SMNR 60: The Risk of Decoupling Efficiency and Decarbonization

Why Efficiency and Scale Are Critical to Heating Electrification/Decarbonization Retrofits

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ENGINEERING
TOMORROW

1. Understand the risks associated with incorporating carbon free solutions on end use or primary efficiency.
2. Explain the major factors impacting emissions from electrified heating.
3. Provide examples of how in certain cases electrification of heating can actually increase heating emissions.
4. Offer general guidelines for assessing the best decarbonization strategy for heating systems

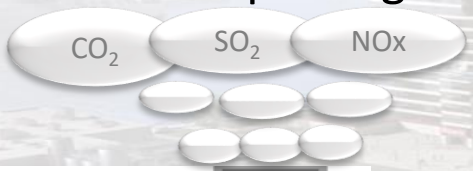
Outline/Agenda

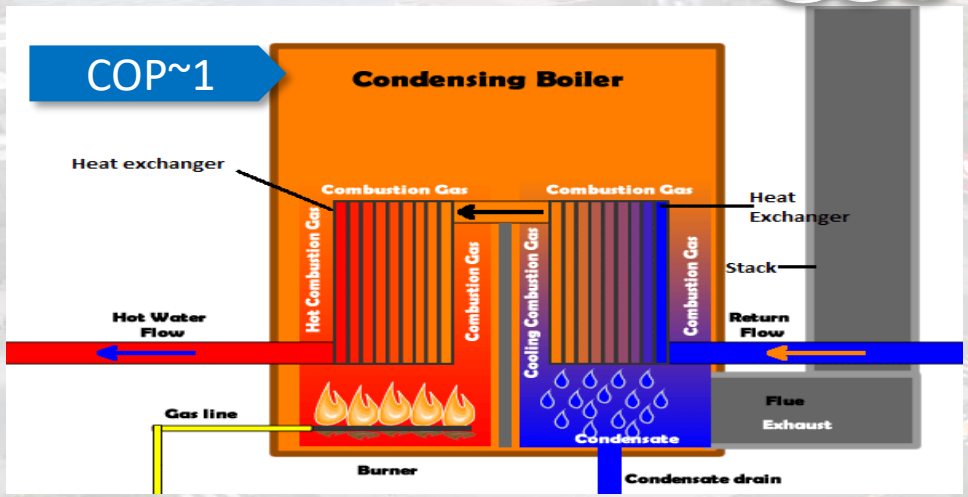
- Why is the market focused on heat pumps
- Challenges created by renewables and heat pumps / How to address
- Integrated system retrofit options
- Why Water-Water Heat Pump & High Heat Recovery Temperature are Critical
- Guidance for Efficient & Resilient Electrification of Heating

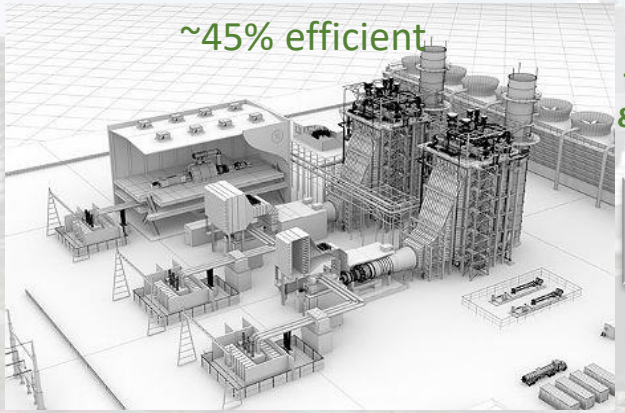
Why is the market focused on heat pumps?
Efficiency & Decarbonization

Fossil fuels	Heat pumps

- Inefficient
- Drive CO_2 & other gas emissions impacting environment







Transmission & Distribution

-10%

COP~2.5-3.5

~35% operating cost reduction
~60% emissions reduction

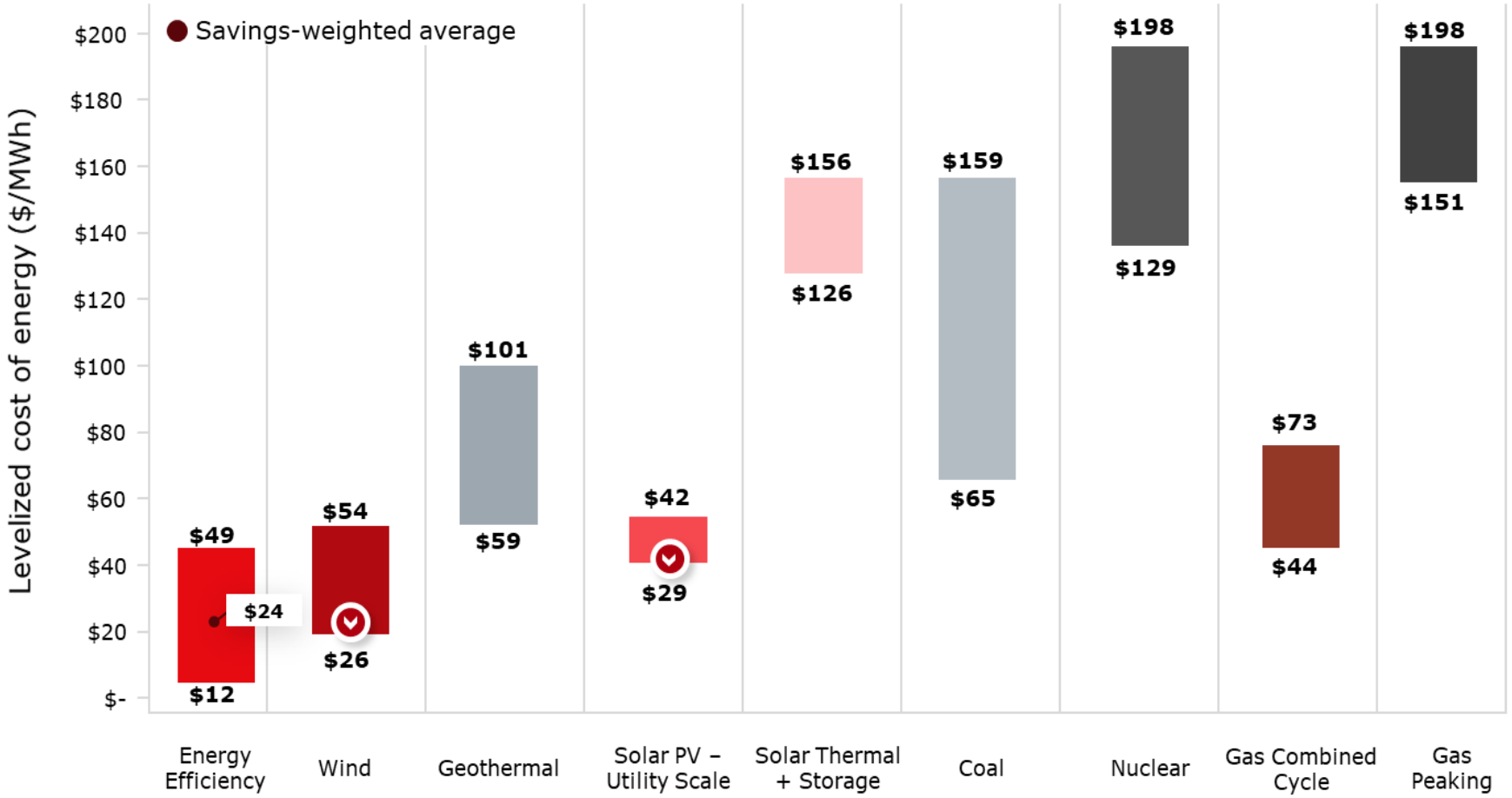
- More efficient
- Efficiency increases at part-load/lift

Heat Pump Part Load Efficiency

Why is the market focused on heat pumps?
Energy costs

Efficiency still the lowest cost energy source

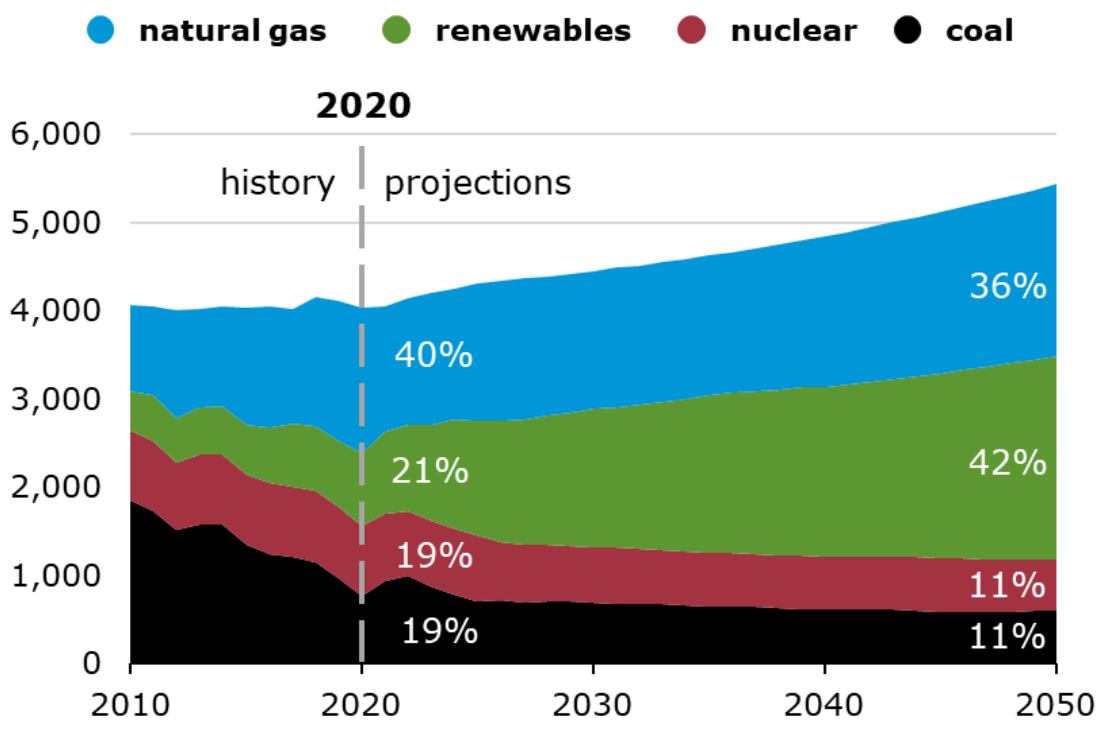
As renewable volumes go up, cost comes down – Lowest cost, next to efficiency



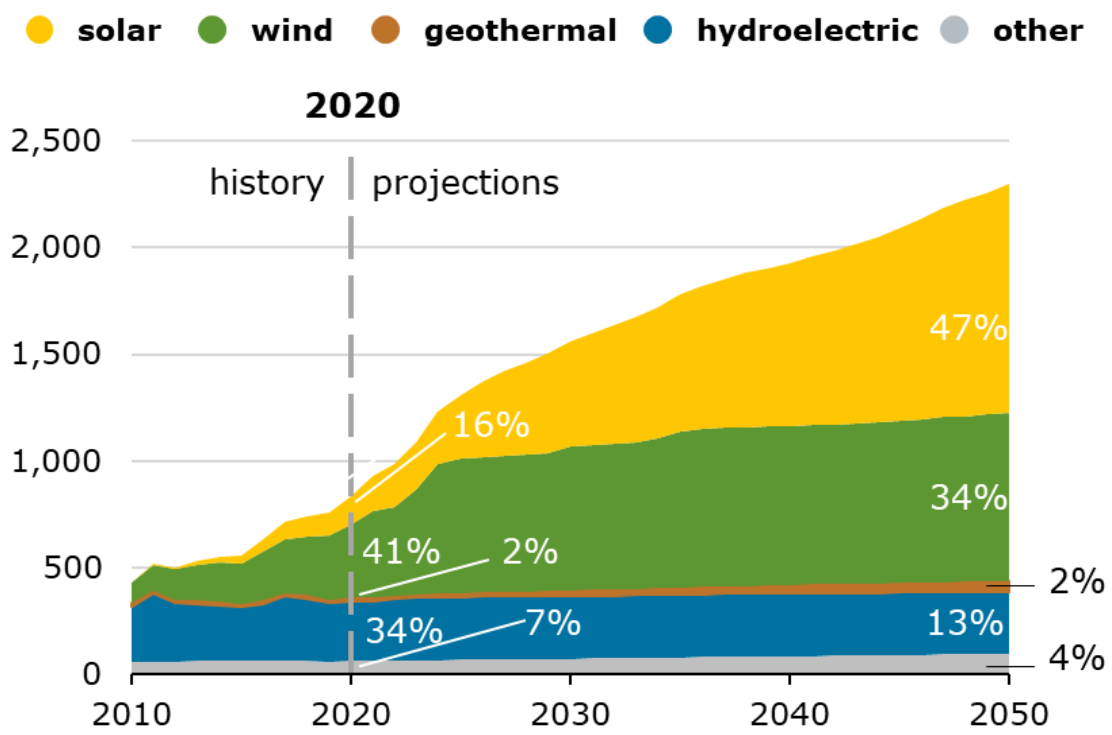
Source: ACEEE

Why is the Market Focused on Heat Pumps?
Emissions Reduction

U.S. electricity generation from selected fuels
AEO2021 Reference case
billion kWh

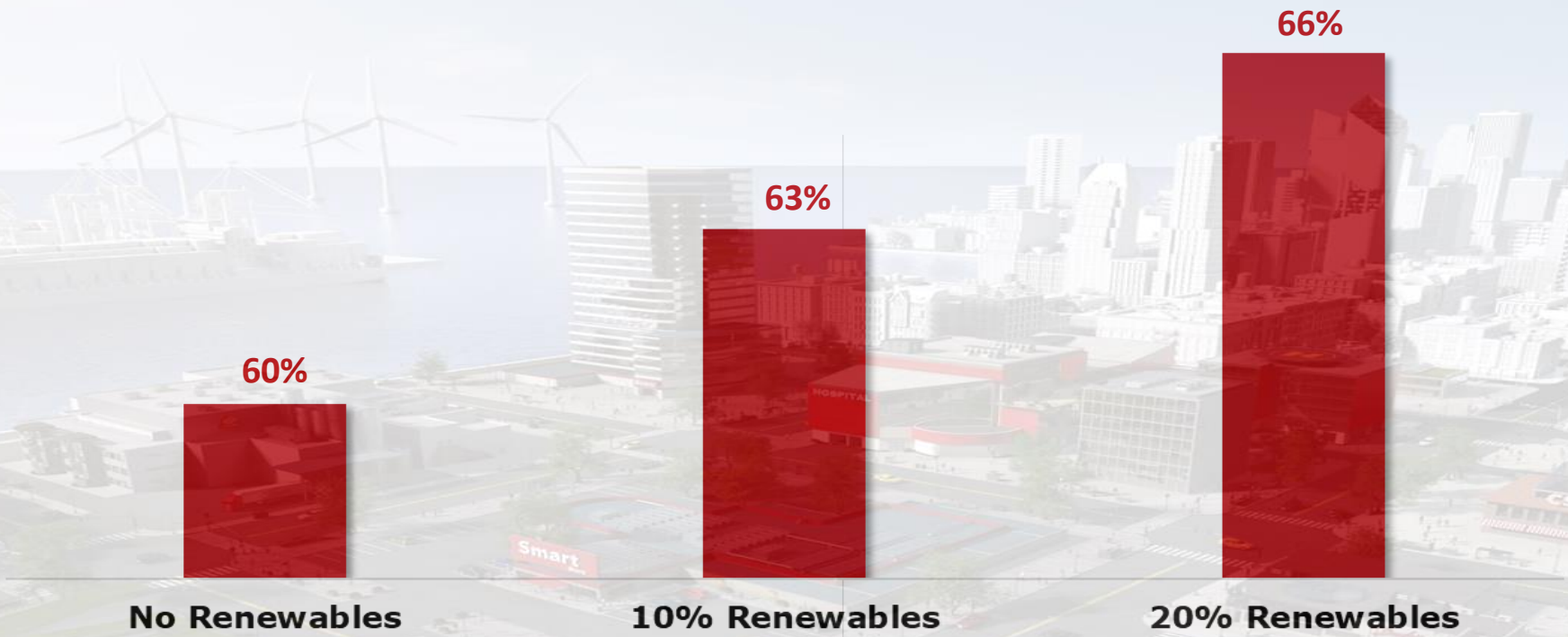


U.S. renewable electricity generation, including end use
AEO2021 Reference case
billion kWh



Source: EIA

Why is the Market Focused on Heat Pumps?
Emissions Reduction – Increase with Renewables



As grid integration of renewable energy grows, so does heat pump resulting **greenhouse gas emissions reduction**

Heat Pump CO_2 Emissions Reduction:
Renewables integration impact

Based on AWHP applied in 'warm' climate

Challenges created by renewables and heat pumps
Supply/Demand Disconnect

Supply

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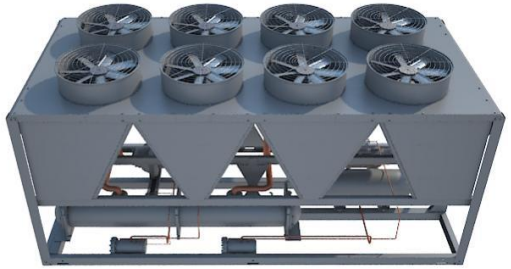
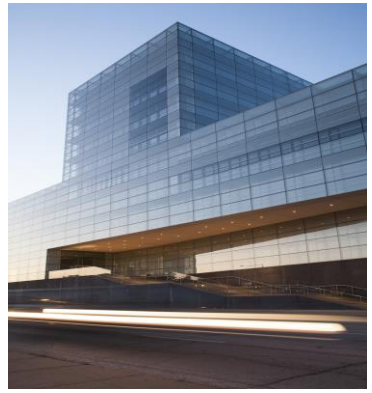
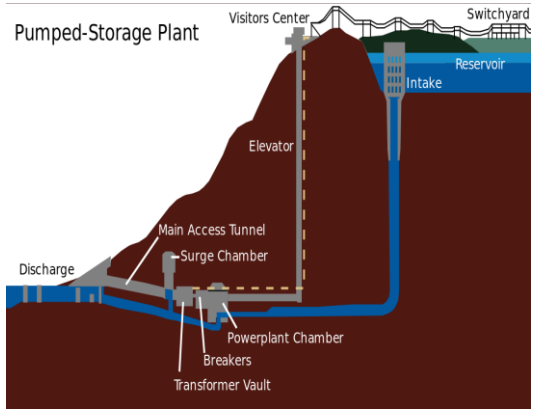
Demand





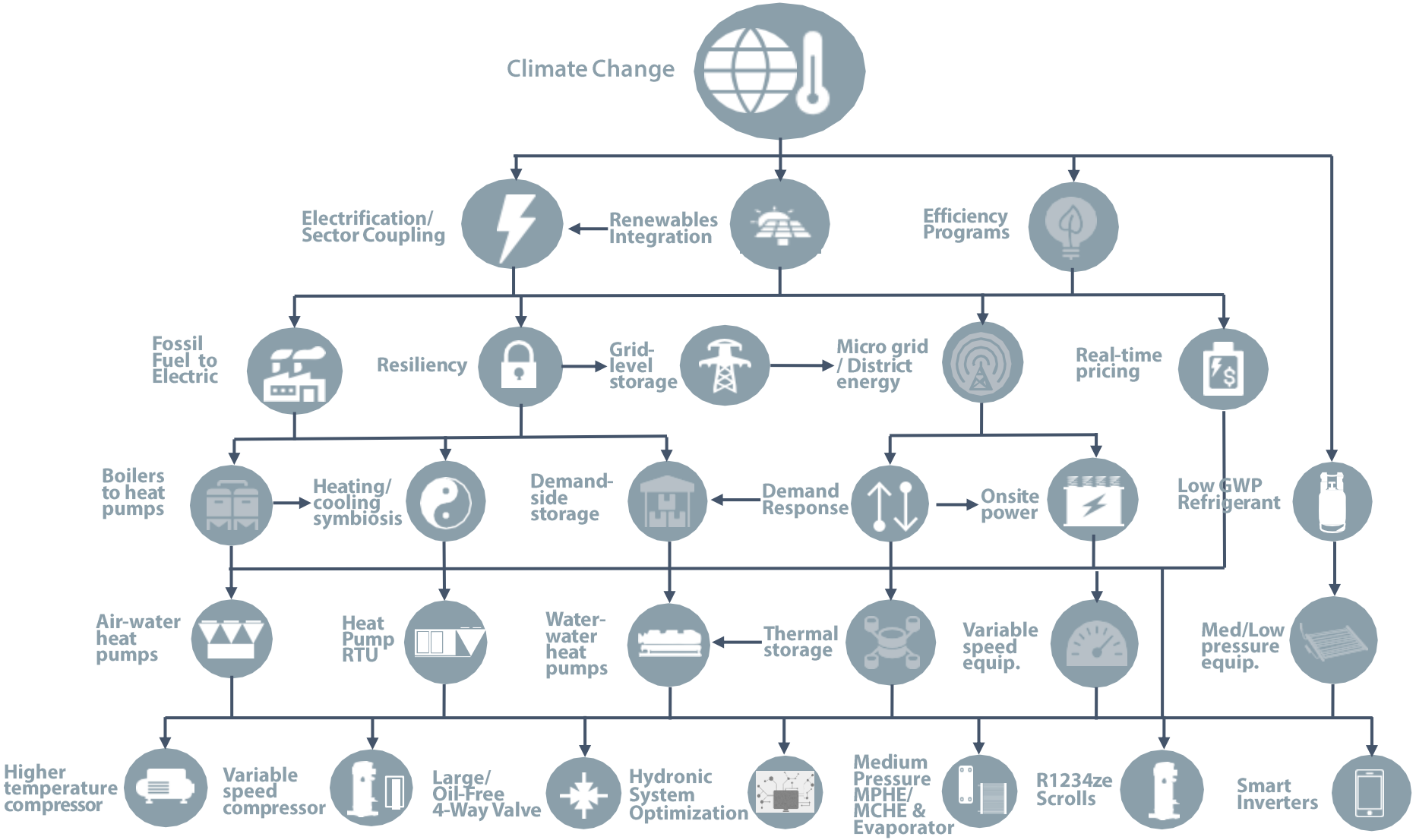
Challenges created by renewables and heat pumps
Supply/Demand Disconnect – How To Address

Energy storage / Thermal storage



Demand-side scale provides built-in flywheel storage & enables options

Challenges created by renewables and heat pumps
Everything is linked…Maximize factors covered



1st Level macro trend

2nd Level supply side / utility

3rd Level supply/ demand

4th Level demand-side

5th Level Equipment Implications

6th Level Component Implications

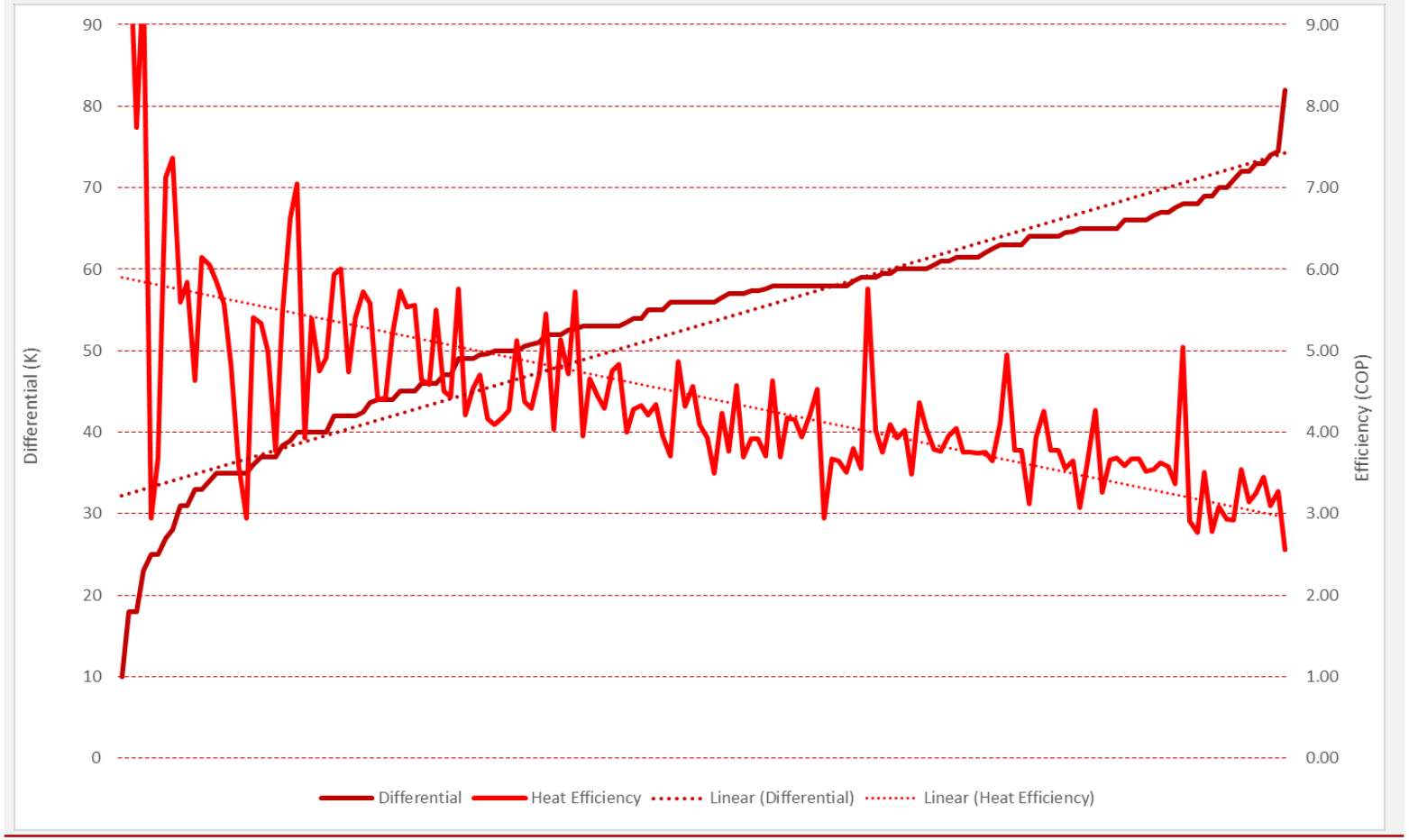
Challenges created by renewables and heat pumps
Efficiency & Electrical Load

- Range of heat source to heat supply differential (K)
- Corresponding heat pump system efficiency (COP)
- 0.3-60MW+ systems

1K differential = 2% heat pump efficiency

= 2% electrical load

Heat Pump – System Differential and Associated Efficiency



Challenges created by renewables and heat pumps
How to Address – Higher Heat Source Temperature

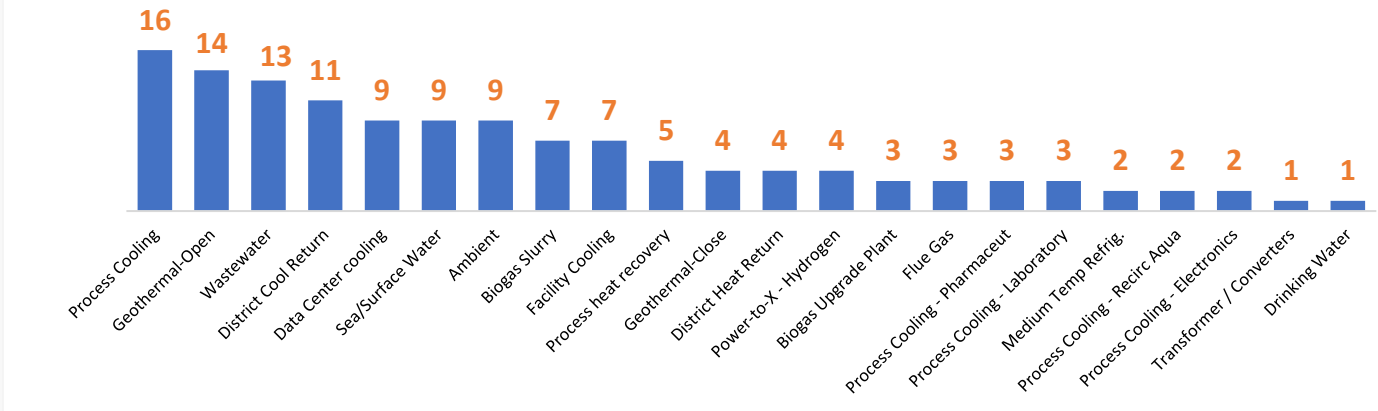
The most prevalent heat recovery heat sources

- Process, Wastewater, district and data center cooling = 44%
- Geothermal total = 14%
- Biogas total = 8%

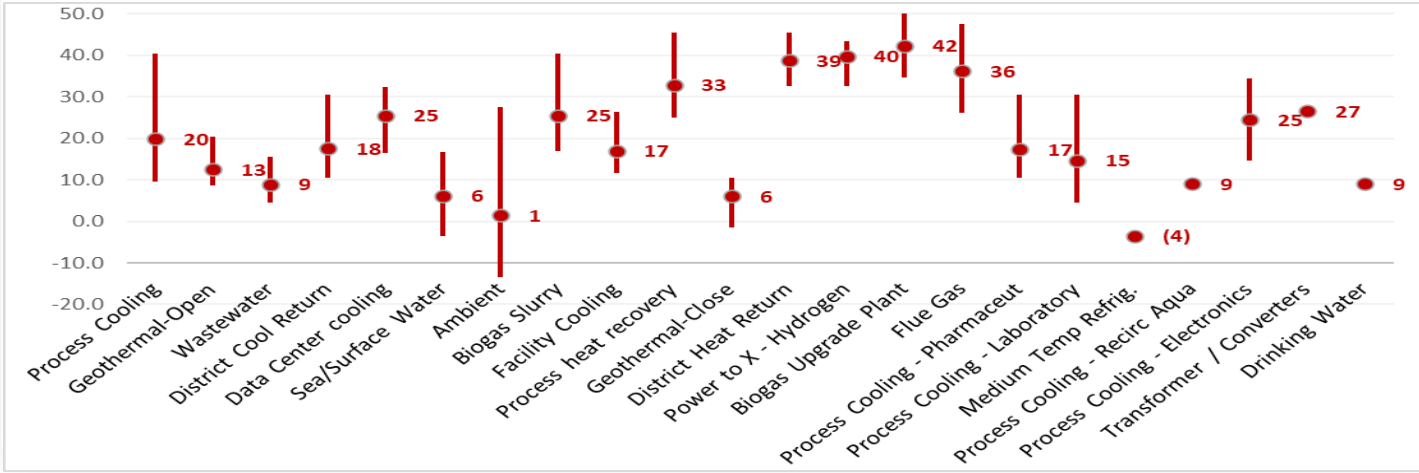
- Target the most consistent availability and highest temperature heat sources

- To drive…
  - highest operating hours
  - best efficiency
  - lowest resulting heat price

Opportunities by Heat Source (# of projects)



Source Temperature Average/Range

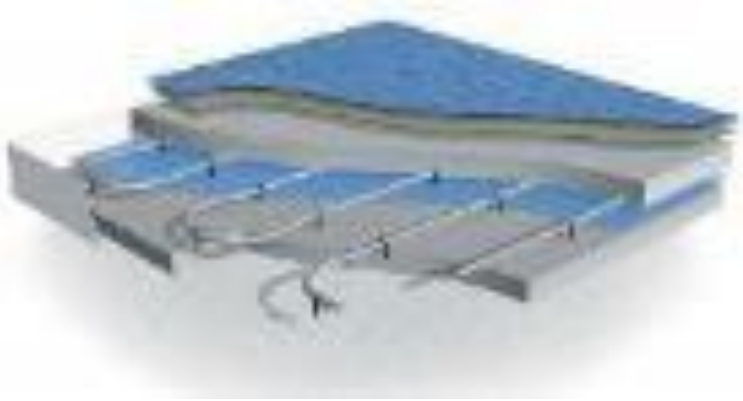


Challenges created by renewables and heat pumps
How to Address – Lower Supply Water Temperature

Radiator 55C

Fan Coil 45C

Floor Heating 35C



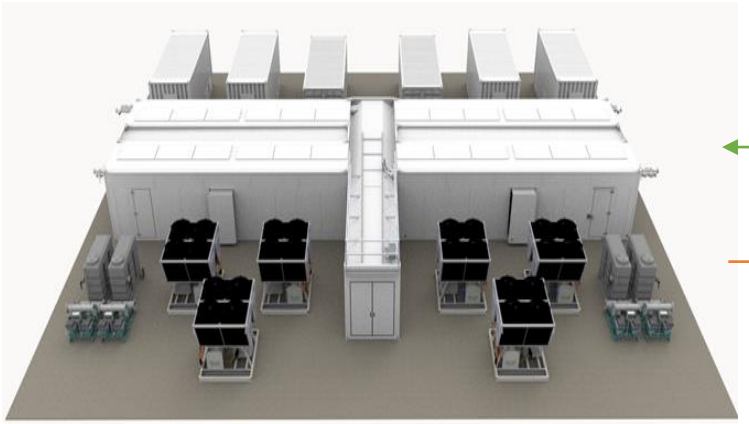
Efficiency

Integrated System Retrofit Options

Baseline - Data Center Cooling / Heat Recovery

Data Center

Chilled Water / Air Cooling

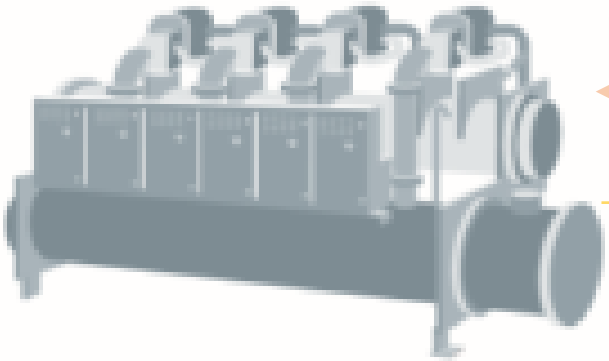


20°C

28°C

Heat Pump

Water-Water

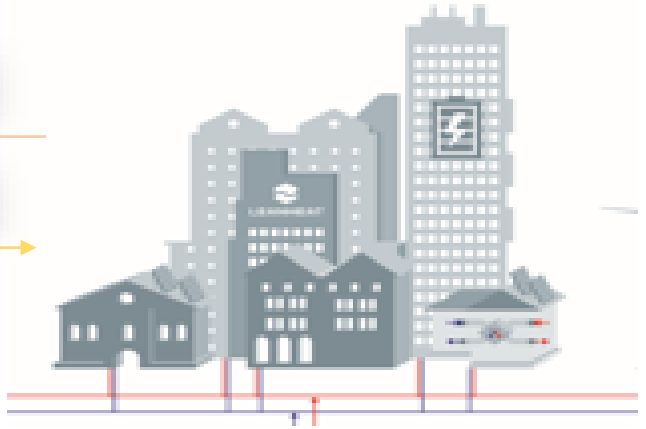


50°C

65°C

District Energy

4th Generation Heating



4.0 COP Cooling

$250k/MW Heat

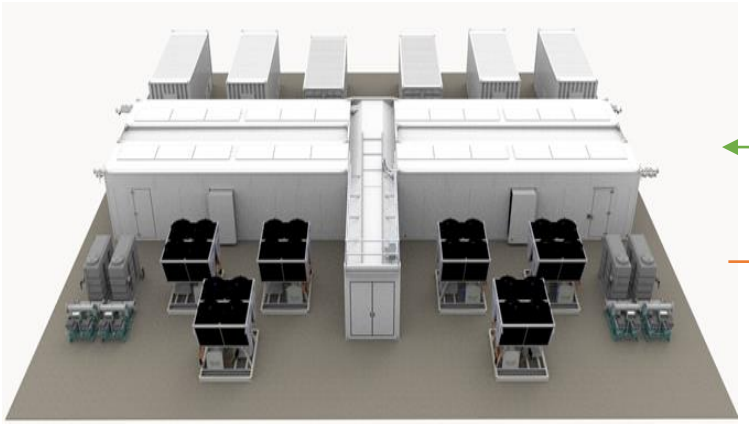
5.0 COP Heating

Integrated System Retrofit Options

Lower Temps Enable Higher Heat Pump Efficiency

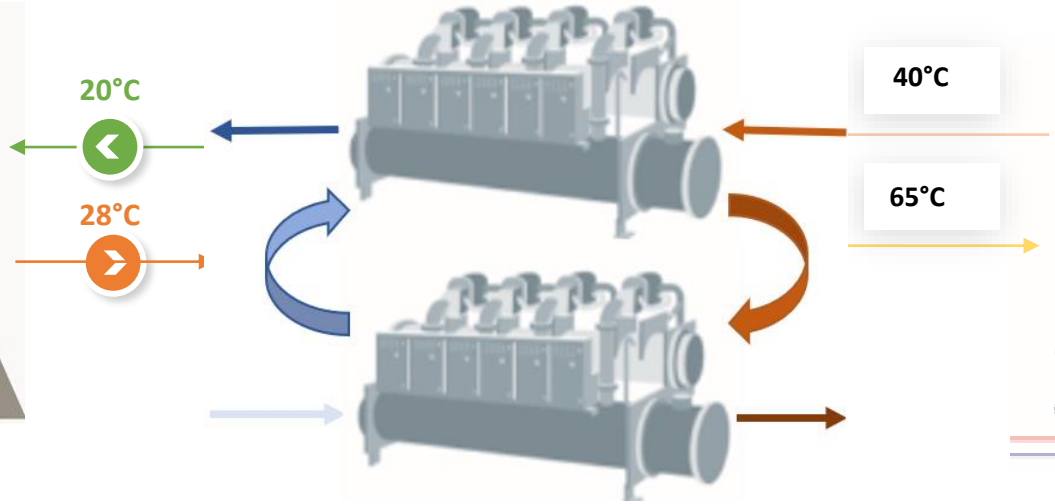
Data Center

Chilled Water / Air Cooling



Heat Pump

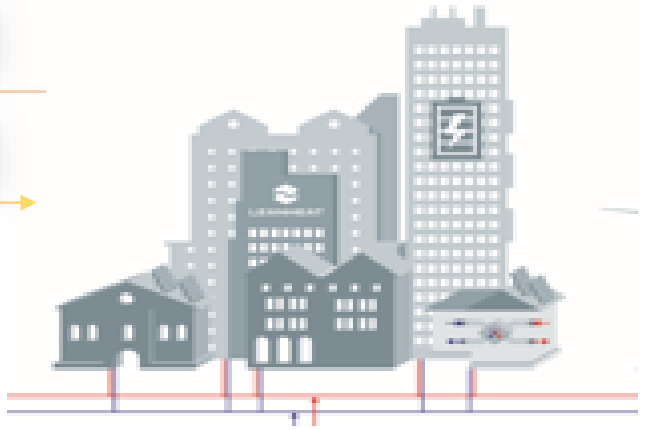
Series-Series Counterflow



District Energy

4th Generation Heating

Lower Return Temp



4.8 COP Cooling

Lower return temp from variable flow, 2-way PICV and hydronic system control optimization

In-turn allows series-series counterflow heat pump - 20% efficiency increase

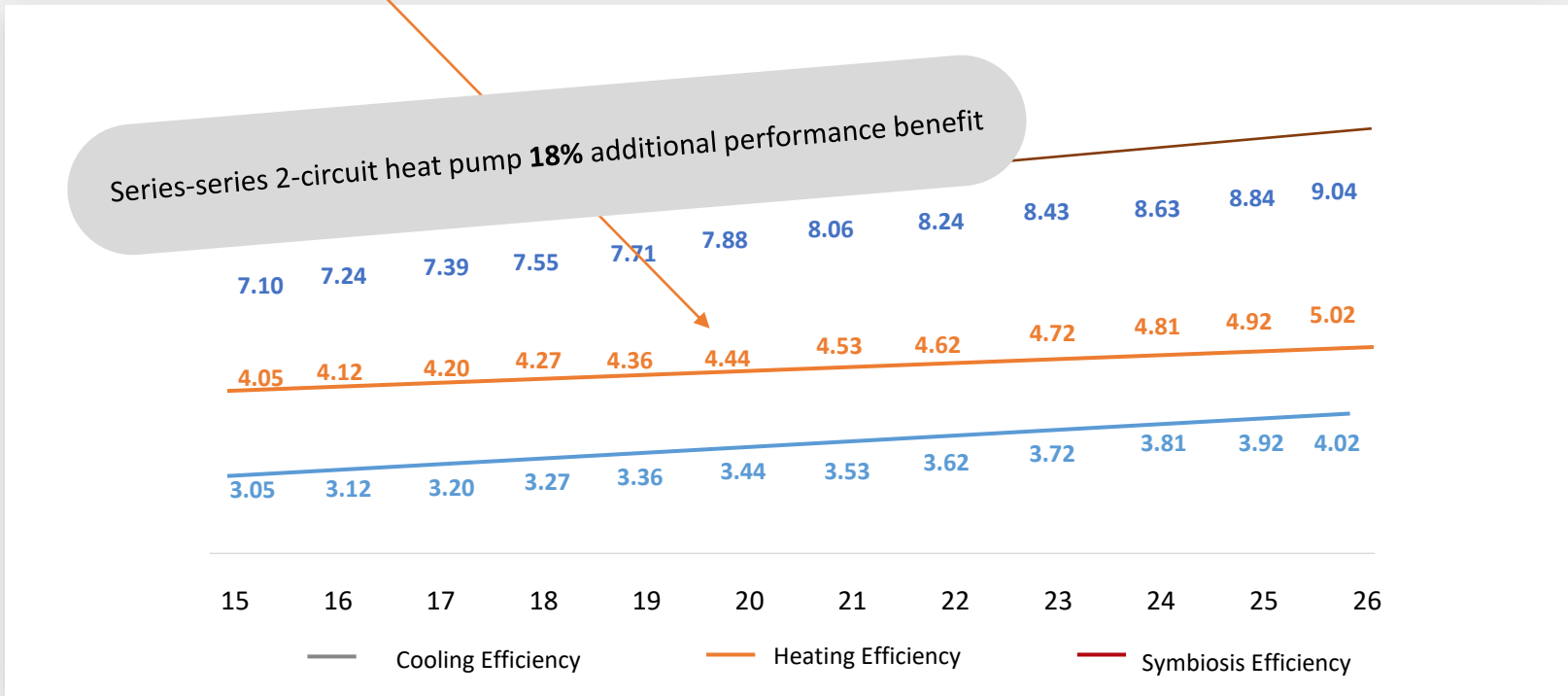
5.8 COP Heating

Integrated System Retrofit Options
How to Address - *Real Example*

Water-Water Heat Pump	Cooling capacity	Heating capacity	Power input	COP Cooling	COP Heating	Chilled water leaving Temp	Chilled water entering Temp	Hot water returning Temp	Hot water supplying Temp	Min. capability ratio
Compressors	**kW**	**kW**	**kW**	**W/W**	**W/W**	**℃**	**℃**	**℃**	**℃**	
Full load, 28-20C	500	617.8	117.8	4.246	**5.25**	20	28	43	67	49.2%

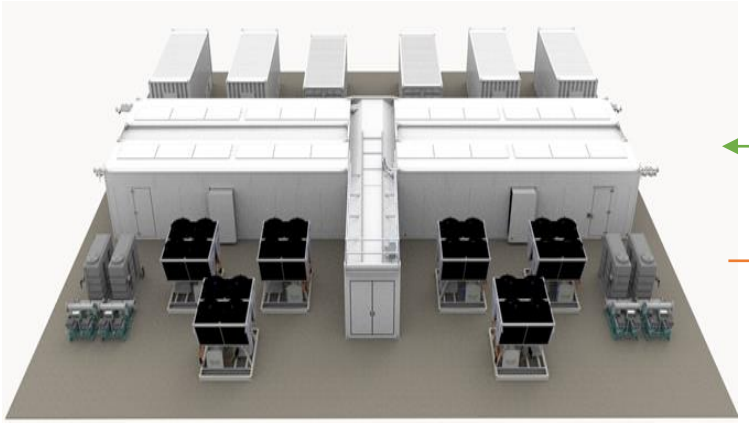
Impact of Increased Cooling Water Temp on Heat Pump Efficiency, supplying 67°C hot water

Symbiosis (combined heating and cooling) efficiency increases **27%** from corresponding chilled water cooling temperature increase of 15°C to 26°C

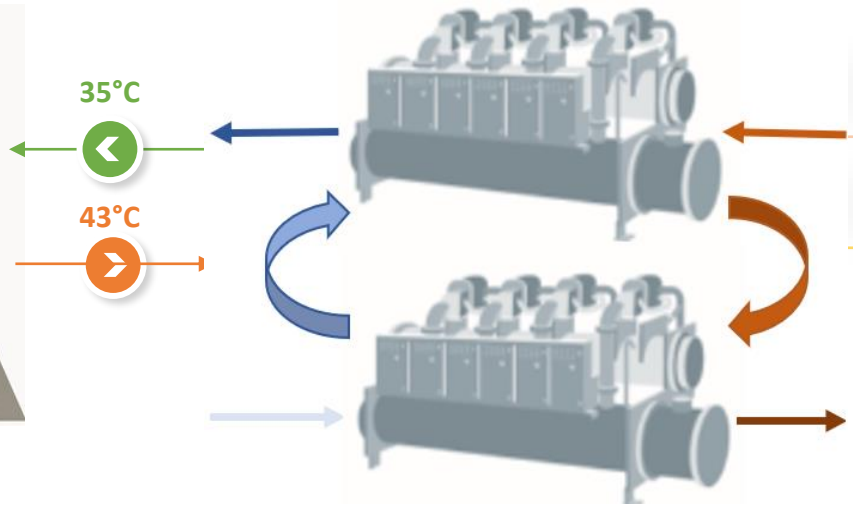


Integrated System Retrofit Options
Liquid Cooling / Higher Temps Allows Max Efficiency

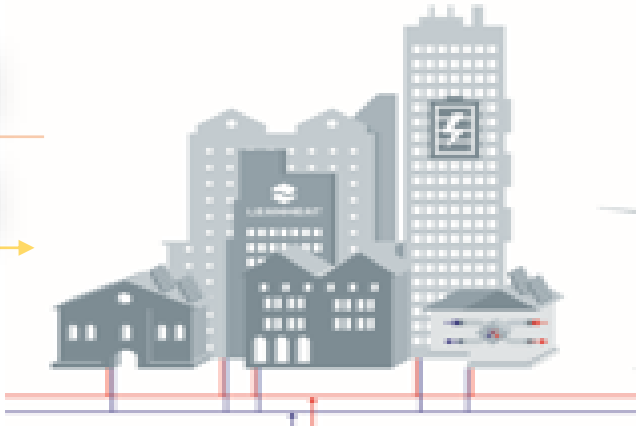
Data Center
Liquid / On-Chip Cooling



Heat Pump
Water-Water



District Energy
4th Generation Heating



6.2 COP Cooling

15K differential decrease

=

30% efficiency increase

7.2 COP Heating

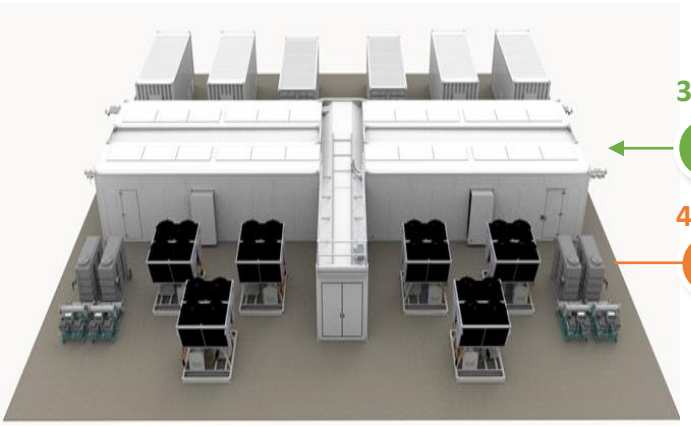
Integrated System Retrofit Options
Data Center Free Cooling / Heat Reuse

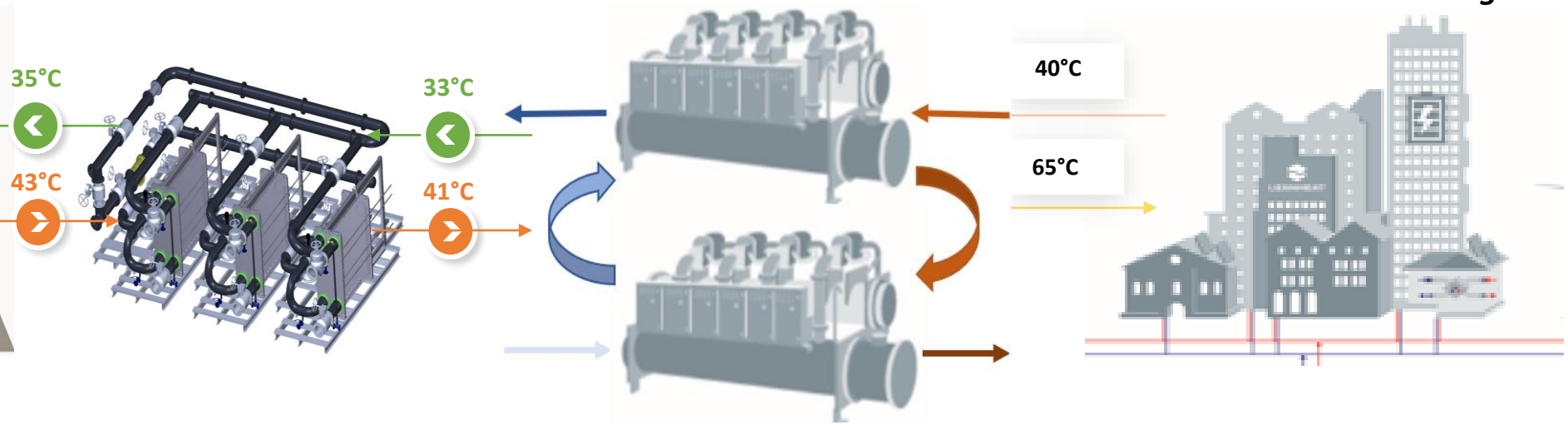
Data Center
Liquid / On-Chip Cooling

Heat Recovery Station
Free Cooling / Heat Recovery

Heat Pump
Water-Water

District Energy
4th Generation Heating





Free Cooling

~20 COP

Data center heat station enables free cooling / heat recovery at 25% heat pump applied cost with minor heat efficiency impact

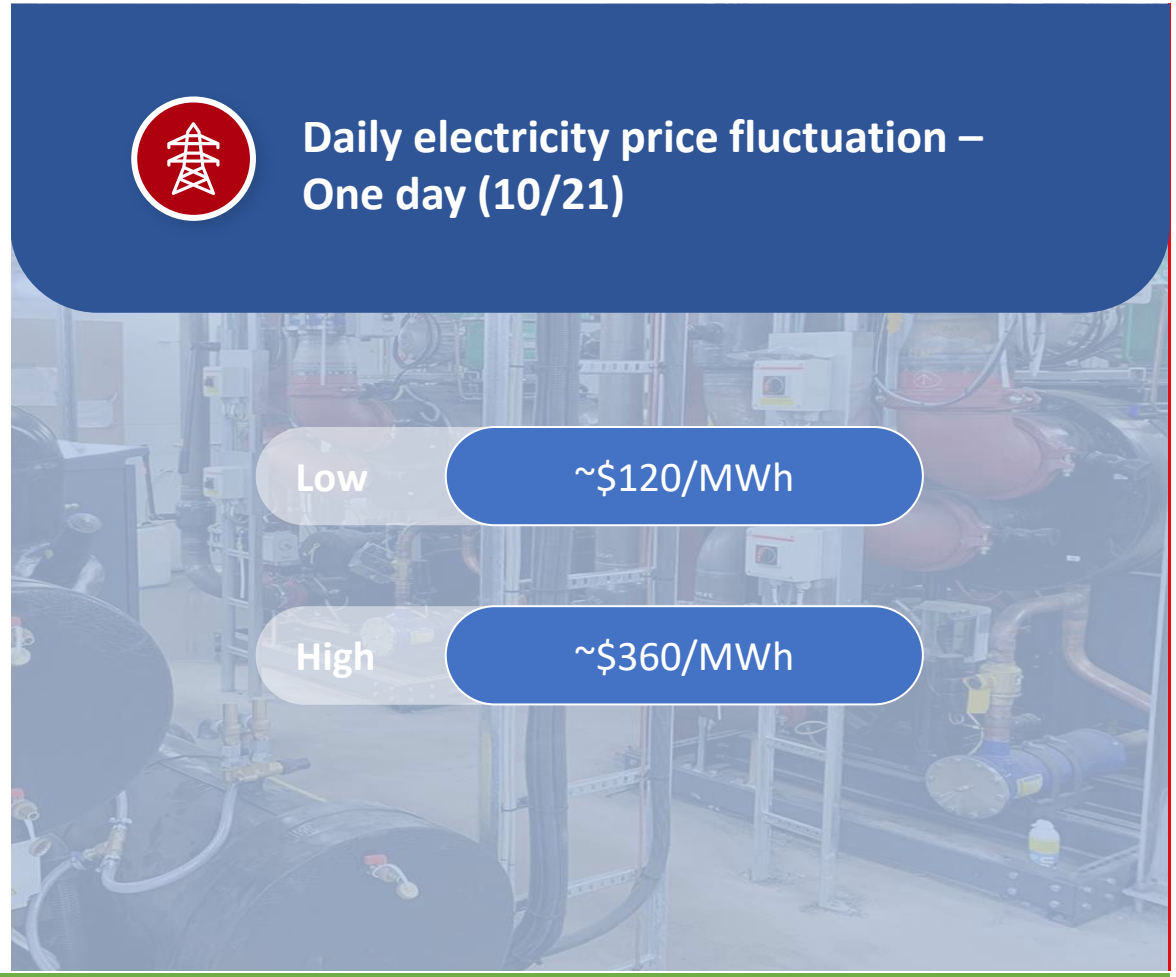
Cooling power limited to supply pumps, driven by recovered heat

7.0 COP Heating

Why Water-Water Heat Pump & High Heat Recovery Temperature are Critical

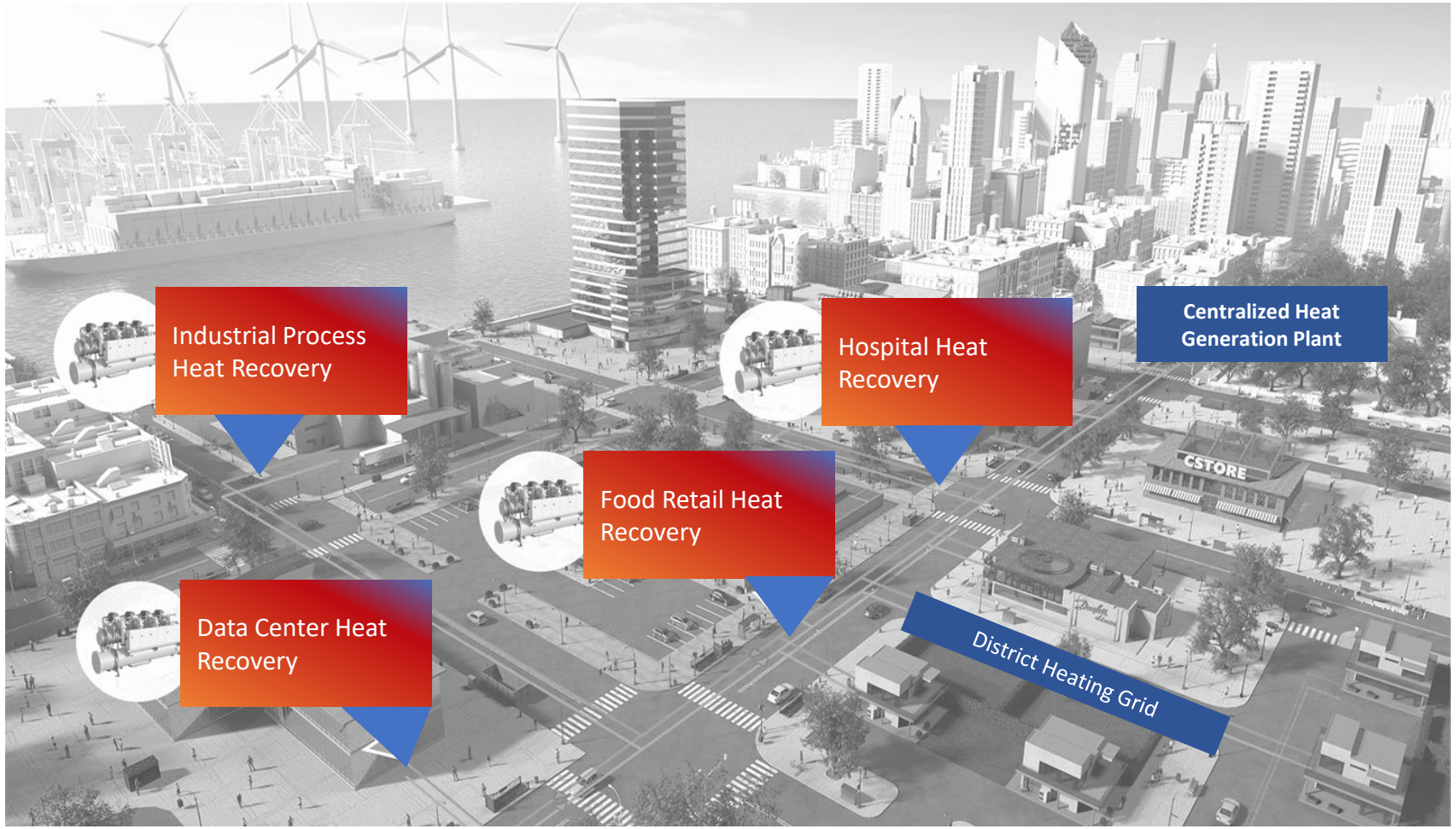
- **Multiple heat source choices**
- **Large air-water heat pump ~3-3.5 COP**
- **water-water recovery heat pumps ~6-7 COP, based mainly on higher source temperature**
- **High electricity price fluctuation**
- **From efficiency & resulting operating cost / heat price**

- Air-water heat pumps operate when electricity price < $100/MWh (~300 hours this year)
- Water-Water Heat pumps operate when electricity price < $200 DKK/MWh (>80% of the year)



For district energy, difference between low-cost baseload heat source with quick payback and peaking plant backup

Guidance for Efficient & Resilient Electrification of Heating



01 Critical facility cooling & heat recovery ~20°C+

02 Geothermal and comfort cooling ~10-20°C

03 Ambient air/water & refrigeration ~<10°C

Conclusions

- The efficiency of heat pumps, integration of renewables and decarbonization via electrification drive heat pump use growth
- The growth of renewables also creates an increasing energy supply/demand disconnect and resulting resiliency and operating cost risk
- All of the trends, risks and potential solution factors are connected, pointing us to the best solutions
- We can learn a lot from recent integrated system design experience, in terms of energy sources
- Demand-side efficiency and operating temperature optimization efforts are critical prior to or as a part of integrated system design efforts
- Critical facility retrofits present the ultimate efficiency and decarbonization opportunity also maximizing energy availability and resiliency
- Smart system design is critical to address the interests of the different business interests of varying large-scale system stakeholders

Questions

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