Heating Electrification Strategies to Decarbonize BU's Major Buildings: January 2022 update

1. Decarbonization framework for BU
2. Technical Constraints & Design Implications
3. Financial Analysis & Policy Questions
4. Summary of Deep & Quick Decarbonization Strategy

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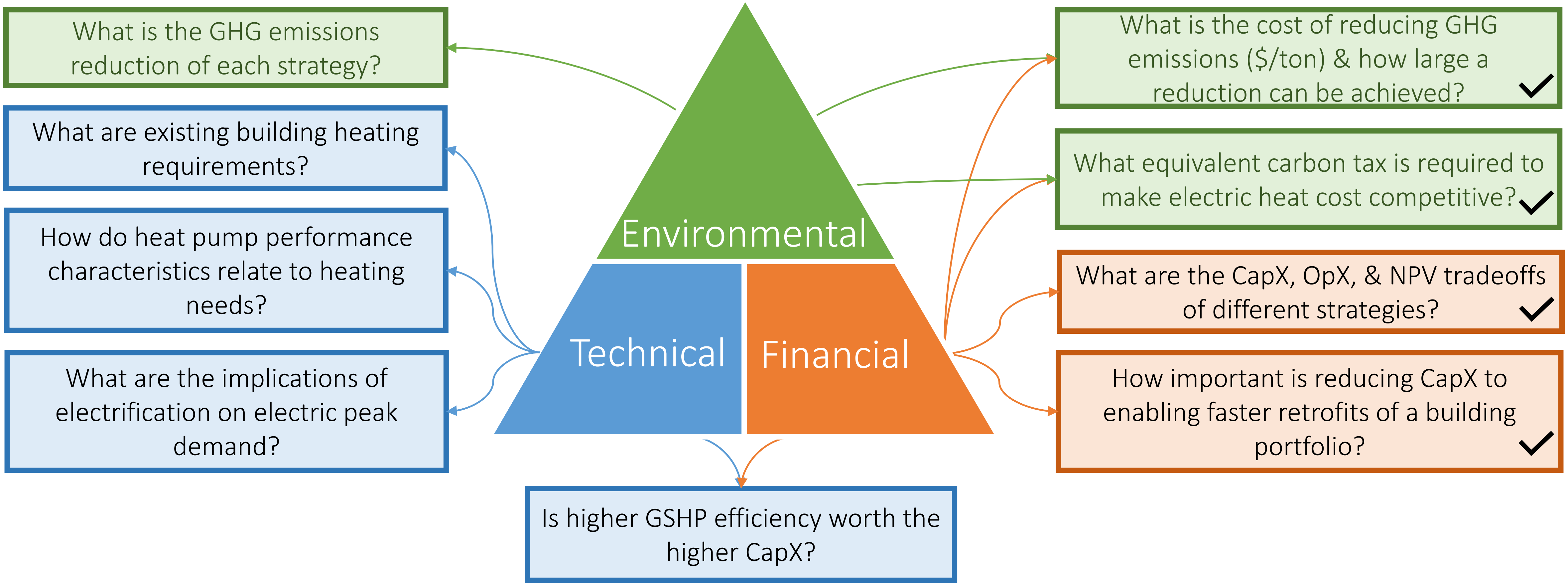
Decarbonization Framework

- 40% of BU's total GHG emissions come from heating loads. 274 buildings (11.8 M GSF)
- Strategy: Electrify 14 largest buildings to reduce up to 46% of heating GHG emissions
- **How can we electrify the greatest % of BU's fossil heating systems, in the shortest time, meeting building heating requirements, & capital/operating budget constraints? →** solutions applicable to existing, commercial buildings



Heating Electrification Technology Tradeoffs

- <u>Air- vs Ground- source Heat Pumps</u>: ASHPs are less efficient than GSHPs and require more capacity on coldest days b/c of de-rating, but require 2X less capX
- <u>High Temp vs Low Temp Heat Pumps:</u> High-temp HPs produce heating fluid compatible with existing perimeter heat exchangers, but are less efficient and require more capX than low-temp HPs
- <u>Natural Gas boiler (baseline) & conventional Electric Boiler:</u> lower capX and efficiency compared to heat pumps
- Note: COP quantifies efficiency, therefor a higher COP = lower OpX
- Analysis based on in-depth detailed studies of several BU buildings

	Conventional Fossil	**Conventional Electric**	**Low-Temp (130°F) Heat Pumps**		**High-Temp (180°F) Heat Pumps**	
	Natural Gas Boiler	**Electric Boiler/ Resistance**	**Low-Temp Air-Source Heat Pumps**	**Low-Temp Ground-Source Heat Pump**	**High Temp Air-Source Heat Pump**	**High Temp Ground-Source Heat Pump**
	NG Boiler	Conventional Electric	ASHP/LT	GSHP/LT	ASHP/HT	GSHP/HT
Coefficient of Performance COP	0.85	1.0	3.0	5.0	2.0	2.5
System Equipment Cost per Ton ($/Ton) [2]	$200	$200	$2,700	$9,500 [1]	$3,600	$8,600 [1]

[1] GSHP equipment costs include installed cost of bore hole

[2] Equipment costs for >200 Ton systems

Constraints: Technical Requirements for Retrofitting Existing Building

Key Considerations:

1) Relation of **required heating power to** equipment sizing
2) **Capacity factor** of equipment (cost-effectiveness, utilization)
3) **Heating fluid temps** for existing building heat exchangers
4) Increased **electrical demand** relative to building capacity

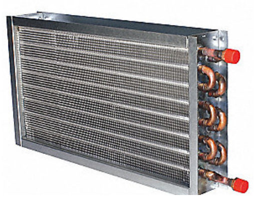
Design Question:

Which configurations / combinations of heating equipment can best meet these consideration?

Critical Heating System Characteristics

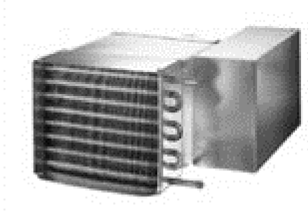
Existing Natural Gas Boilers

AHU Fluid Temps:
160 F Supply & 120 F Return



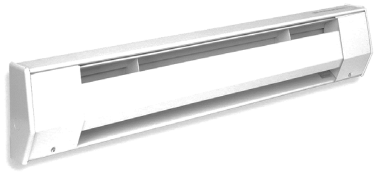
AHU Heating Coil

VAV Fluid Temps:
160 F Supply



VAV Heating Coil

Perimeter Fluid Temps:
190 F Supply



Perimeter Heat Radiator

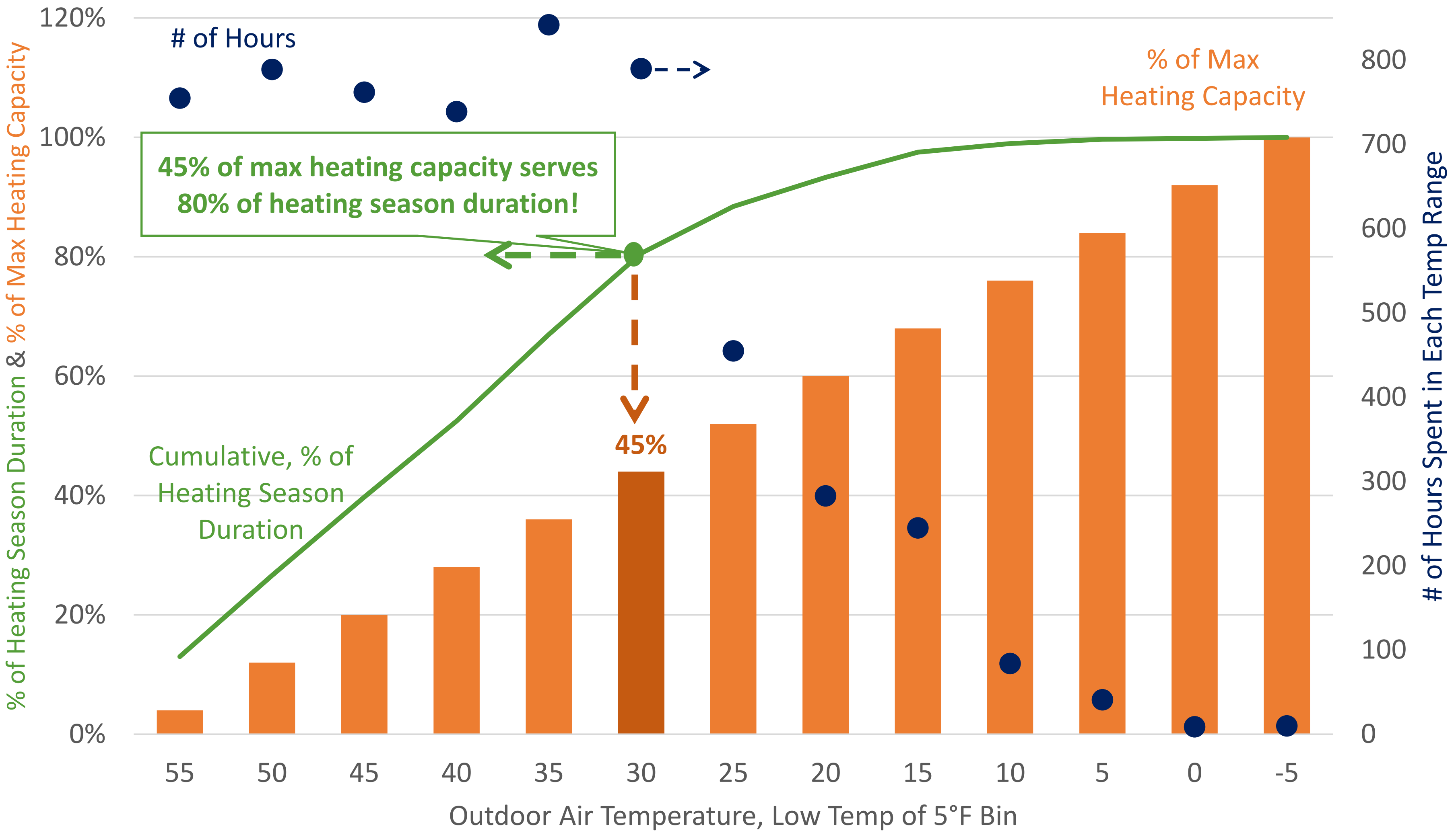
Model building: 380K ft^2 office / classroom with ~350 ton heating load

Required Heating Capacity: Impact on CapX, OpX, & GHG emissions

- Typically, equipment sized to meet heating demand on coldest day
- However, only ~20% of the heating season has temp <30F

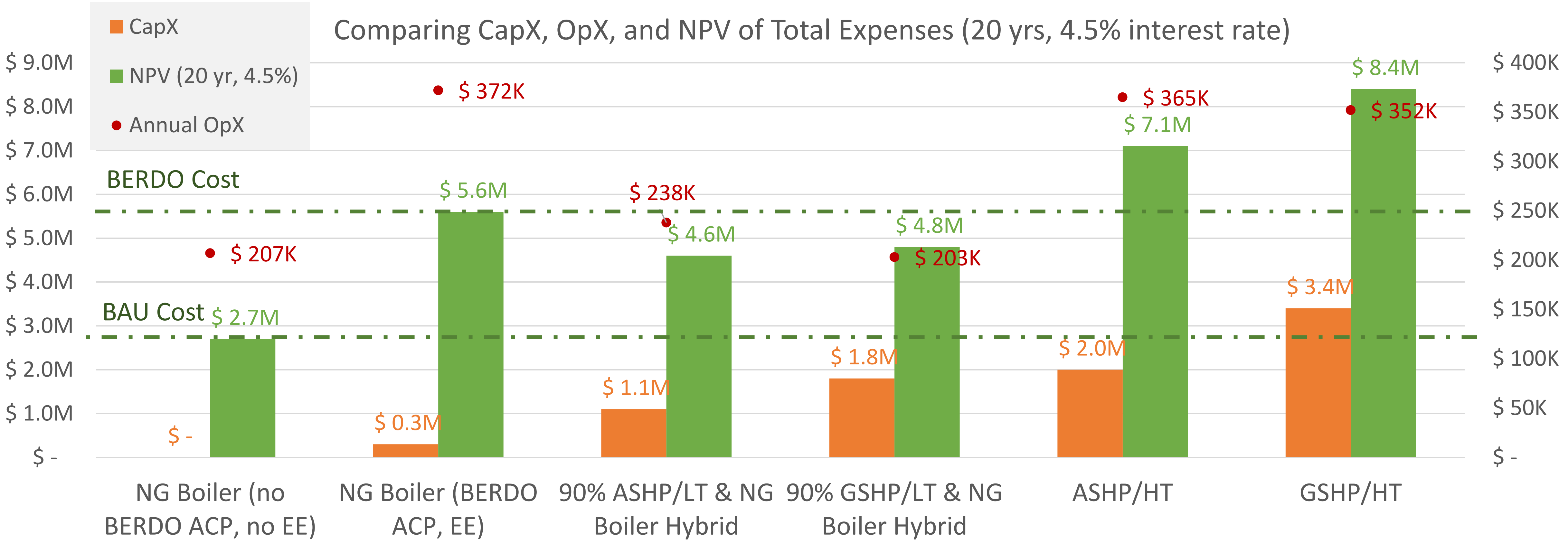
<u>Hybrid Solution:</u>

- Size expensive heat pumps for 45% of peak heating demand → reduces CapX
- Use conventional boilers for coldest days
- Increases Heat Pump Capacity Factor to 64%
- Achieves 92% GHG reduction



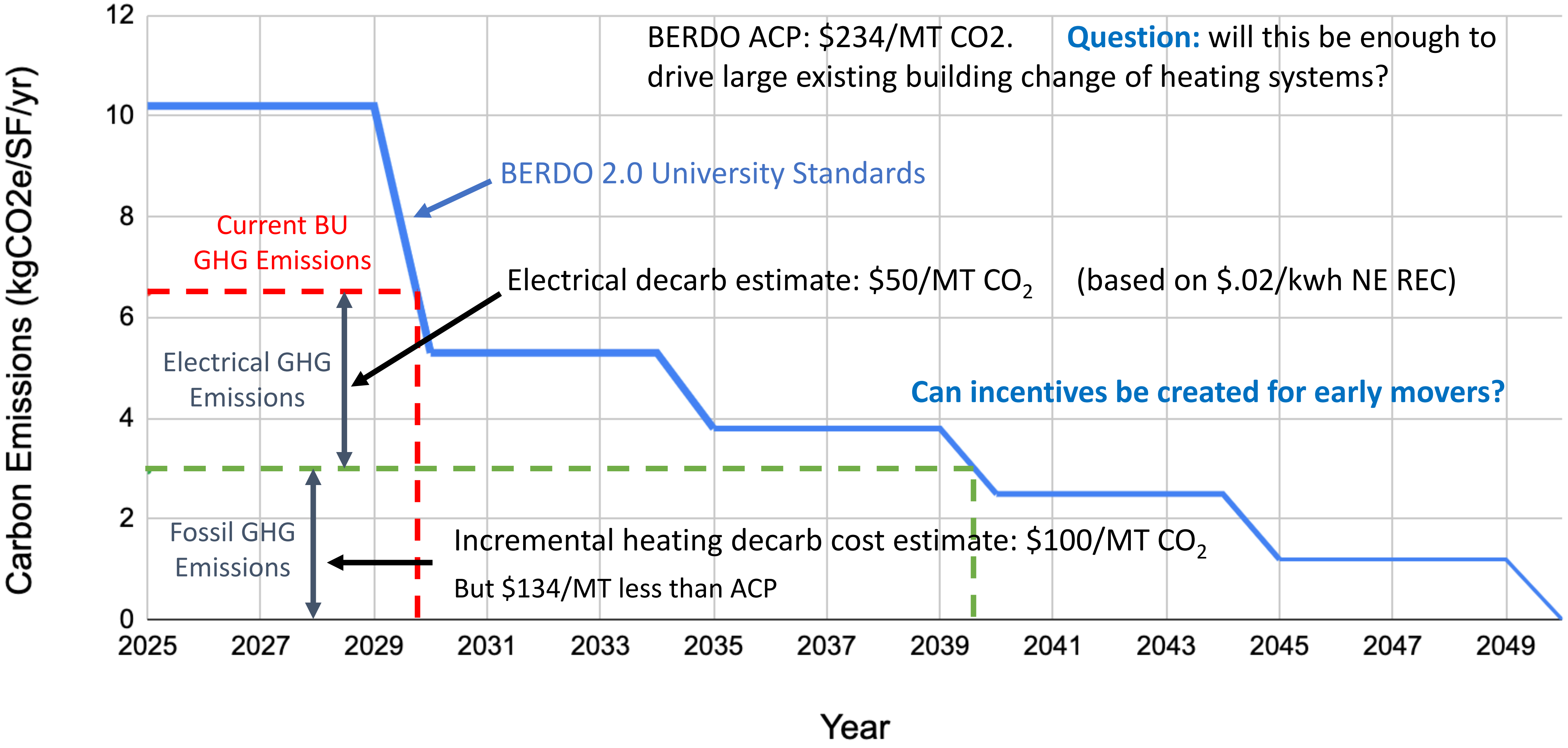
Financial Analysis of Alternative Electrification Strategies

- Electrification is a net cost increase compared to BAU
- **BERDO ACP** cost ($234/Mton of CO2e) increases “cost” of operating existing NG Boilers
- Capital limitations → GSHP Hybrids ~1.6x the CapX of ASHP Hybrids w/ similar NPV. Does it limit roll out?



Estimated Compliance Time Frame & Costs:

Boston BERDO 2.0 University Requirements & Current BU Campus Emissions



Electrification Summary for Fast & Deep Decarbonization

- **Hybrid strategy**: achieves high-capacity factor for heat pumps, reduces CapX to enable faster rollout, meets heating demand on coldest days, achieves 90% carbon reduction.
  - ASHPs vs GSHPS: ASHPs are ~40% cheaper than GSHPs in CapX, but are ~20-40% less efficient
  - Hybrid Incremental cost: $100/MT CO2 [relative to $234 ACP & BAU] 92% carbon reduction
- **Estimated Impact under BERDO (whole BU campus):** a) BU doesn't need to start changes till 2030. b) First round: cheapest to buy green electrons (depends on price conditions in 2030-2040 time frame), c) ACP impact for heating electrification starts in 2040, $134 savings relative to BERDO ACP [Suggestion: don't allow area to count from building parking areas]
- **Climate needs quicker action. How to drive that? Incentives to early movers?**
- **Proposed BU implementation plan**
  - 12 yr plan: Electrify 3.8M GSF (14 key buildings) to reduce 46% of BU CRC's heating fossil fuel use
  - CapX: $3.5M/yr ($32.2M investment) Annual OpX: $10.3M/yr
  - Post-Electrification OpX will be 40% less than existing NG system with BERDO ACP
- **Key Issues for Spring 2022**
  - Capacity and COP vs. OA, heat recovery for summer reheat, buildings on steam loops, ASHP and heat exchanger configuration, and refining cost estimates

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Estimating Costs & Financing Large CapX Projects

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Understanding Boston University's Planning, HVAC Implementation, & Budget

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Understanding Building HVAC Design & Heat Pumps

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Additional Slides

Constraint: Heating Fluid Temperatures

Key Question: How well will low-temperature (130F) heat pumps perform in buildings with existing high-temperature (170-190F) hot water heat exchangers (perimeter heat, VAV, AHU)?

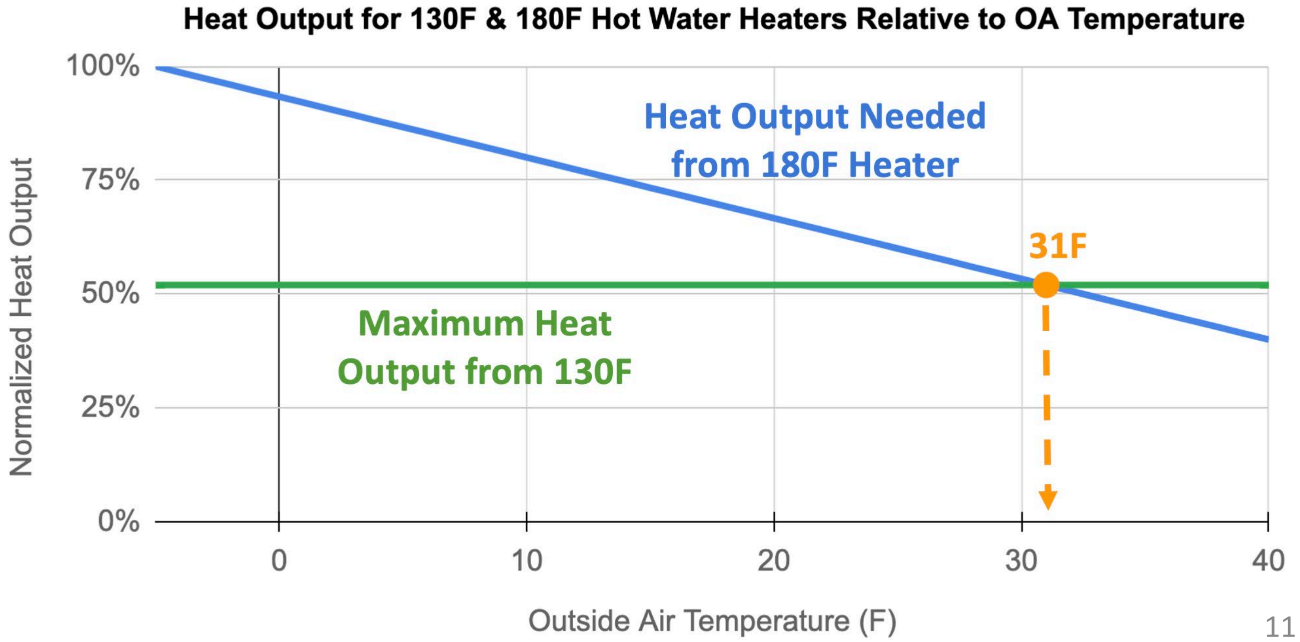
Motivation: Determining whether we can use low-temperature heat pumps (lower capX, higher COP) in hybrid heat pump system and provide required thermal comfort throughout the heating season.

Results:

- Our analysis shows 130F hot water provides required heat when outside air temps are >= 31F [1]
- When temps are <31F, use NG/Electric Boilers for supplemental heating with higher temperature working fluids (only 20% of heating season hours & 10% of energy used)

Conclusion:

- Low-temp heat pump hybrid strategy will meet heating needs [2]
- Enables 90% GHG emissions reduction



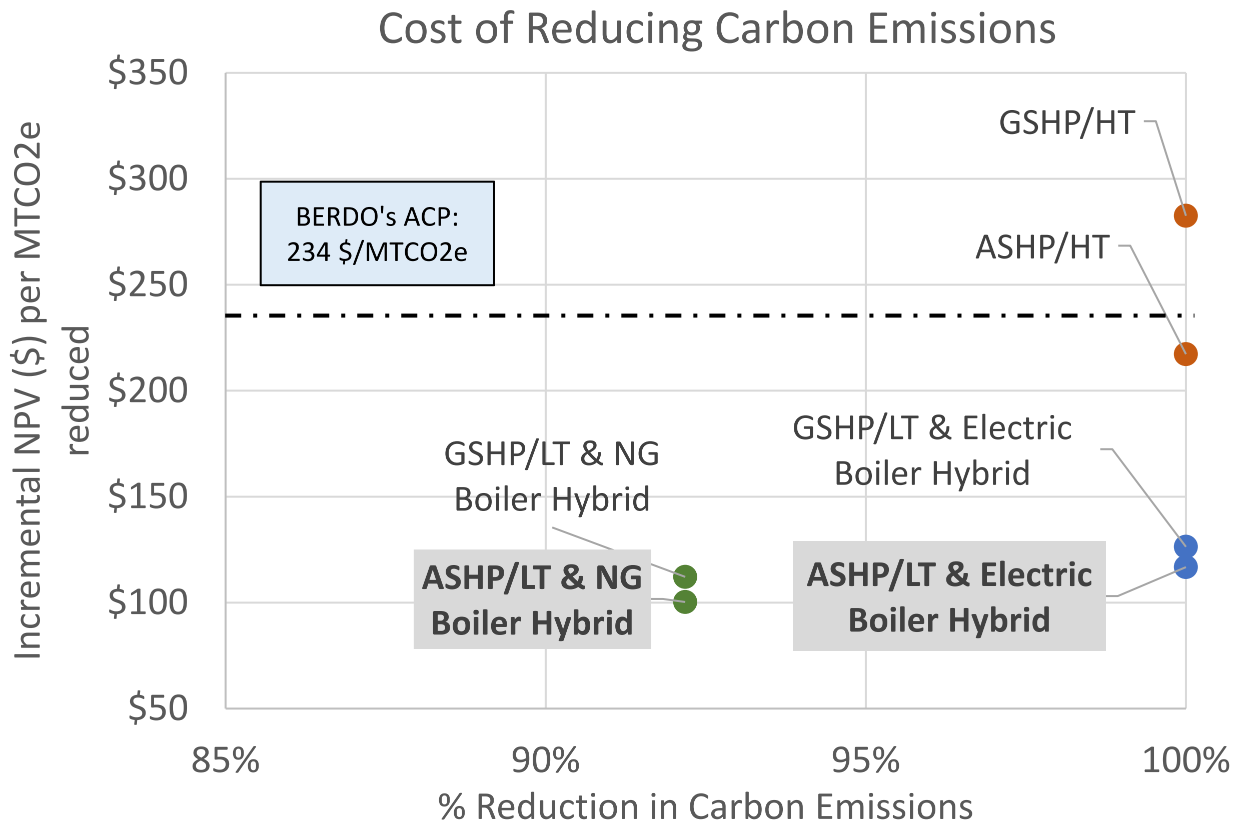
[1] Verified by Sterling HS application manuals
[2] Strategy applicable to both ASHPs and GSHPs

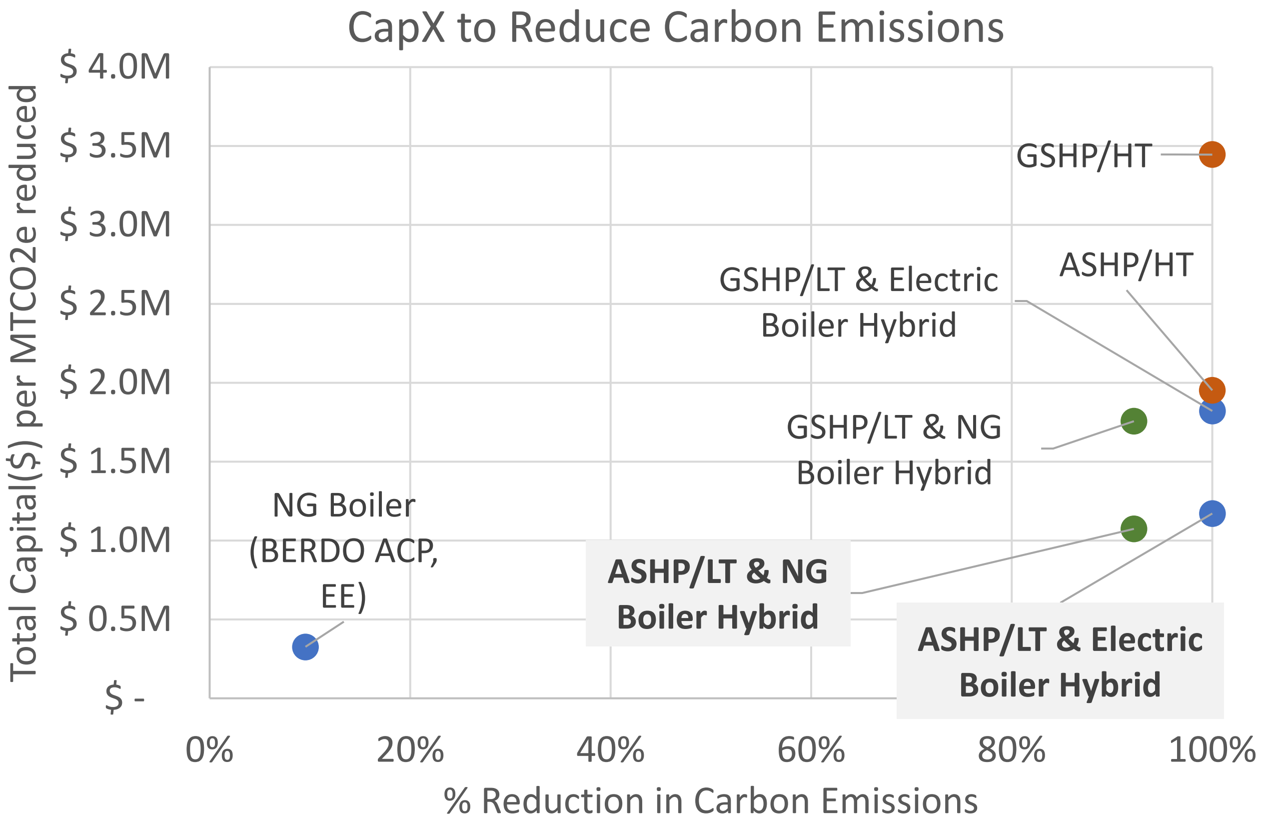
Cost of Reducing Carbon Emissions: NPV & CapX

- Boston BERDO's Alternative Compliance Payment (ACP): $234/MTCO2e **Corresponds to 2.2X NG price** ($1.07/therm → $2.31/therm)

<u>Insight:</u>

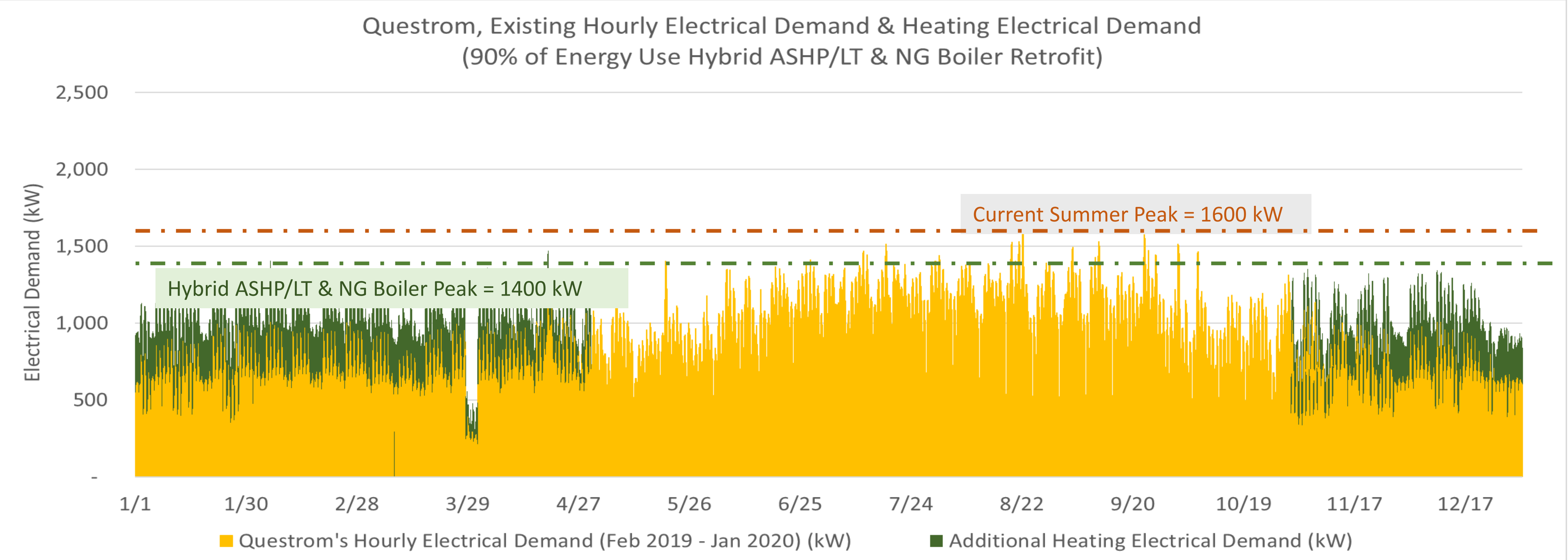
- Hybrid systems provide *cost savings* vs NG system with BERDO ACP (y-axis), minimize CapX needs for heating electrification, w/ 92% GHG reduction
  - Hybrid Electric Boiler + ASHP/LT systems can achieve 100% reduction: but would require increase in electric capacity





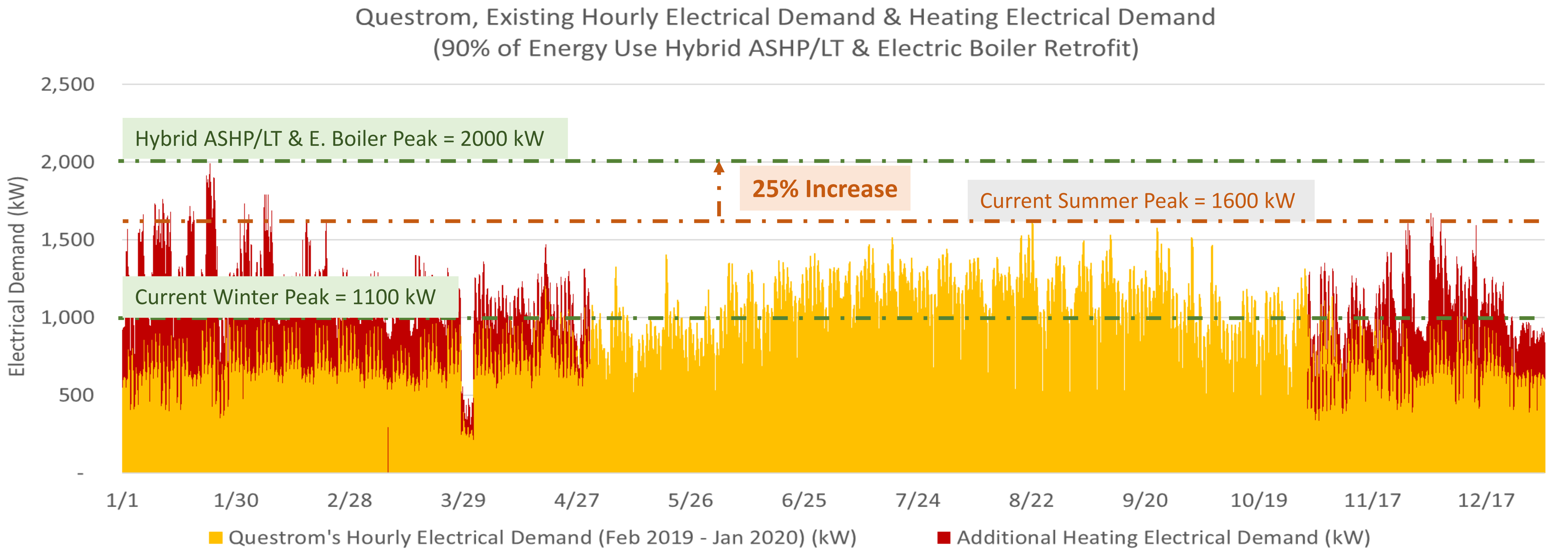
Heat pump impact on Electrical Capacity & Peak Demand

- For Hybrid System: ASHP/LT & existing NG boiler
- **New heating season electrical peak but less than existing cooling season peak**
- Building electrical capacity upgrade not required for 90% decarbonization retrofit



100% Decarbonization: ASHP/LT & Electric Boilers

- 90% → 100% decarbonization strategy: Replace existing NG boilers with electric boilers
- Change in electrical demand: Expect increase of ~0.9 MW on coldest days
- Outcome: Although peak electrical demand exceeds summer peak, 2.0 MW need < 13.6 MW supply → may not require building electrical upgrades to operate



Hybrid System: operation with higher capacity factors

- Using Heat Pumps & Boilers: Increases Capacity Factor (CF) of Heat Pumps but decreases total GHG emission reduction
  - Capacity Factor (CF): % of time one uses an expensive CapX system → Higher CF enables more efficient utilization of expensive heat pump
  - 31% → 64% Capacity Factor: increases cost-effectiveness of high CapX heat pumps
  - 89% of heating Energy Use: Indicates % of GHG reduction if NG boiler used to supplement heat pump