AtmosZero

Industrial scale decarbonization

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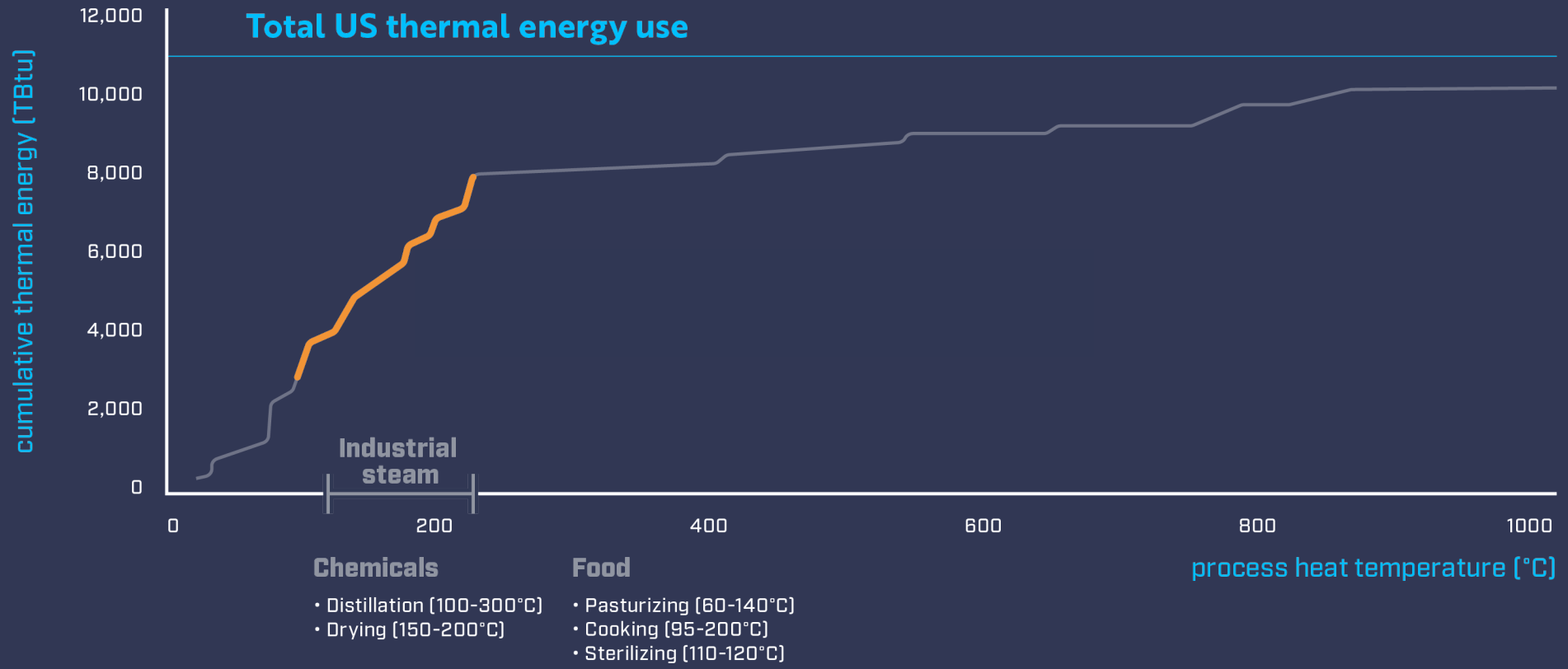
THE ~~PROBLEM~~ OPPORTUNITY

The sweet spot: Steam temperatures

50% of all process heat is delivered by steam.



Source: Renewable Thermal Collaborative, "RTC Vision Report"

The power of steam

Steam accounts for:

50%
of process heat used in industry

8%
of global primary energy use

2.25 GT
GHG emissions per year

→ Decarbonizing steam has huge global impact

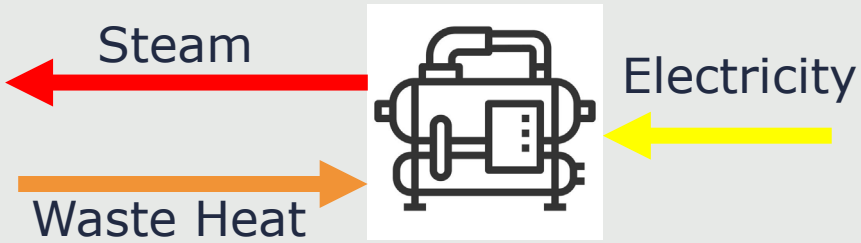
Introduction – Steam Generation

Fuel Boiler

State-of-the-art, requires combusting fuel such as natural gas

Waste Heat Driven Heat Pump

High efficiency, requires site specific engineering for facility integration



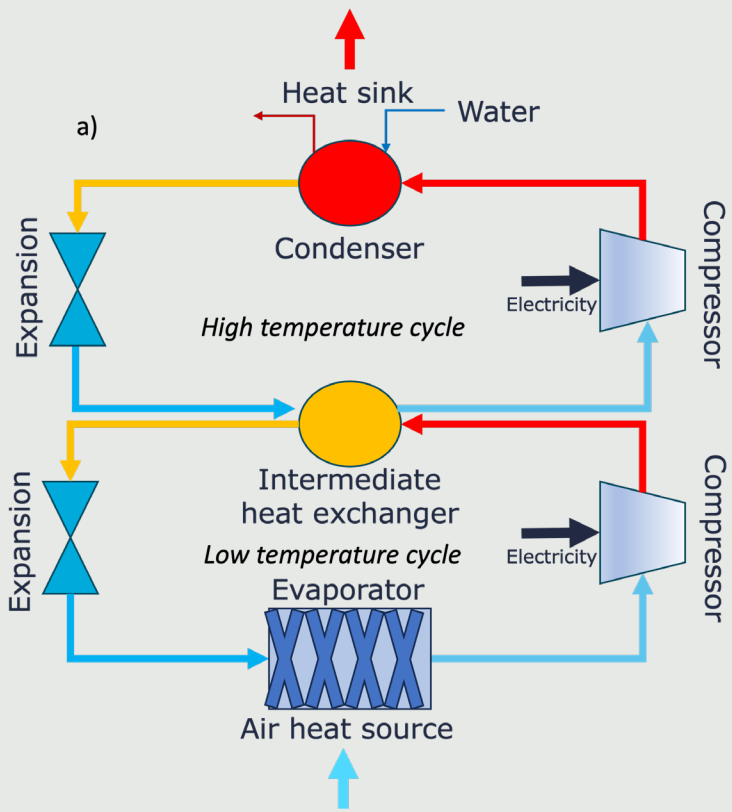
Electric Boiler

Commercially available and low-CAPEX, efficiencies <100%

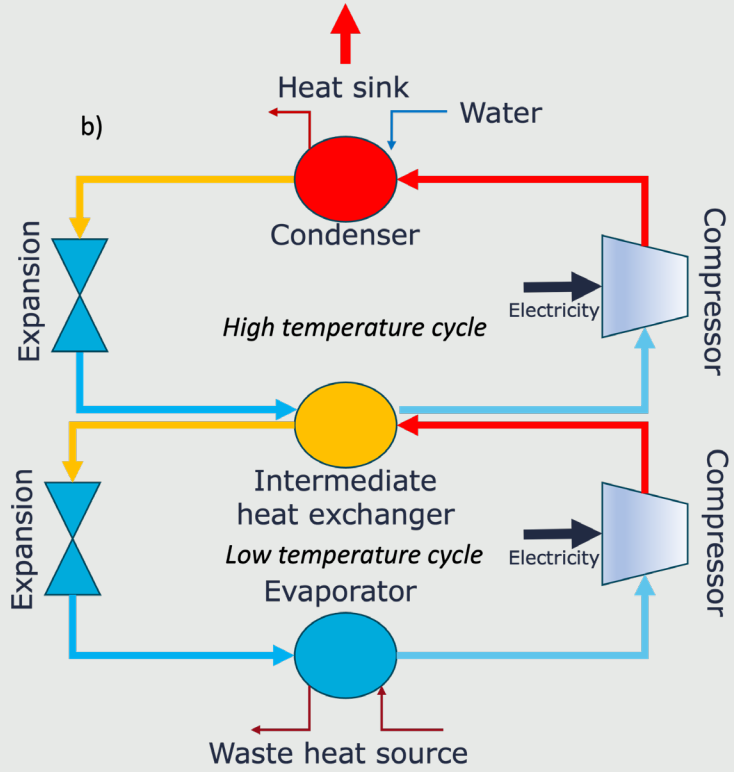
Air-Sourced Heat Pump

Lowered efficiency, reduced integration challenges

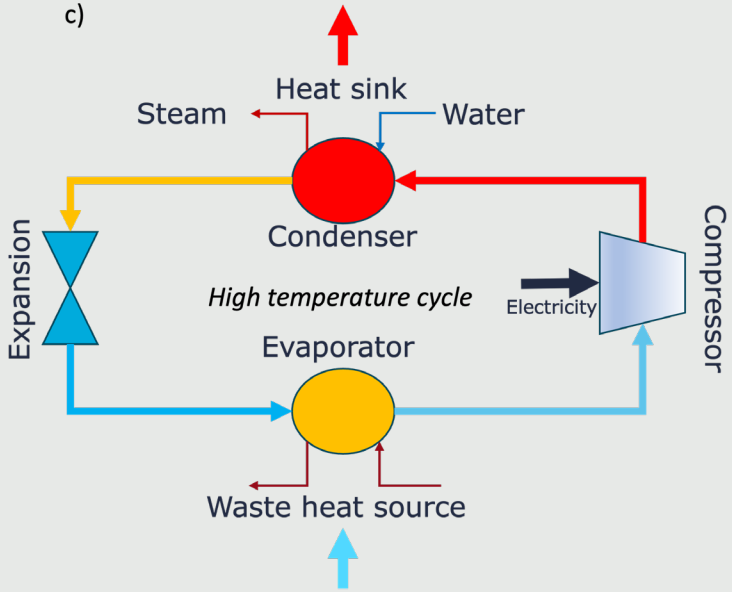
Heat Pump System Configurations



Air-Sourced Steam Generating Heat Pump

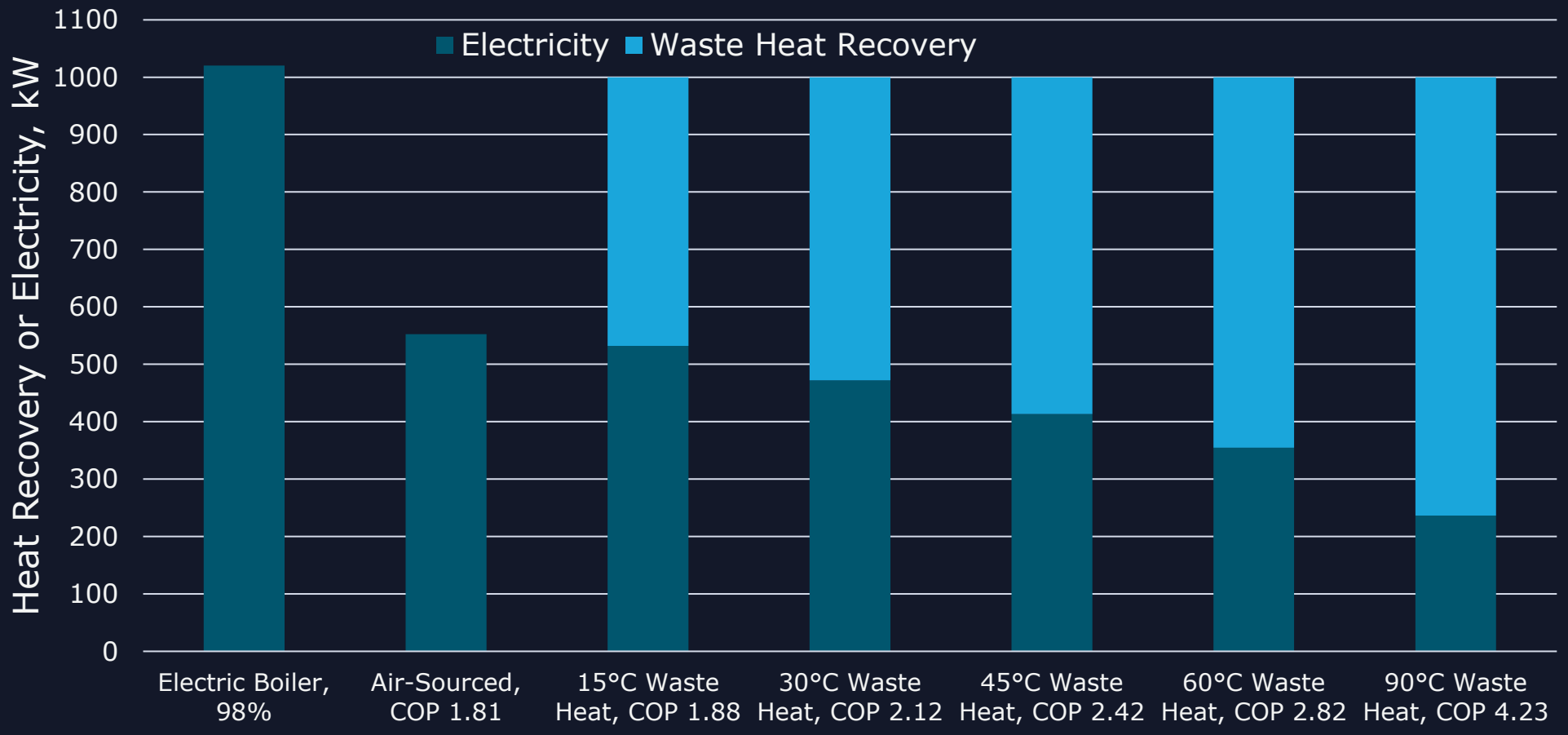


Low-Temperature Waste Heat Sourced (≤45°C) Steam Generating Heat Pump



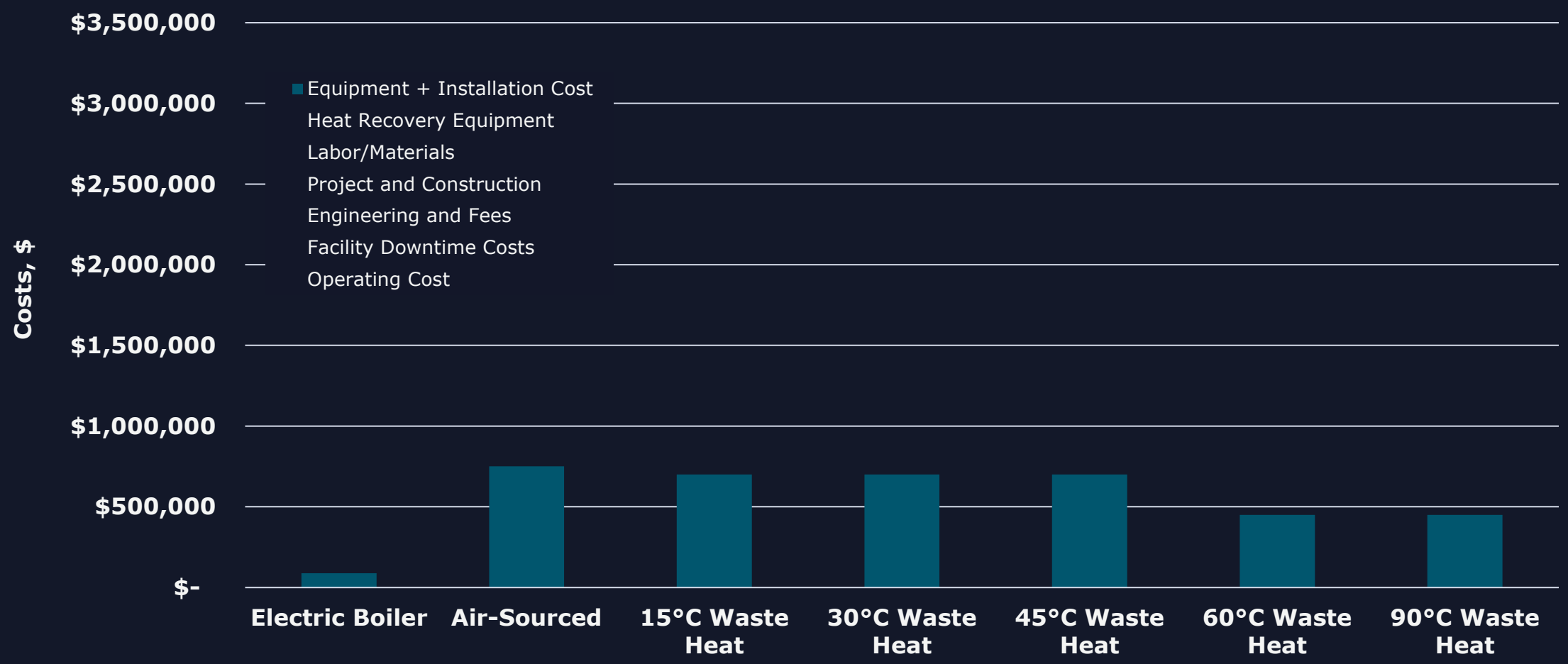
High-Temperature Waste Heat Sourced (≥60°C) Steam Generating Heat Pump

Waste Heat Recovery is Good, Right?



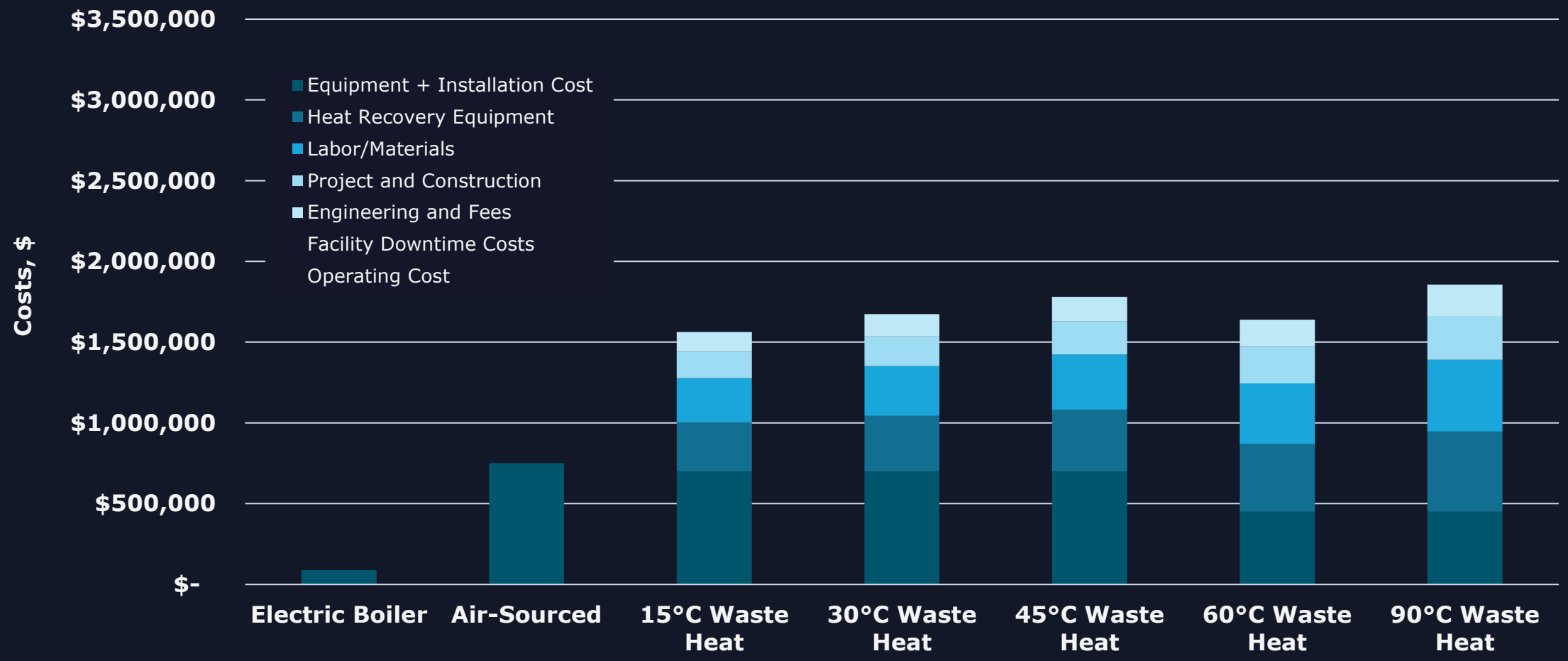
* COP values assume 60% of Carnot COP and a steam delivery temperature of 150°C

Invisible Costs



* All costs shown are for a 1MW steam capacity installation
** Revenue lost assumes $100M per annum company and 5 days of lost revenue for the installation period

Invisible Costs



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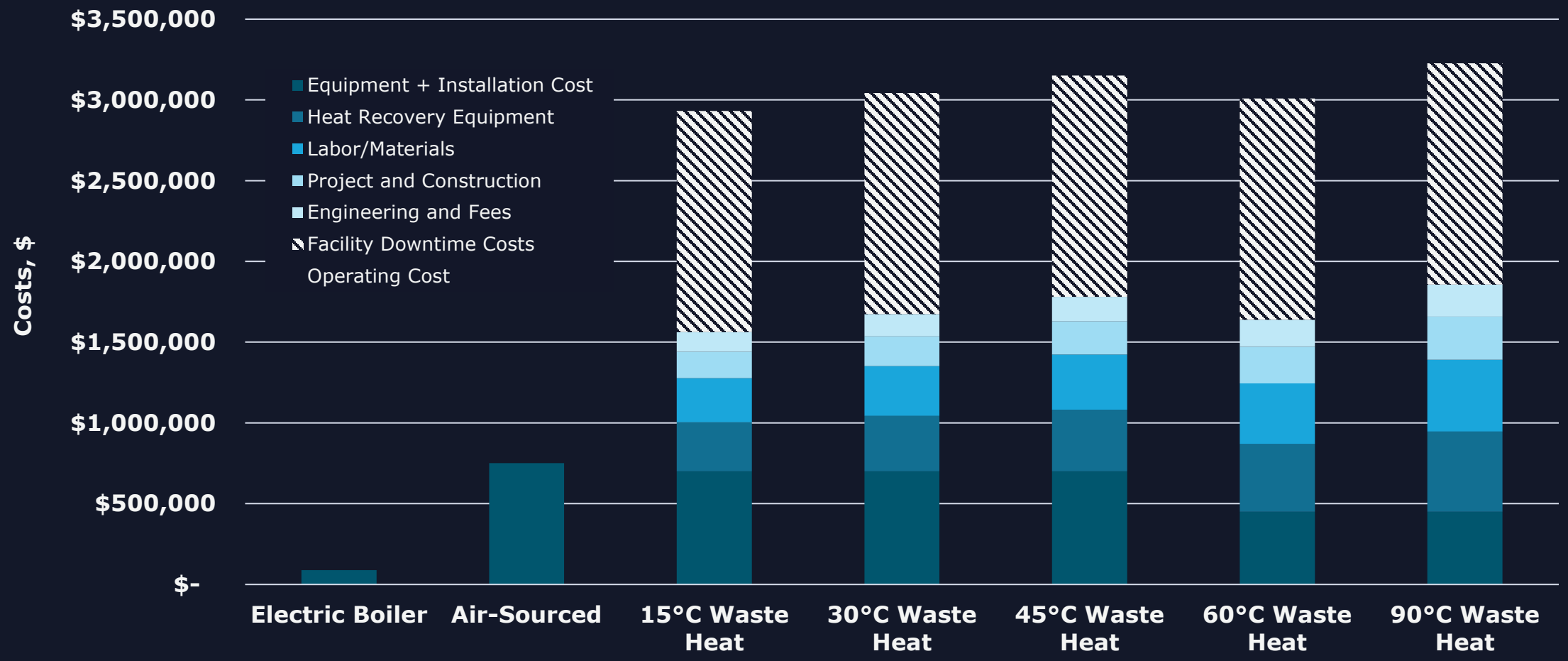

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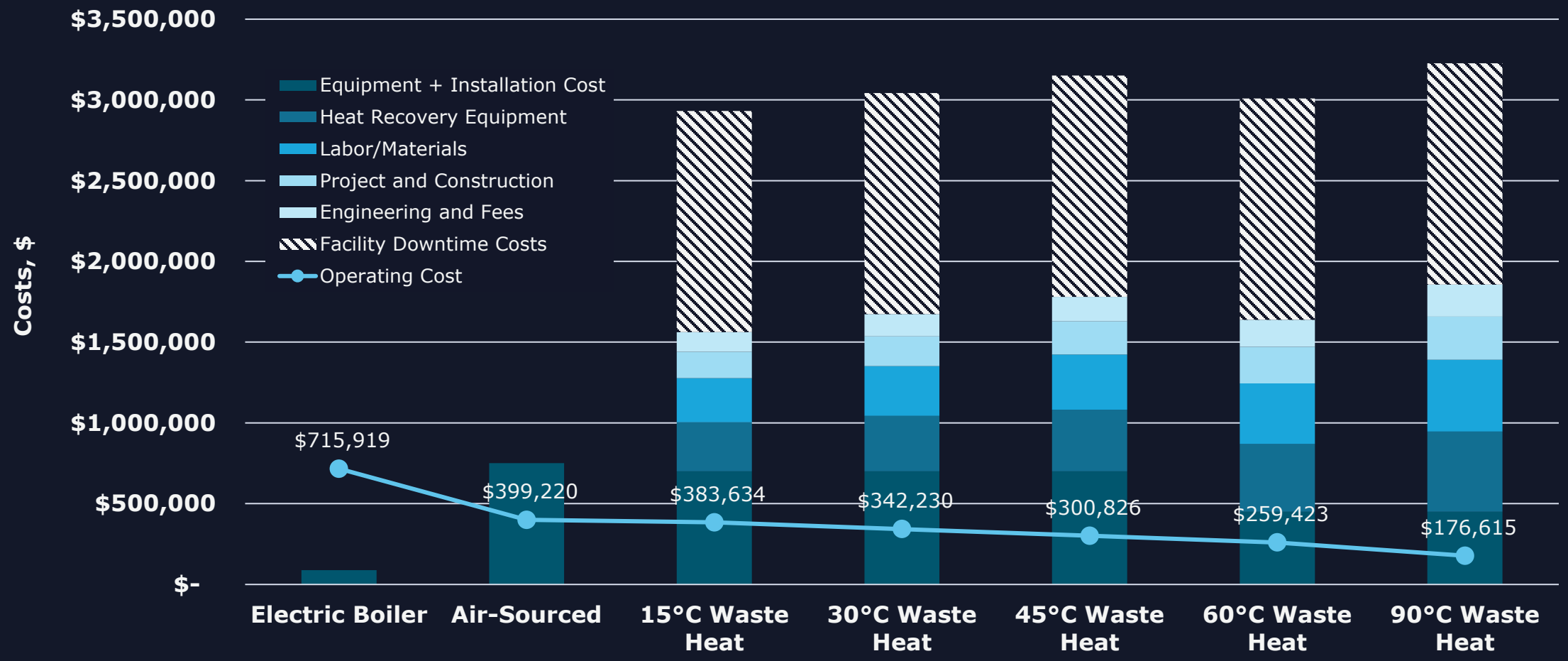

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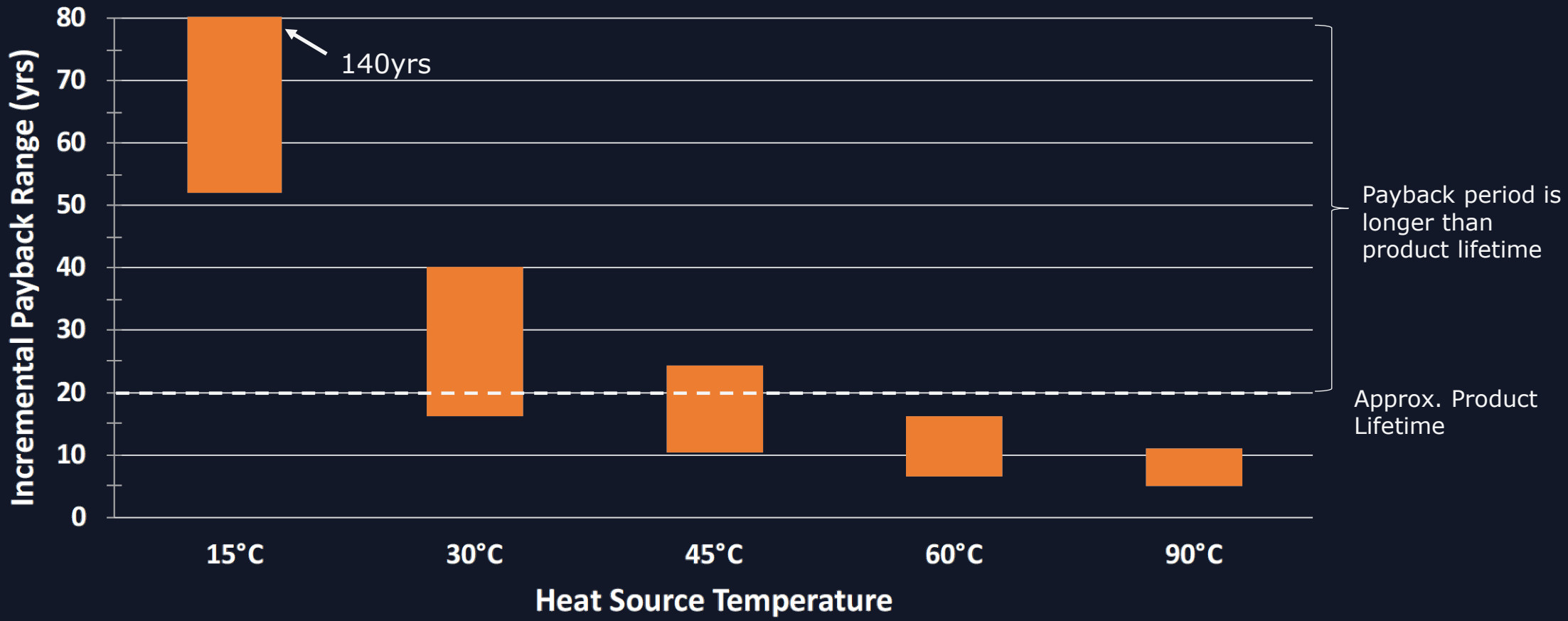
Simple Incremental Payback Period



* All costs shown are for a 1MW steam capacity installation
** Revenue lost (upper bound) assumes $100M per annum facility and 5 days of lost revenue for the installation period. Lower bound assumes no facility downtime.

Industrial Steam Requirements

Modular
Must scale to meet global demand

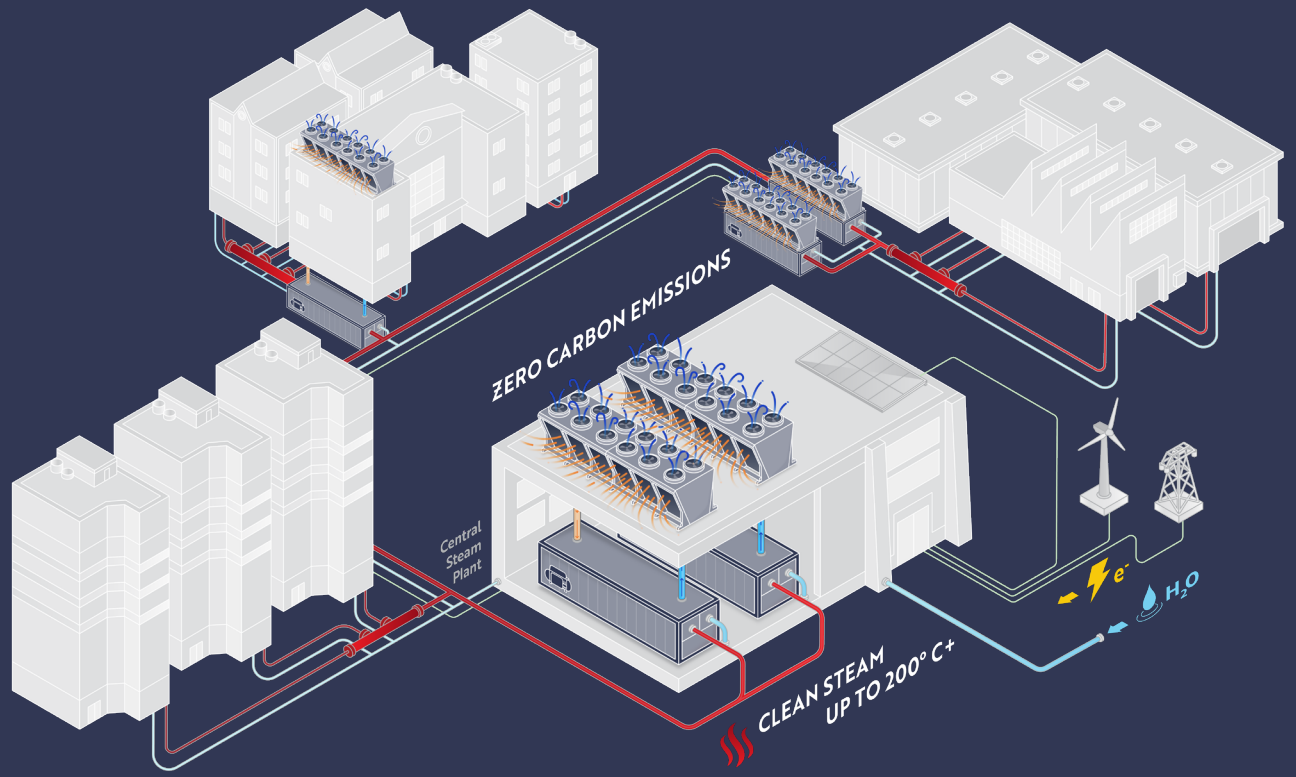
Drop-in
Must install quickly and deliver instant results

Minimize integration
Reduce complexity, increase repeatability.

24-7
Consistent output for energy security and resilience

A mass-manufacturable and scalable solution enables rapid decarbonization

Case Study: Built Environment – De-steaming Campus



	Air-sourced steam	Ground-sourced hydronic
Energy Cost ($/MWh for NG and electric, $/kg for hydrogen)	70	70
CapEx ($/MW)	$ 500,000	$9,750,000-25,000,000
Energy Efficiency	200%	444%
Annual Energy Costs	$ 102,098	$ 45,969
Annual O&M	$ 11,000	$ 11,000
Total Annual OPEX	$ 113,098	$ 56,969
Amortized Capex	$ 58,730	$1,145,231 - 2,936,491
Levelized Cost of Steam ($/MWh)	$ 59	$412 - 1,026
Simple payback (AZ baseline, yrs)	-	**165 - 436**

Payback for de-steam

Thank you!

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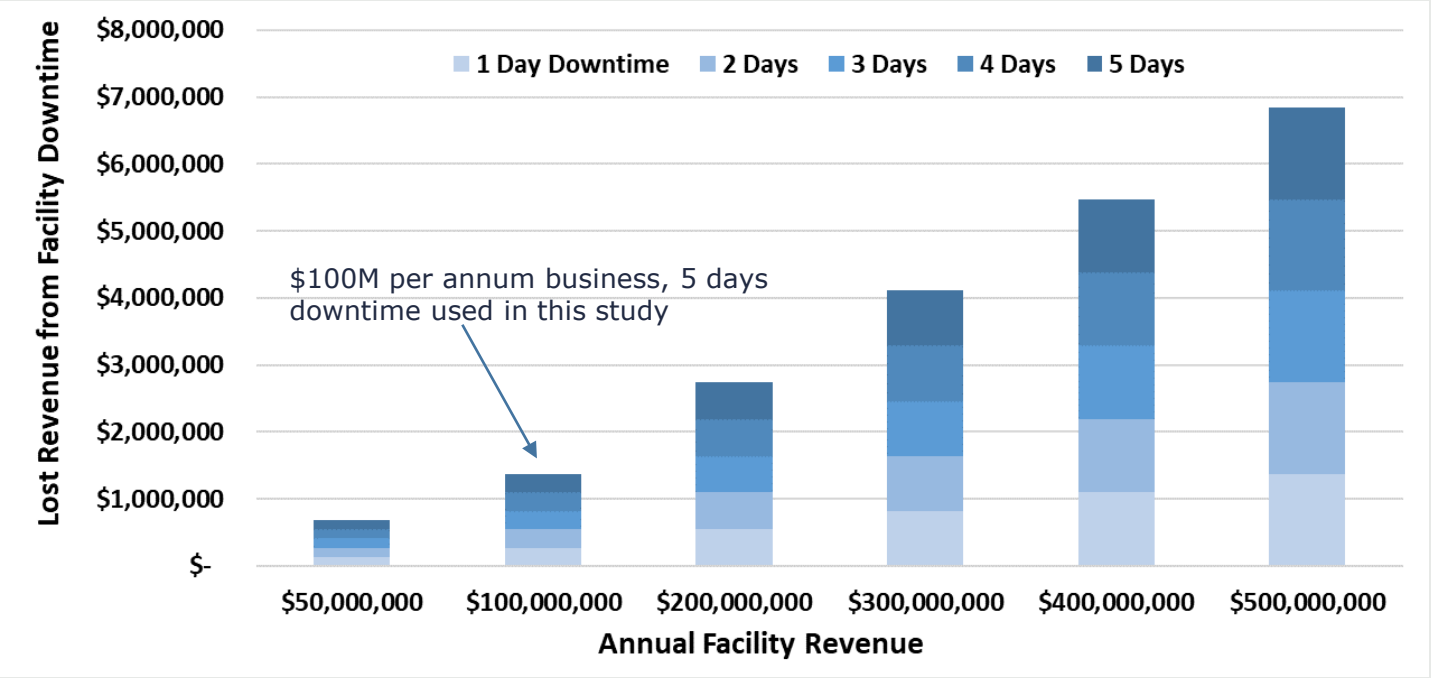
Hidden Costs of Installing Waste Heat Equipment

- Careful consideration must be made based on cost to recover waste heat and the downtime required to install equipment

Category	Cost ($/kW, 2023 dollars)	Description
Heat Recovery	650	Heat exchanger hardware for extracting heat, circulation pump, controls, piping
Labor/Materials	582	Labor costs for civil, mechanical, and electrical work; material costs for ductwork, piping, wiring
Project and Construction	350	General contractor markup and bonding, performance guarantees
Engineering and Fees	260	Project engineering and fees



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K. Darrow, R. Tidball, J. Wang and A. Hampson, "Catalog of CHP Technologies," U.S. Environmental Protection Agency, 2015.