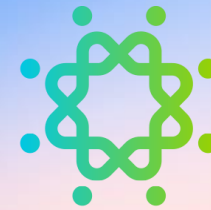


Mission

Backed by many of the world's top business leaders, Breakthrough Energy Ventures (BEV) invests in technology innovation companies that will lead the world to net-zero emissions, accelerate the transition to a clean economy and avoid the most disastrous impacts of climate change.

110+ companies funded to date



Breakthrough Energy
Ventures



#1 NEW YORK TIMES BEST SELLER

BILL GATES

**HOW TO
AVOID A
CLIMATE
DISASTER**

THE SOLUTIONS WE HAVE AND THE
BREAKTHROUGHS WE NEED

“If a genie offered me one wish, a single breakthrough in just one activity that drives climate change, I’d pick making electricity: **It’s going to play a big role in decarbonizing other parts of the physical economy.”**



Generation



Transmission (+ optimization)



Storage





Generation



Geothermal



Hydro, Solar, Wind



Fusion

Transmission (+ optimization)



Transmission



Grid Optimization

Storage



Electrochemical



ANTORA



Thermal



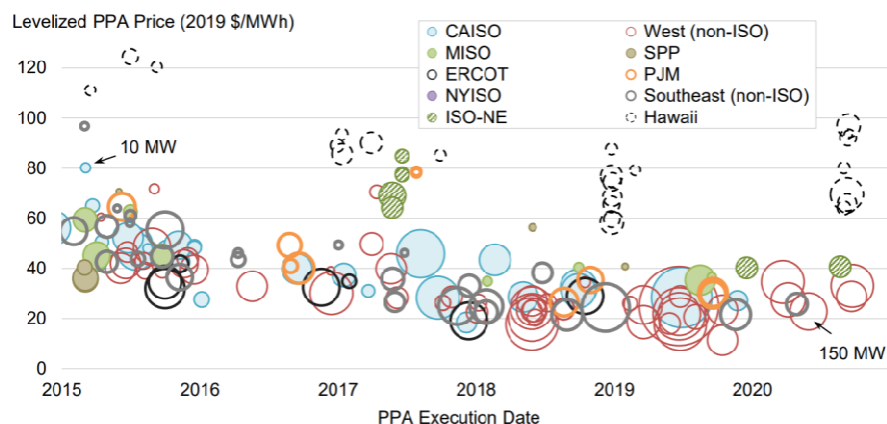
Pumped/Mechanical



Grid of the near future:

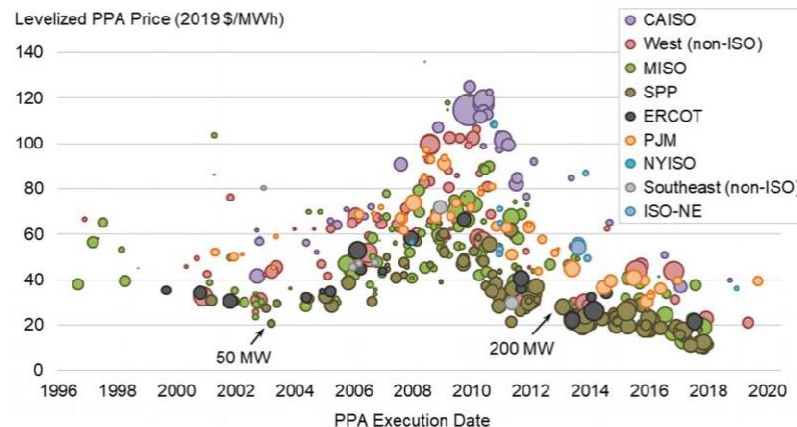
Wind and solar prices have been trending downwards and are boosted by the IRA and other policies

Levelized utility-scale PV PPA prices by PPA execution date and region (recent sub-sample of the data shown on prior slide)

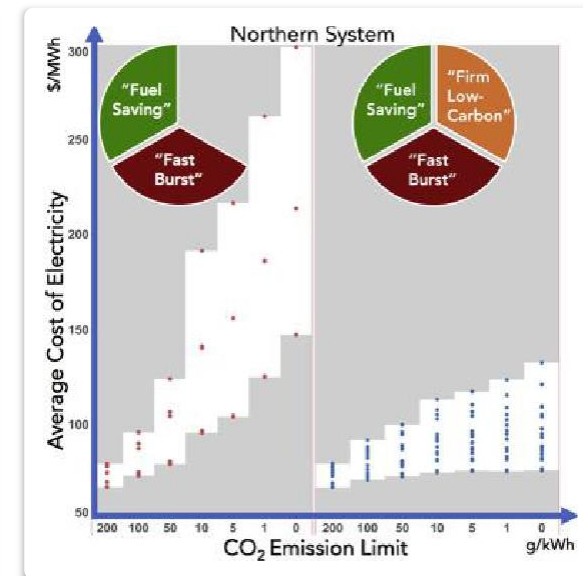


[LBNL: 2020 Utility Scale Solar Update](#)

Levelized wind PPA prices by PPA execution date and region (full sample)



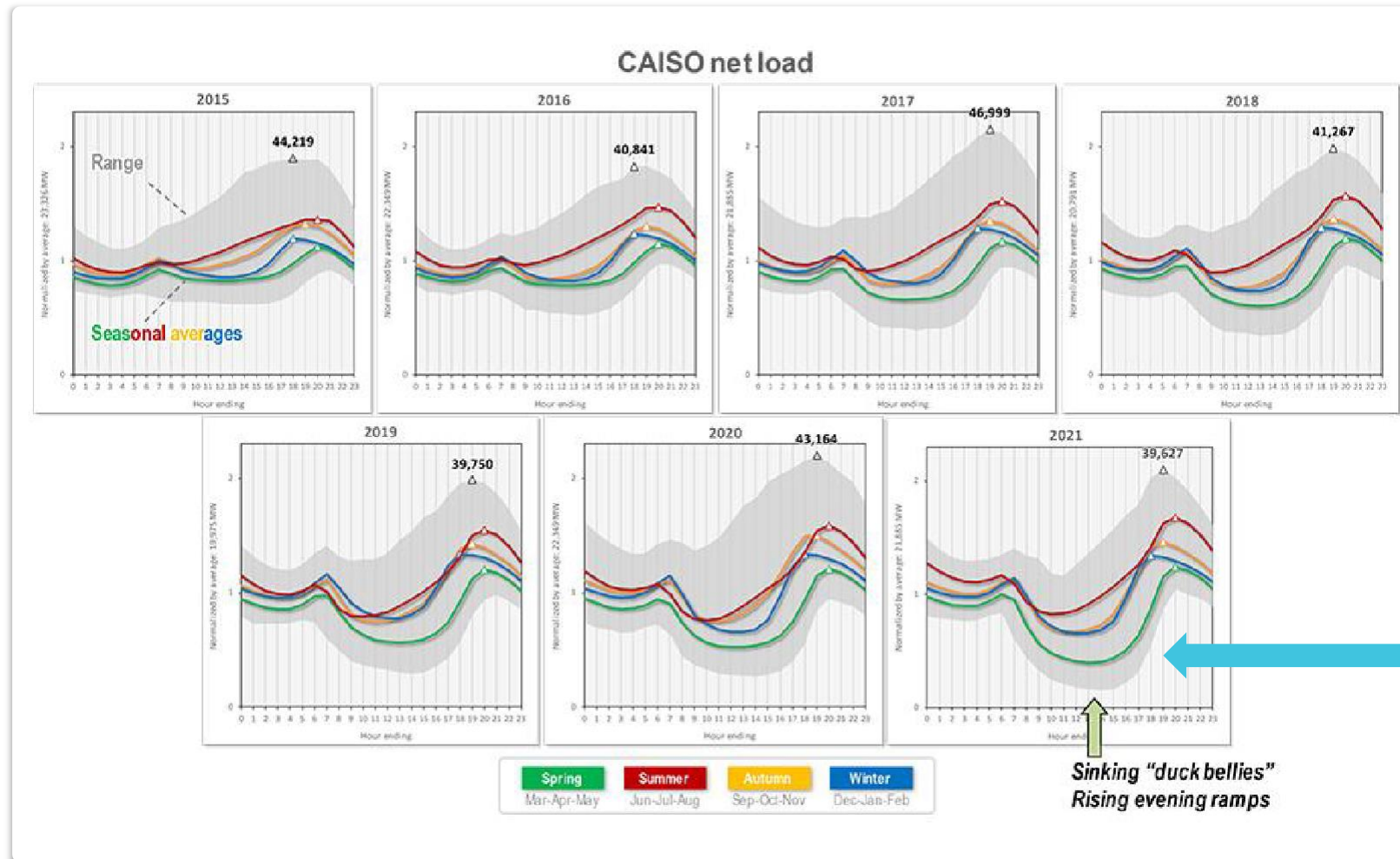
[LBNL: 2020 Wind Technology Data Update](#)



[Jenkins et Al., Joule 2018: The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation](#)

But how do you integrate them and what will be the cost?

Renewable Integration – Energy Challenge



2021 –
17.1% solar
7.8% wind
34% Renewables
50% Gas

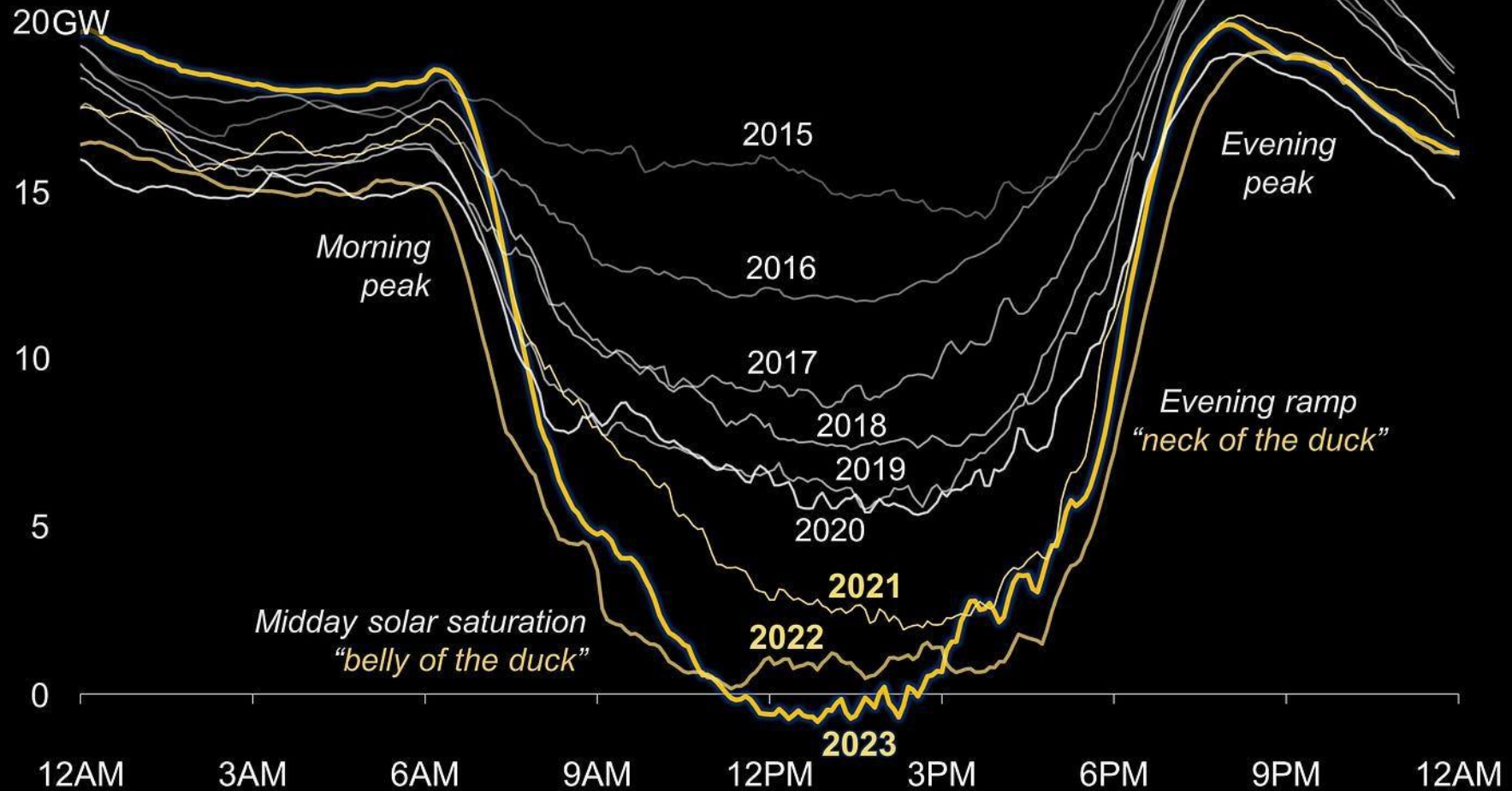
[CAISO – Our Evolving Grid, 2022](#)

[CEC - 2021 Total System Electric Generation](#)



California's duck curve hits record lows

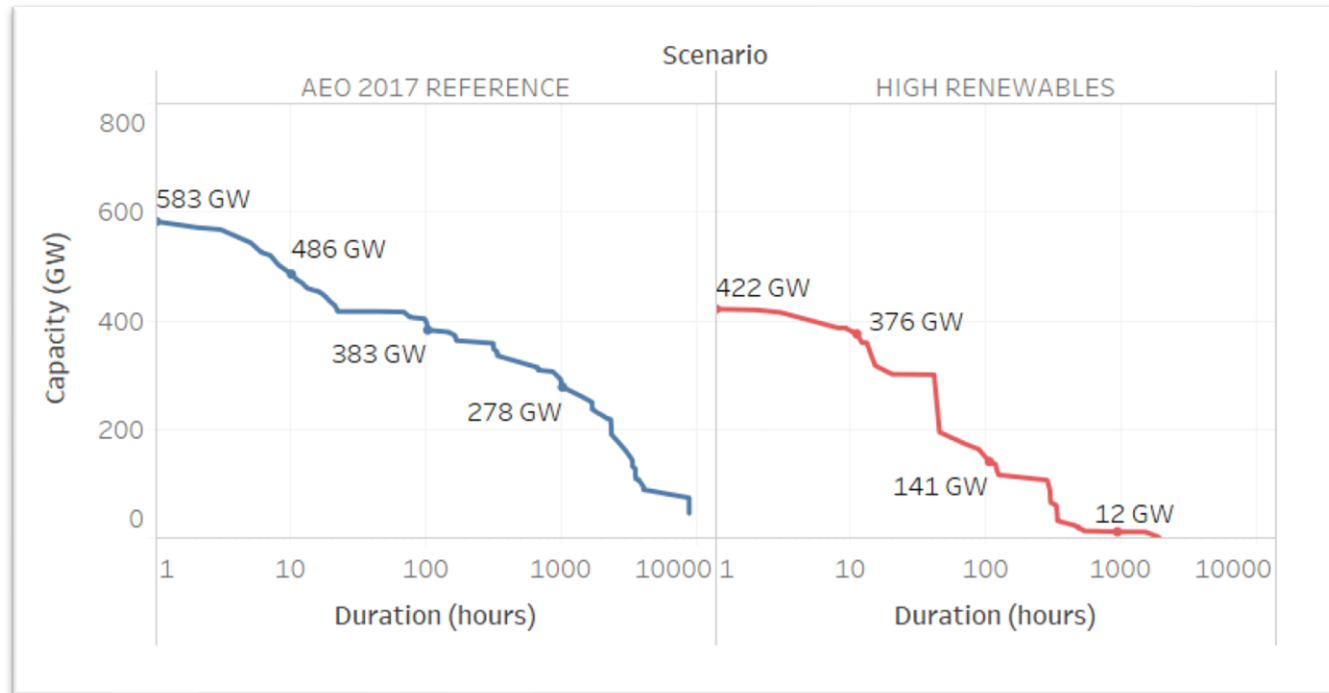
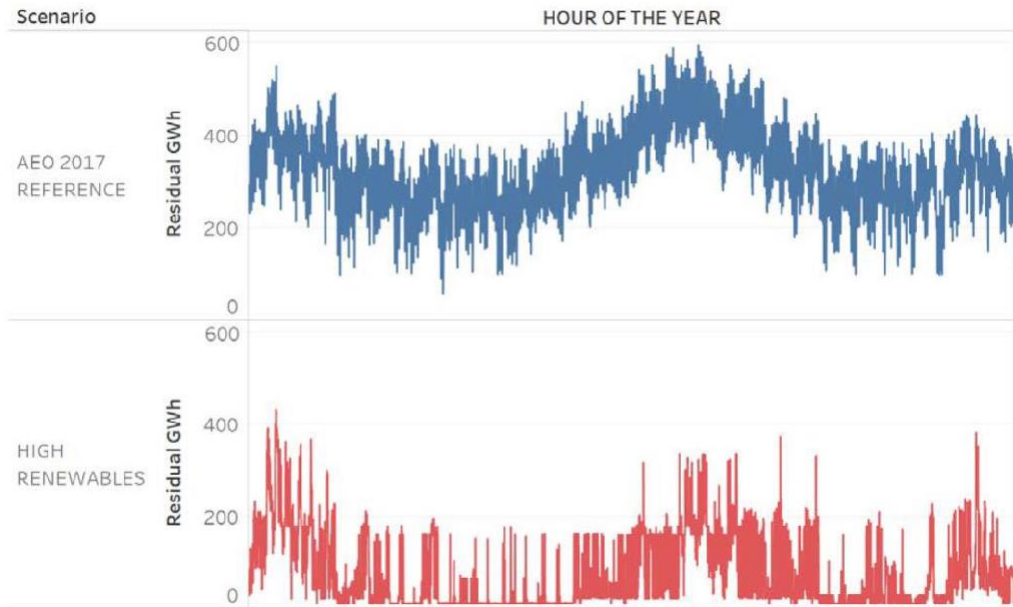
Lowest minimum net load day each year in CAISO, 2015-2023



Source: CAISO | @BPBartholomew

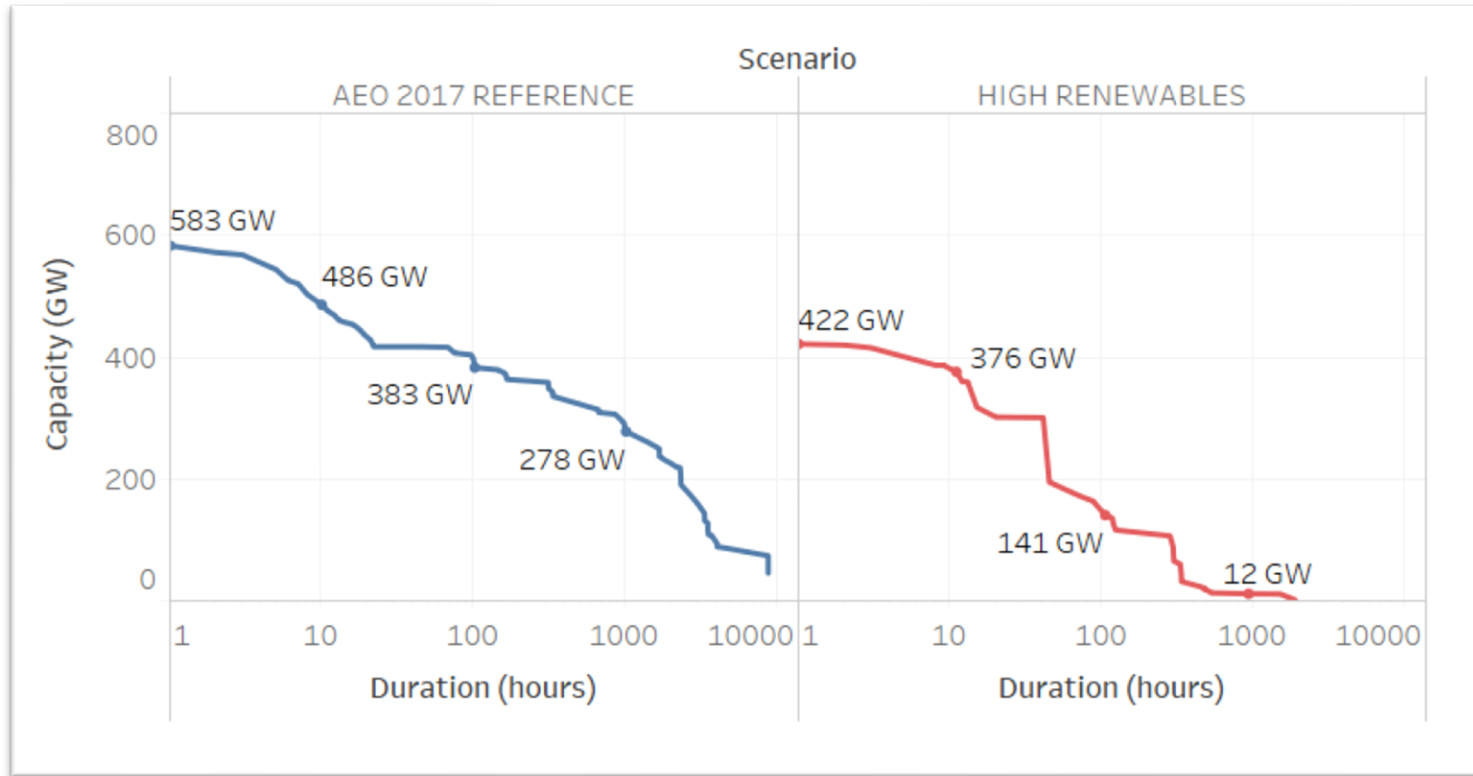
Note: Net load shown is demand minus utility-scale wind and solar

Renewable Integration– Reliability Challenge



[Evolved Energy Research: Electrification and The Future of Electricity Markets](#)

Reliability Challenge: How many hours of runtime do you need to support renewables?



In the US: To balance high renewable penetration and maintain reliability you need either storage or dispatchable generation that can provide:

- 376 GW @ > 10 hours
- 141 GW @ > 100 hours
- 12 GW @ > 1000 hours

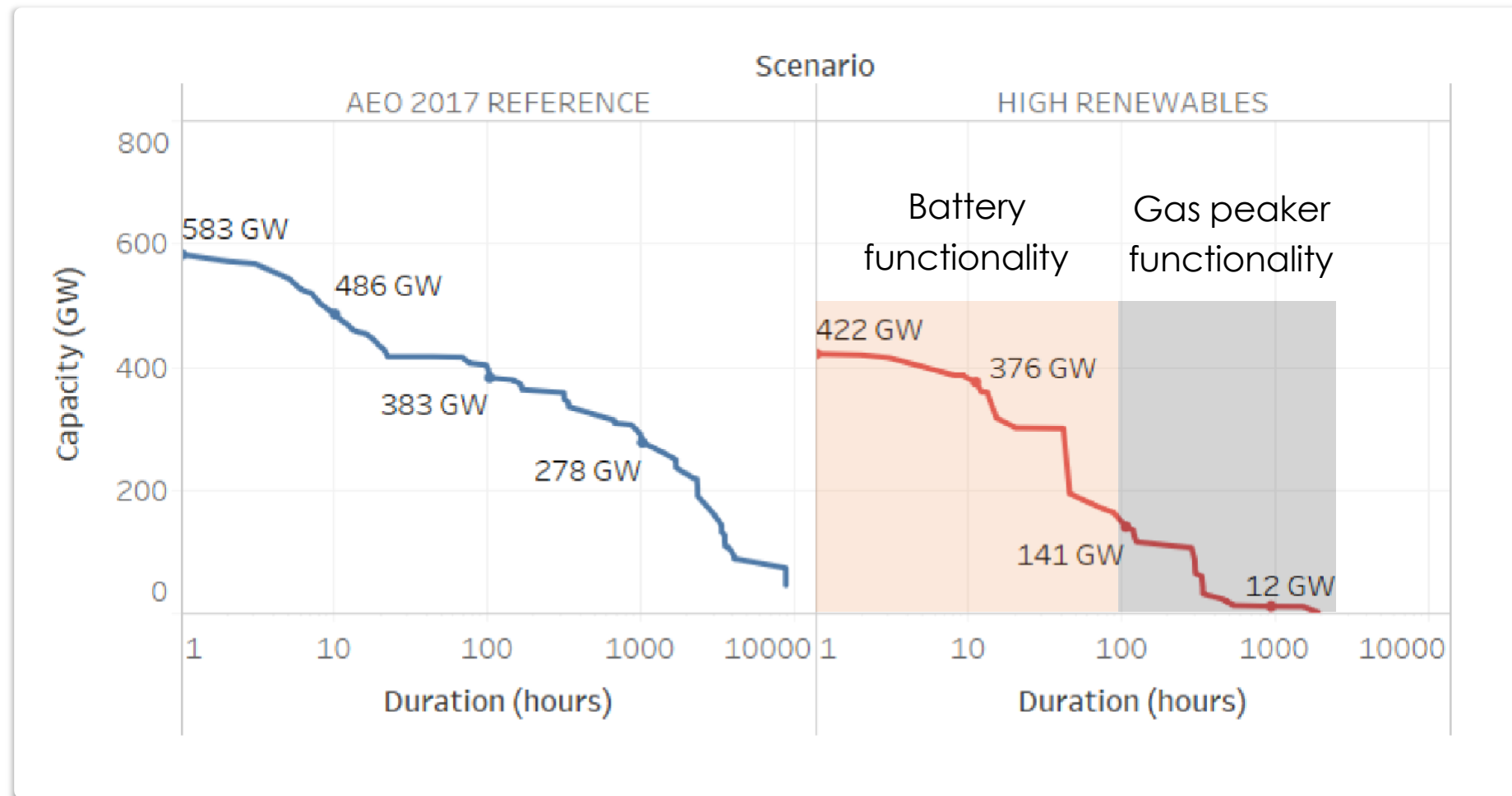
Even with very optimistic transmission assumptions

BUT > 10 hours rarely dispatched

Can batteries provide ALL or MOST of this reliability? **Form Energy is working on it**

[Evolved Energy Research: Electrification and The Future of Electricity Markets](#)

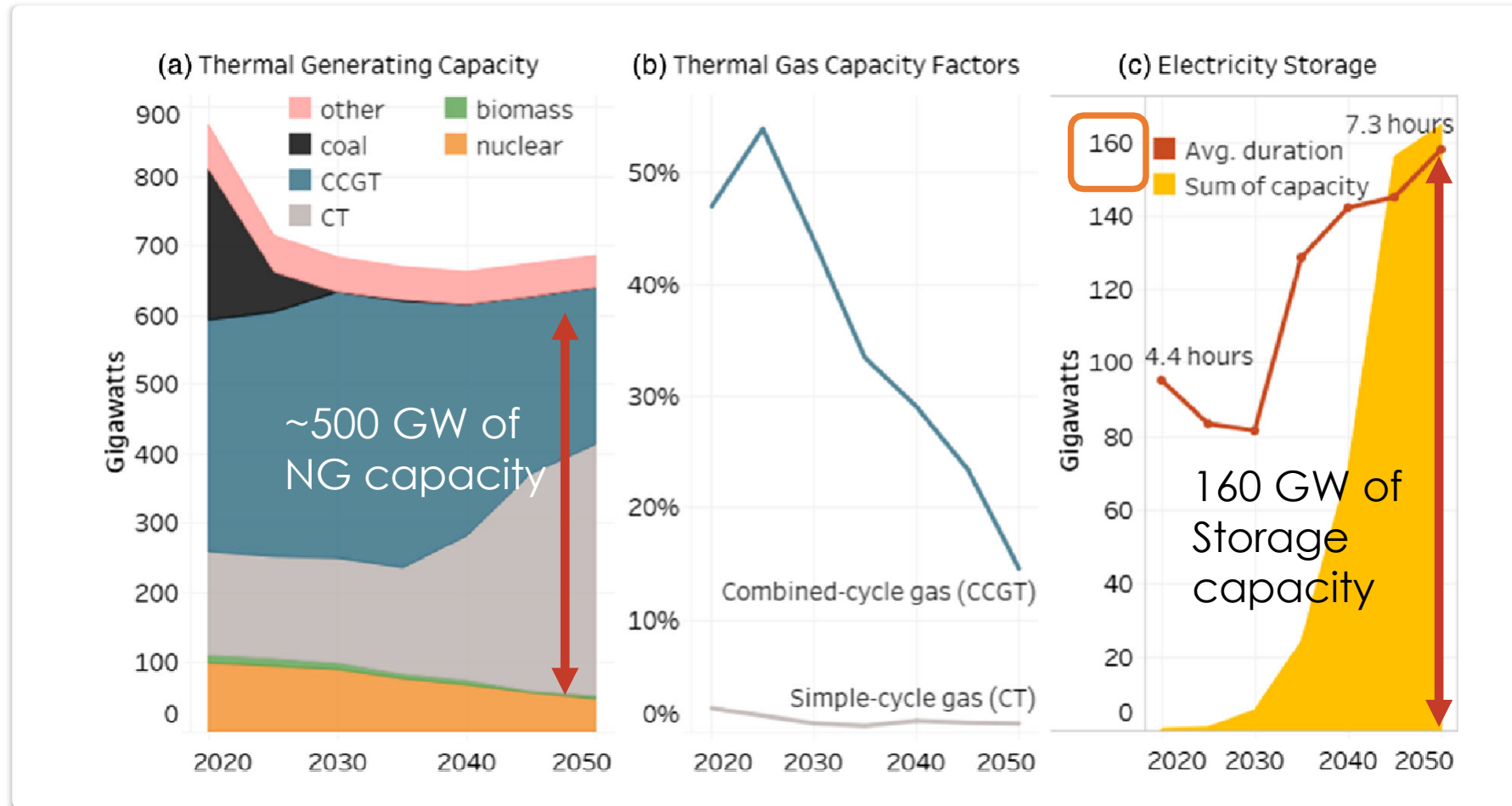
But with existing tech – Natural gas plays a big role



[Jones et Al. Evolved Energy Research: Electrification and The Future of Electricity Markets](#)



Grid needs both storage + NG peakers



[Williams et al.: AGU Advances: Carbon-Neutral Pathways for the United States](#)

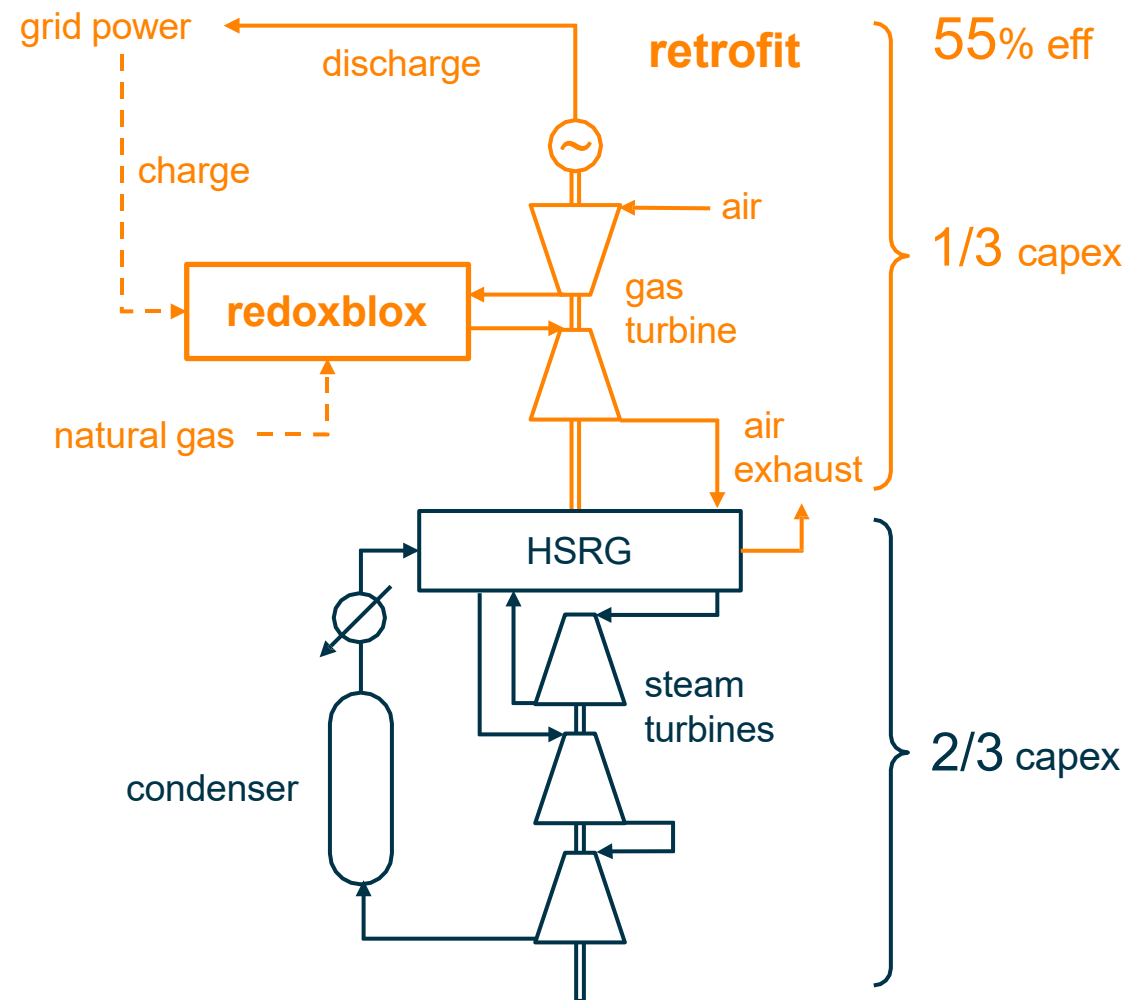
Can you combine them in one device?

A “Plug-in Hybrid for the Grid?”



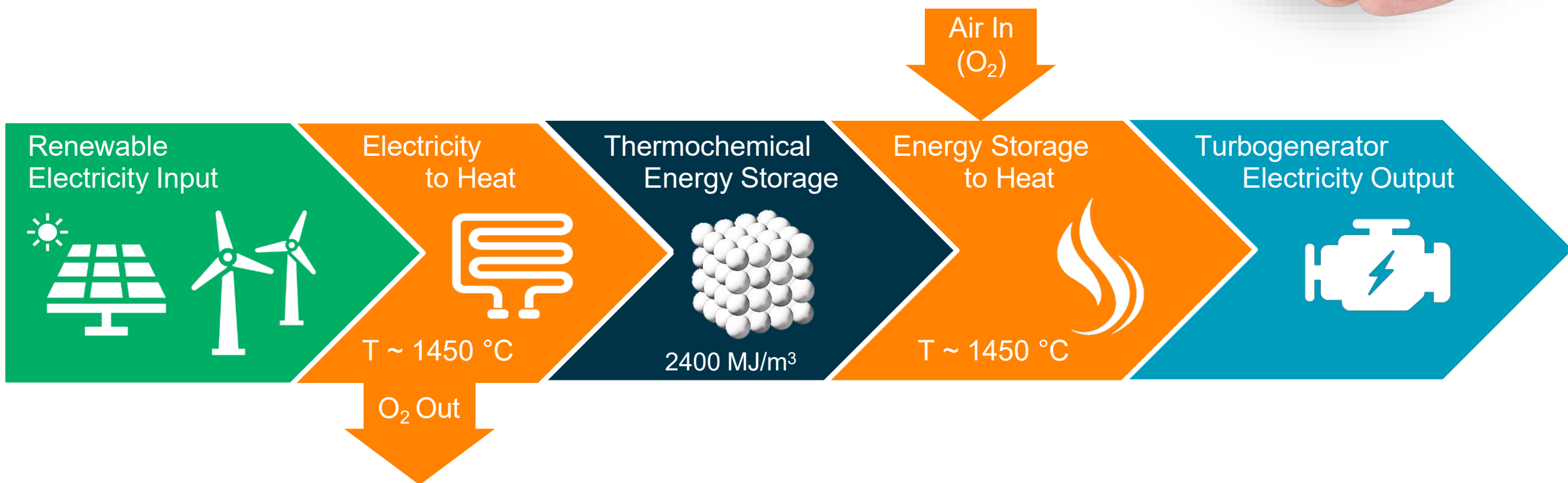
gas power plants to renewable storage

retrofit every natural gas combined cycle power plant with zero-carbon energy 6+ hour storage



our “thermochemical battery”

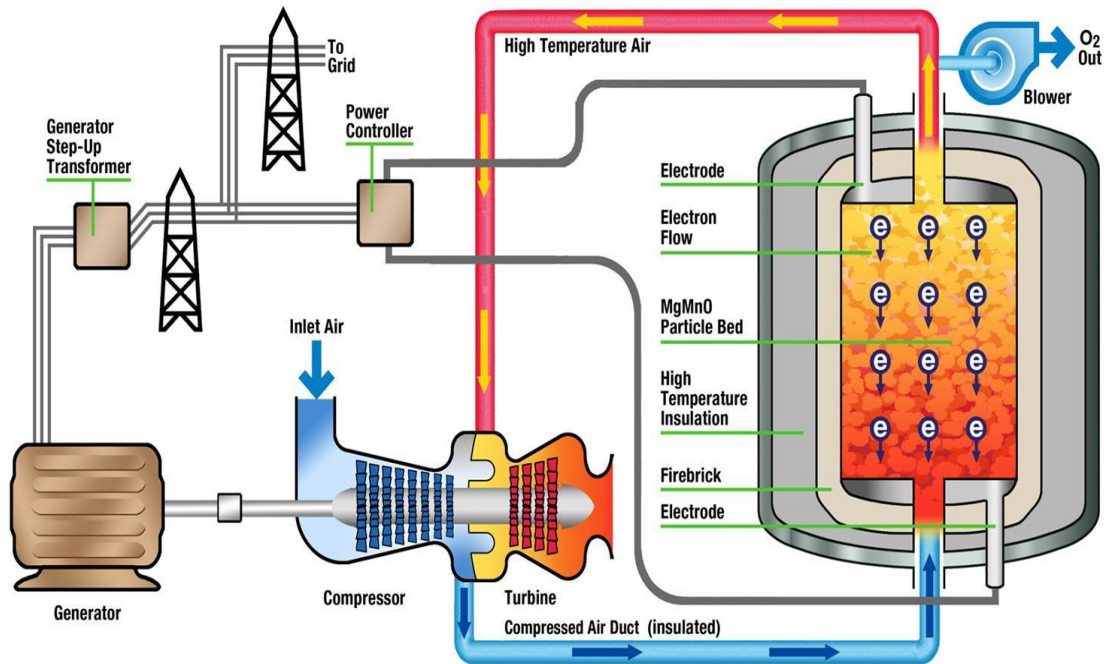
reversible combustion: $\text{MgMnO}_3 + \text{heat} \leftrightarrow \text{MgMnO}_2 + \frac{1}{2}\text{O}_2$



low-cost • earth-abundant • earth-friendly • energy dense • reversible • recyclable

grid storage

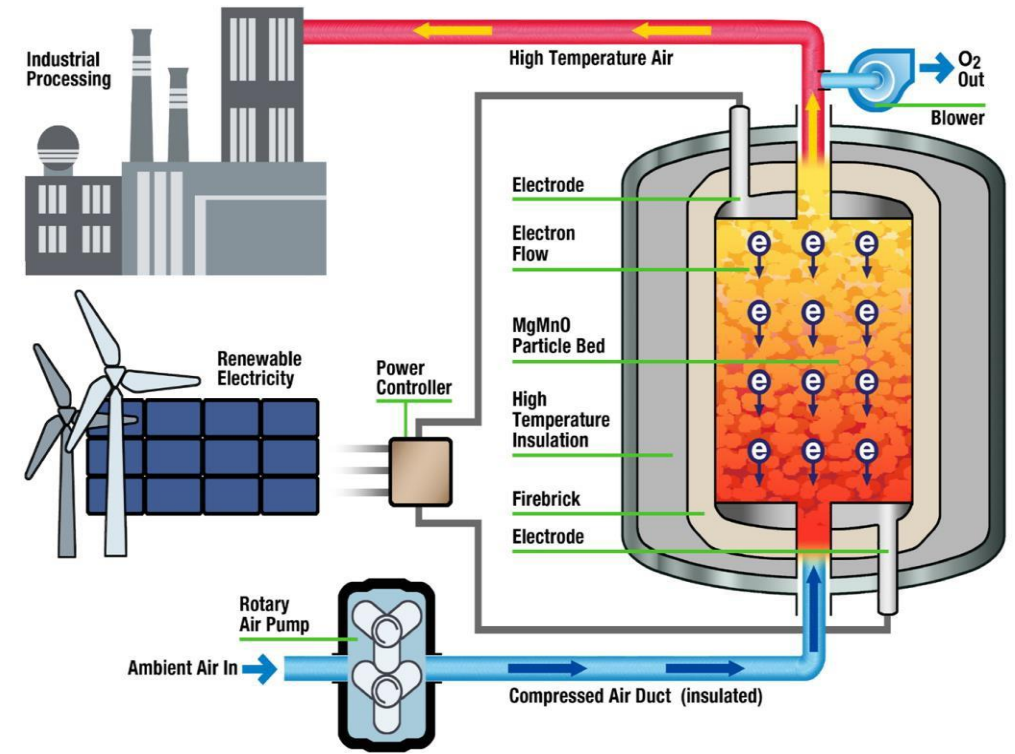
electricity \Rightarrow heat \Rightarrow store \Rightarrow heat \Rightarrow electricity
~ 55% roundtrip efficiency



installed cost 30-60 \$/kWh-e (with turbine)

industrial heat

electricity \Rightarrow heat \Rightarrow store \Rightarrow heat
~ 95% roundtrip efficiency



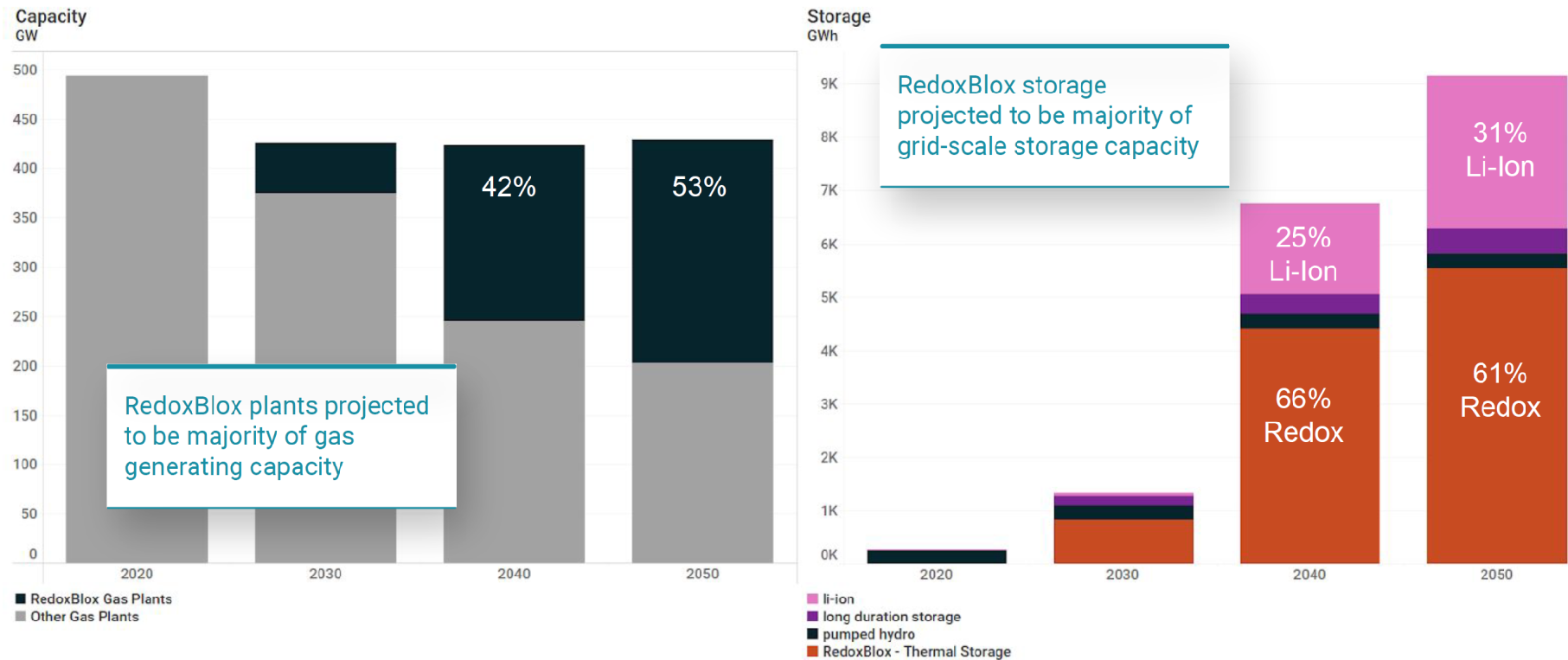
installed cost 10-20 \$/kWh-t

Modeling of Deployment of RedoxBlox Technology

> 50% of all Combined Cycles are Retrofitted by 2050

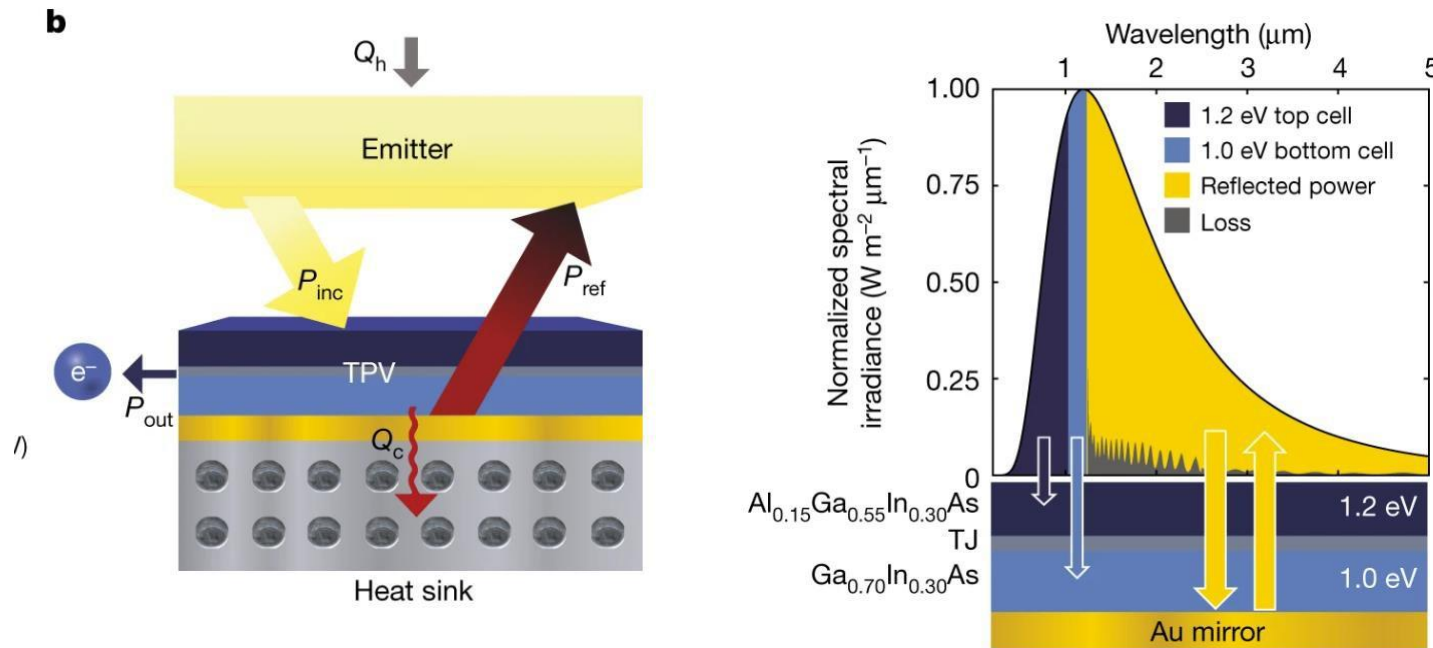


Deployment in Context





Thermophotovoltaic (TPV) Cells – A solid state heat engine with potential for 50%+ efficiency



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Thermophotovoltaic efficiency of 40%

[Alina I. Potin](#), [Kevin L. Schulte](#), [Myles A. Steiner](#), [Kyle Huznitsky](#), [Colin C. Kelsall](#), [Daniel J. Friedman](#), [Eric J. Lervo](#), [Ryan M. Lence](#), [Michelle R. Young](#), [Andrew Rohsopf](#), [Shomik Verma](#), [Lvelyn N. Wang](#) & [Asegun Henry](#)

Nature **604**, 287–291 (2022) | [Cite this article](#)

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Abstract

Thermophotovoltaics (TPVs) convert predominantly infrared wavelength light to electricity via the photovoltaic effect, and can enable approaches to energy storage^{1,2} and conversion^{3,4,5,6,7,8,9} that use higher temperature heat sources than the turbines that are



ANTORA



Antora converts cheap wind and solar into reliable industrial energy—cheaper than fossil fuels

Antora's thermal battery being installed at an industrial site

Input:

Cheap, clean, intermittent renewables

Storage:

Energy stored as heat in solid carbon blocks

Output:

Cheap, clean, reliable heat and power



FOURTH POWER

High Level Concept: TPV + Graphite + Liquid Metal Tin

