


Assumed Energy Costs: $1.25 / therm; $0.12 / kWh

Cost per Delivered Unit of Heat

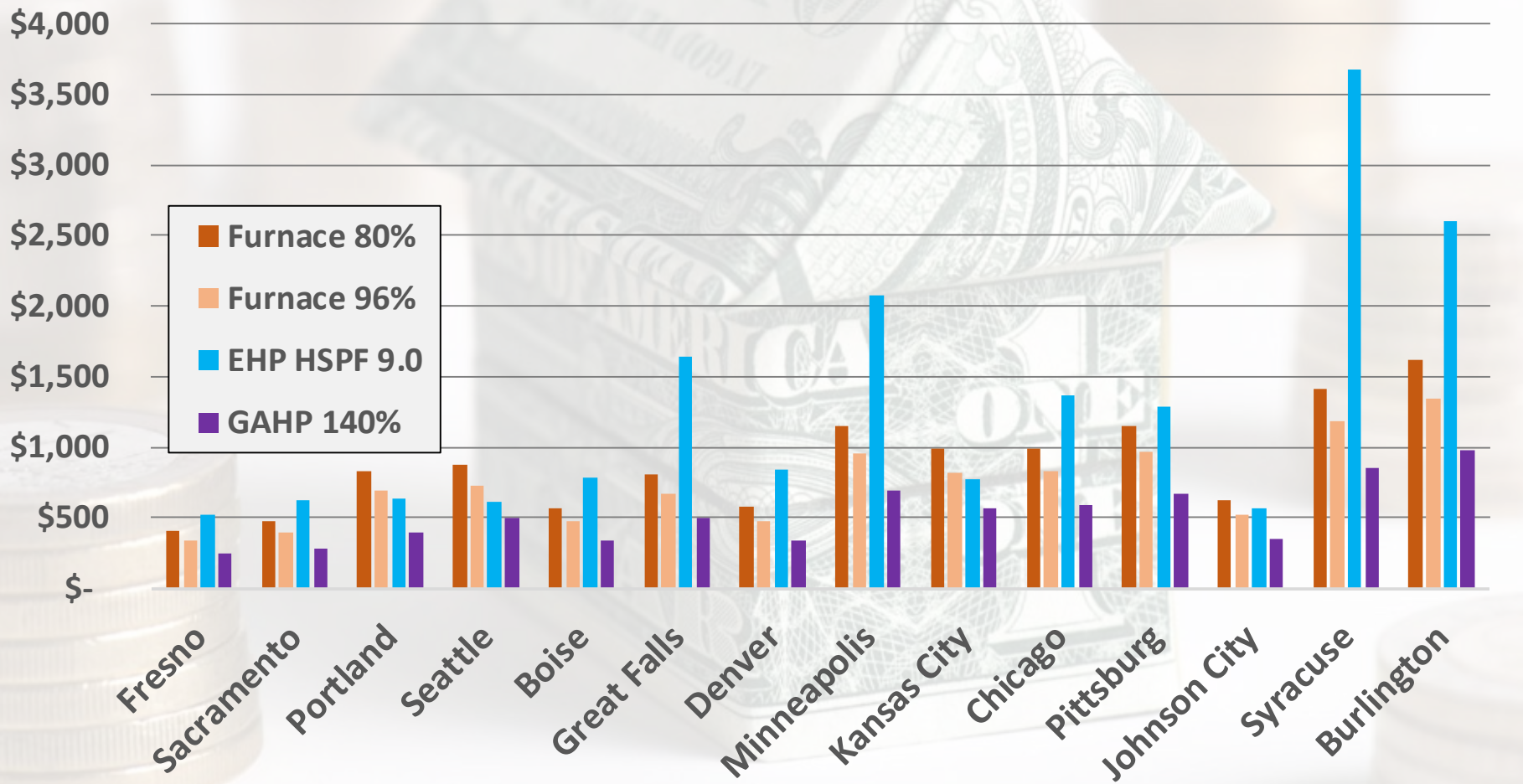
California

When electricity gets expensive…



Assumed Energy Costs: $1.19 / therm; $0.19 / kWh

Comparative Costs to Heat Homes – all Cool(er) Climates



Method and Assumptions

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- Space-heating load only
- EIA 2018 energy prices by state
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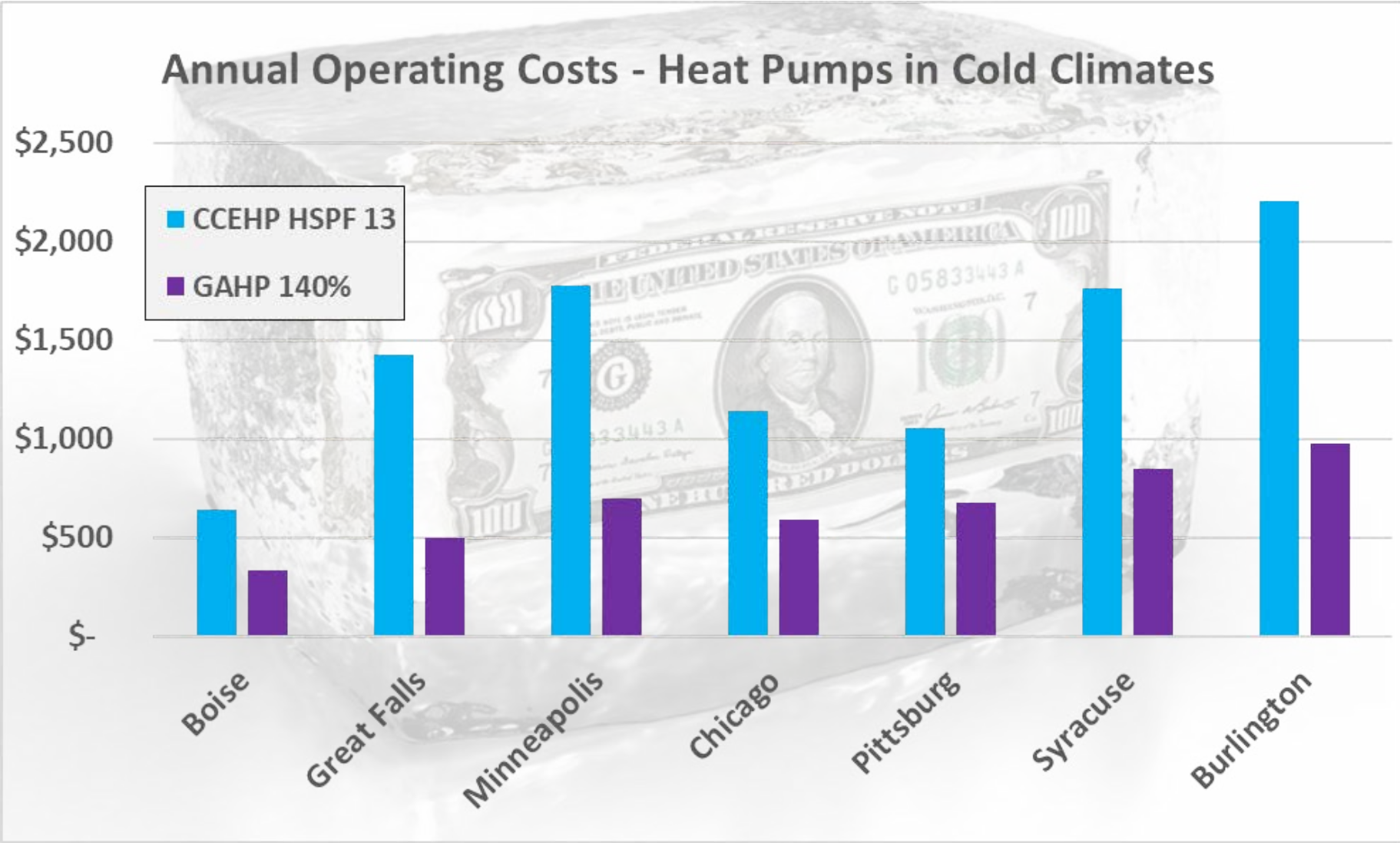
Comparative Cost to Heat Home – Cold Climates



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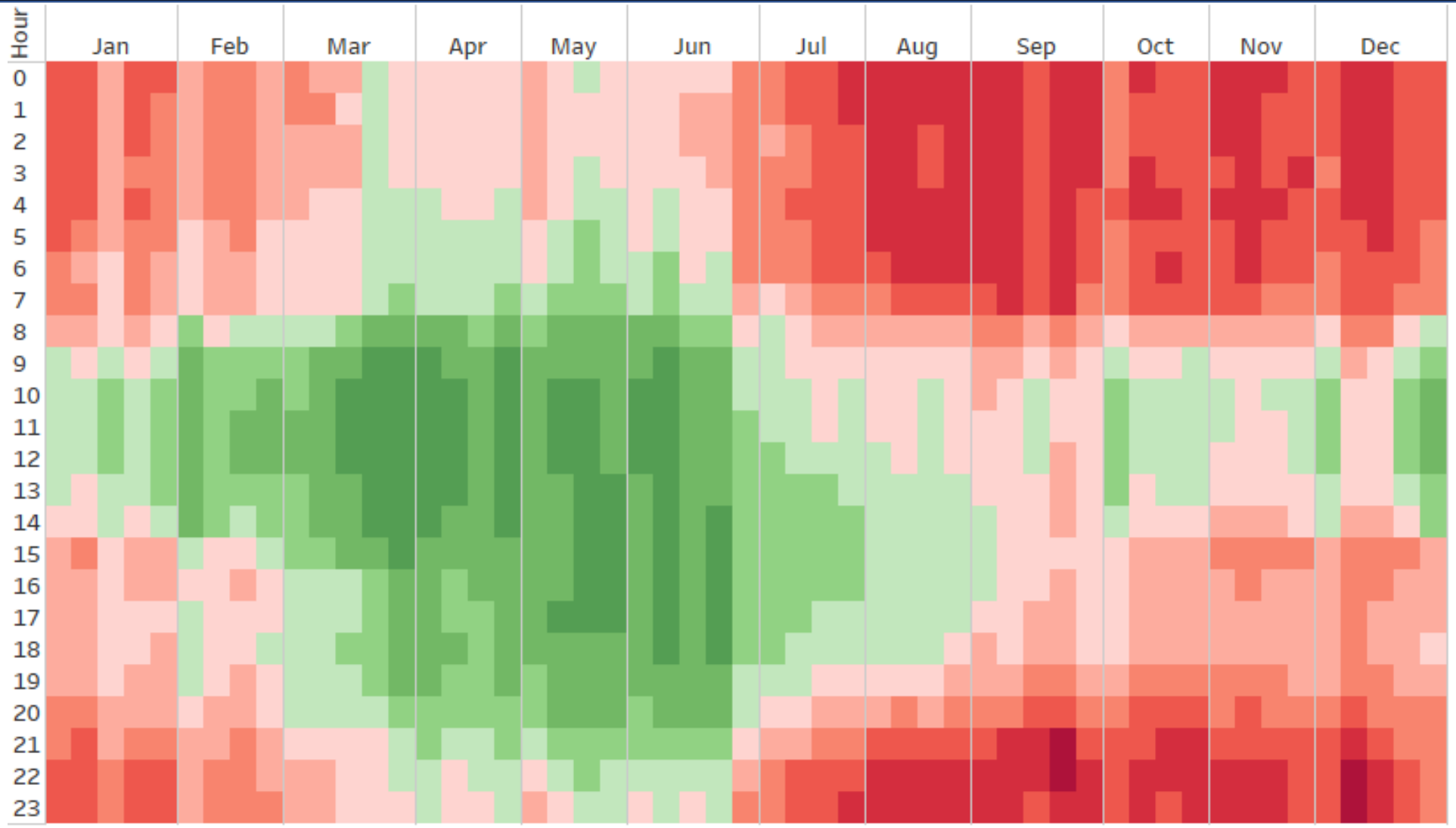
Other Considerations

California Grid Emissions Intensity Relative to Natural Gas 2019

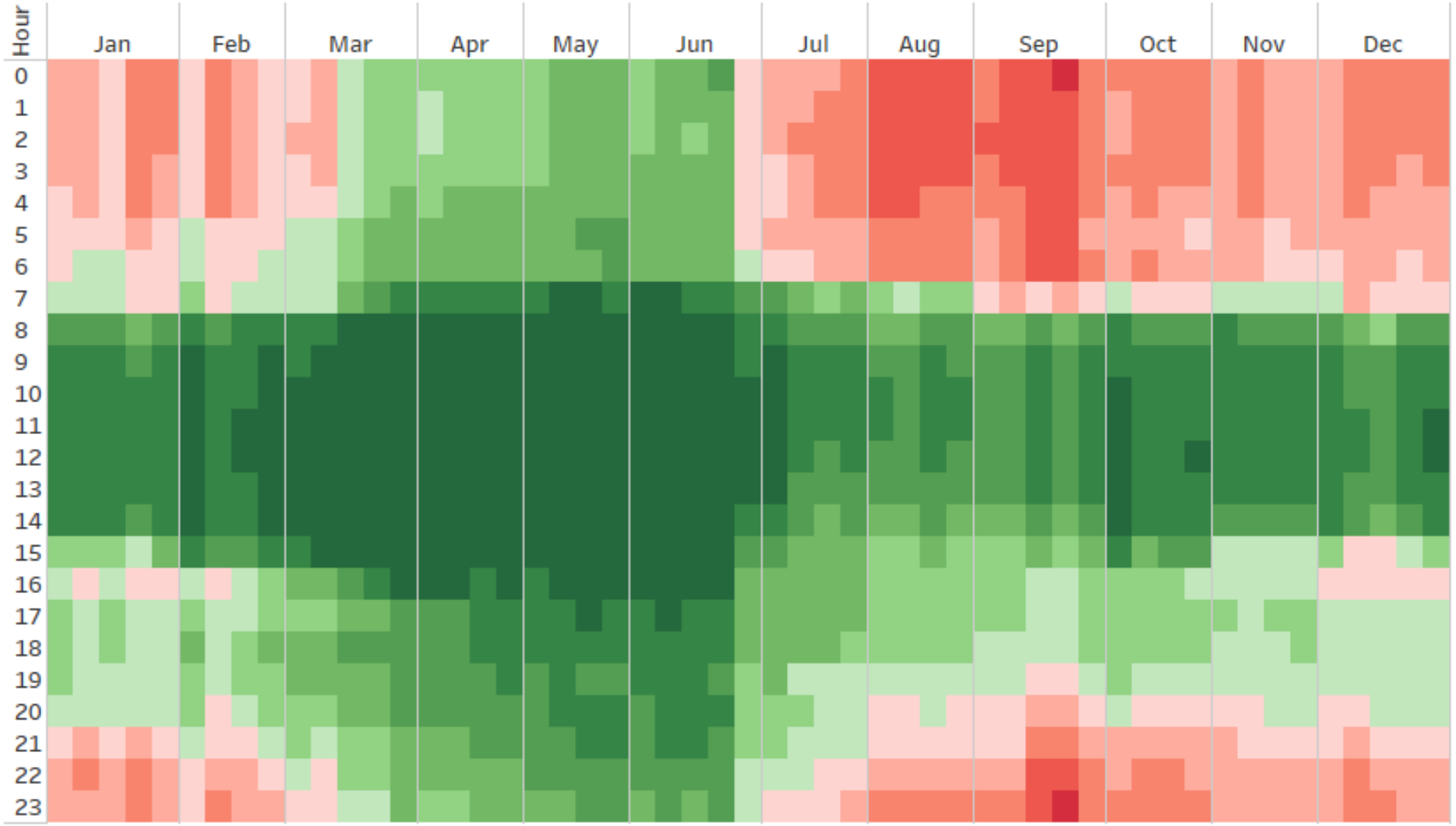


Season of Use and Time of Use affect Carbon Intensity

Building Heat is needed more often in the Red Zones

Courtesy
California Energy Commission

California Grid Emissions Intensity Relative to Natural Gas 2030 (proj)



Season of Use and Time of Use affect Carbon Intensity

Building Heat is needed more often in the Red Zones

Courtesy
California Energy Commission

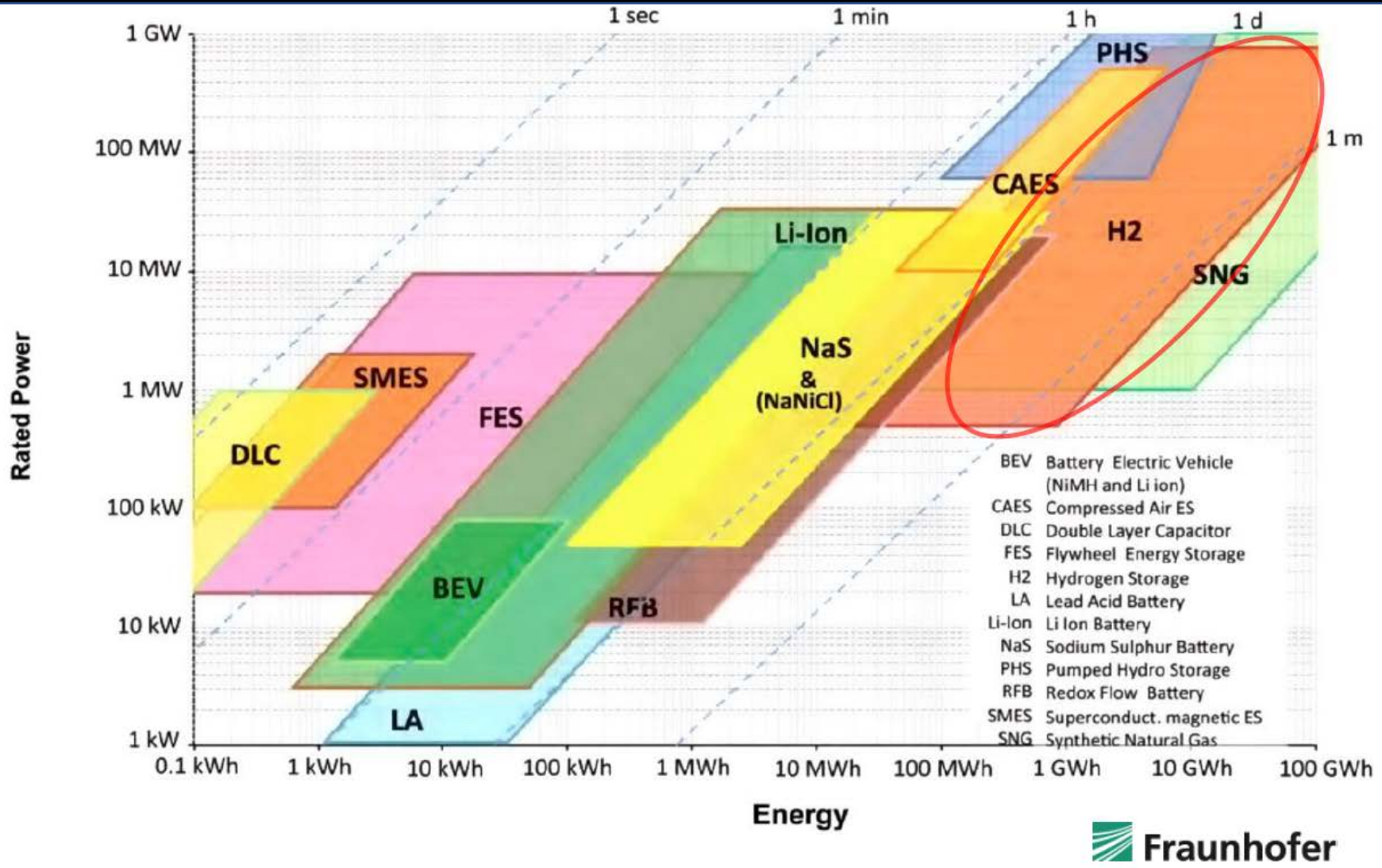
Other Factors to Consider

- How long until the electrical grid is nearing full use of renewables?
- How long until renewable gas (CH_4 , H_2) comes online at scale?

Is this a discussion about electricity vs. thermal fuels?

Or is it one about the fastest and lowest cost method to decarbonize?

What technology-class(es) can do energy storage at grid scale?



Fraunhofer

Renewable Fuel ideas

Manta Biofuels

- Algae 2.0 – magnetic harvest technique
- Scalable – species insensitive, wide climate range
- Scalable – farmers with some extra acres
- Prototype ponds making/selling #2 HH oil now
- Could also do 100% renewable CH_4

Electrochaea

- Generates H_2 from “stranded” PV / Wind power (a growing phenomenon with higher RPS)
- Natural “volcano bug” with CO_2, converts it to CH_4
- Utility-scale energy storage, no chemicals
- Demonstration projects in Europe (Germany!); also developing in US

Solutions?? (Think near- and long-term)

Near-Term

- Let <u>all</u> Heat pumps rule!
    - Incentivize decarbonization outcomes (not technologies or fuels)
- Invest in all-things renewable energy (solar / wind / H_2, CH_4)

Long-Term

- Depends on relative progress of renewable electricity and gas
- Remember, people don't generally accelerate replacement of HVAC equipment. Complete technology transitions are >25 years out
- Provide variety of options that enhance decarbonization opportunities for building owners

Thank you

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Basic Analysis Water-heating

Residential WH	U.S Average - current				
Per Year (25,000 gallons)	**GHPWH**	**EHPWH**	**Std Gas Storage Tank**	**Non-Cond Tankless**	**Cond Tankless**
UEF	1.2	3.7	0.64	0.82	0.95
therms used	100		225	168	145
kW-hr used	147	1105		5.0	5.1
CO2, lbs (baseload)	1,311	1,103	2,631	1,970	1,704
CO2, lbs (non-baseload)		1,659			
Nox, lbs (baseload)	0.22	0.77	2.09	1.57	1.36
Nox, lbs (non-baseload)		1.22			
Electric Rate, $/kWhr	$0.12				
Gas Rate, $/therm	$1.25				
Operating Cost, Annual	$142	$133	$281	$211	$182
Retail Price	$2,000	$1,750	$570	$1,152	$1,907
Est Installation Cost	$800	$1,300	$700	$1,200	$1,400
Total Install	**$2,800**	**$3,050**	**$1,270**	**$2,352**	**$3,307**
Est. Maintenance/Year	$15	$15	$10	$30	$30
Lifecycle Cost (12-year)	$4,686	$4,821	$4,766	$5,241	$5,854
Payback (yrs) vs. Std Gas	11.4	12.4		21.4	25.8

Another way to look at Water Heater Lifecycle Cost

LifeCycle Cost / Gallon	Install	Operating	Maint./yr	Years	Cost / Gal
GHPWH	$2,800	$142	$20	15	**$ 0.014**
EHPWH	$3,050	$133	$20	15	**$ 0.014**
Std Gas Storage Tank	$1,270	$281	$0	12	**$ 0.015**
Non-Cond Tankless	$2,352	$211	$150	20	**$ 0.019**
Cond Tankless	$3,307	$182	$150	20	**$ 0.020**

Space Heating Calculations

Space Heating: U.S. Average Electric Heat Pump: 14 SEER/8.2 HSPF						
Ambient Temp.	**47**	**37**	**27**	**17**	**7**	**-3**
COPe	3.68	3.27	2.88	2.45	2.09	1.62
therms delivered	1,500	1,500	1,500	1,500	1,500	1,500
kWhr Used	11,946	13,444	15,265	17,944	21,035	27,137
CO2 lbs, avg load)	11,927	13,423	15,240	17,915	21,001	27,094
CO2 lbs (marginal load)	17,931	20,180	22,912	26,934	31,573	40,733
NOx lbs (avg load)	8.4	9.4	10.7	12.6	14.7	19.0
NOx lbs (marginal load)	13.1	14.8	16.8	19.7	23.1	29.9
Electric Rate, $/kWhr	$0.12					
Gas Rate, $/therm	$1.20					
Operating Cost	$1,434	$1,613	$1,832	$2,153	$2,524	$3,256
Retail Price, per kbth	$45	$45	$45	$45	$45	$45

Space Heating: U.S. Average SMTI GAHP						
Ambient Temp.	**47**	**32**	**0**			
COP	1.45	1.35	1.17			
therms delivered	1,500	1,500	1,500			
therms used	1,034	1,111	1,282			
kWhr/therm delivered	0.56	0.58	0.60			
kWhr used	840	870	900			
CO2 lbs, avg load)	12,932	13,857	15,886			
CO2 lbs (marginal load)						
NOx lbs (avg load)	3.0	3.2	3.6			
NOx lbs (marginal load)						
Electric Rate, $/kWhr	$0.12					
Gas Rate, $/therm	$1.20					
Operating Cost	$1,342	$1,438	$1,646			
Retail Price, per kbth	$58	$58	$58			

Combi-heating (DHW & space): Emissions and Operating Costs

GTI Study

Paper 204, ASHRAE 2019

Demonstration and Simulation of Gas Heat Pump-Driven Residential Combination Space and Water Heating System Performance

Assumptions & Methods

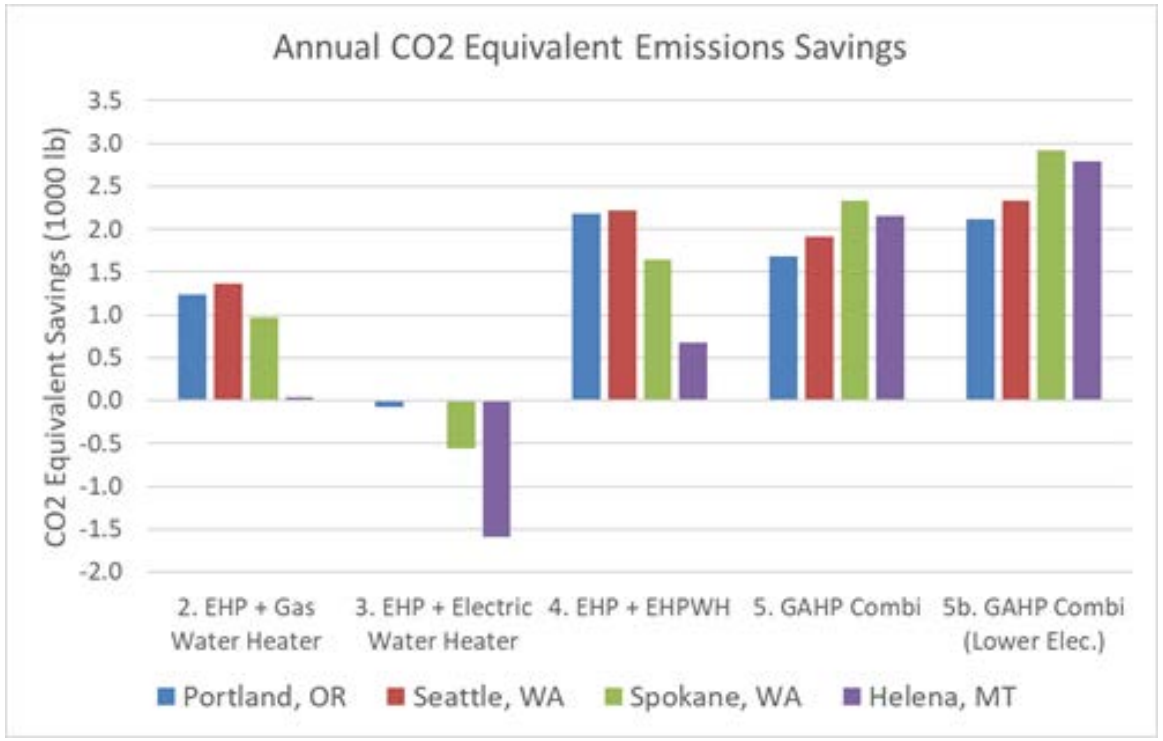
- EnergyPlus modeling
- Local costs of energy
- DHW prioritization
- Sized to Design Load + 10-20%
- GAHP: 140% AFUE (field data fit)

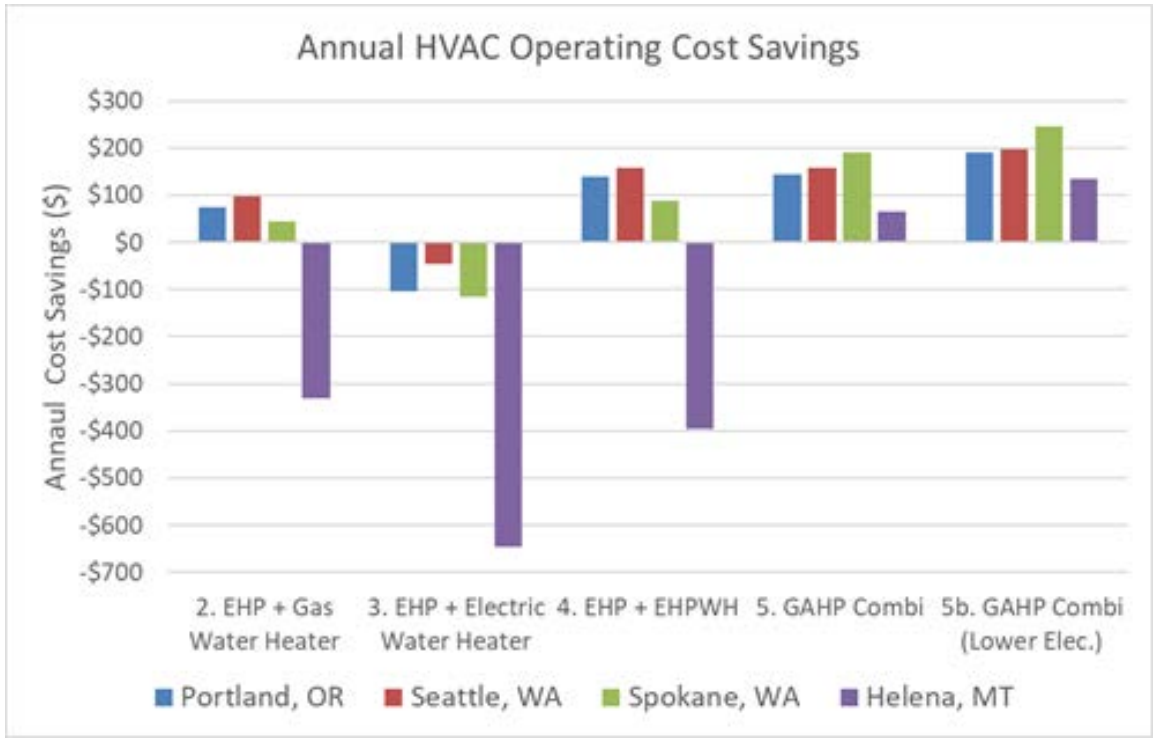
Table 1. Equipment Scenarios for Building Energy Simulation

Scenario	Water Heater	Space Heating	Space Cooling
1 (baseline)	Conventional Gas (UEF= 0.62)	Condensing Furnace (AFUE = 92%)	SEER13 AC
2	Conventional Gas (UEF= 0.62)	Unitary Electric Heat Pump (HSPF = 8)	SEER13 AC
3	Electric (UEF = 0.92)		SEER13 AC
4	Electric Heat Pump Water Heater (UEF = 2)		SEER13 AC
5	GAHP combi (data fit)	GAHP combi (data fit)	SEER13 AC

Courtesy GTI

Combi-heating (DHW & space): Emissions and Operating Costs





Courtesy GTI

Consider costs to change out the grid for all-electric building heat

Electricity Grids

- Build out new transmission / distribution
- Utilize the new capacity only during winter
- Build many more renewable assets (wind/solar)
- New Renewables used at ½ the usual Capacity Factor (= 2x the price per unit)
- The energy storage puzzle

Gas Pipelines

- Abandoned pipelines
- Who pays? (ratepayers)

Example: SoCal Gas

- Value of assets: $14.2 billion
- Total Ratepayers: 5.9 million
- Per Ratepayer: $2400