Are We on the Cusp of a Nuclear Renaissance?

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SCHOOL OF GLOBAL POLICY AND STRATEGY

BROOKINGS

UC San Diego
DEEP DECARBONIZATION INITIATIVE

Four Topics Today

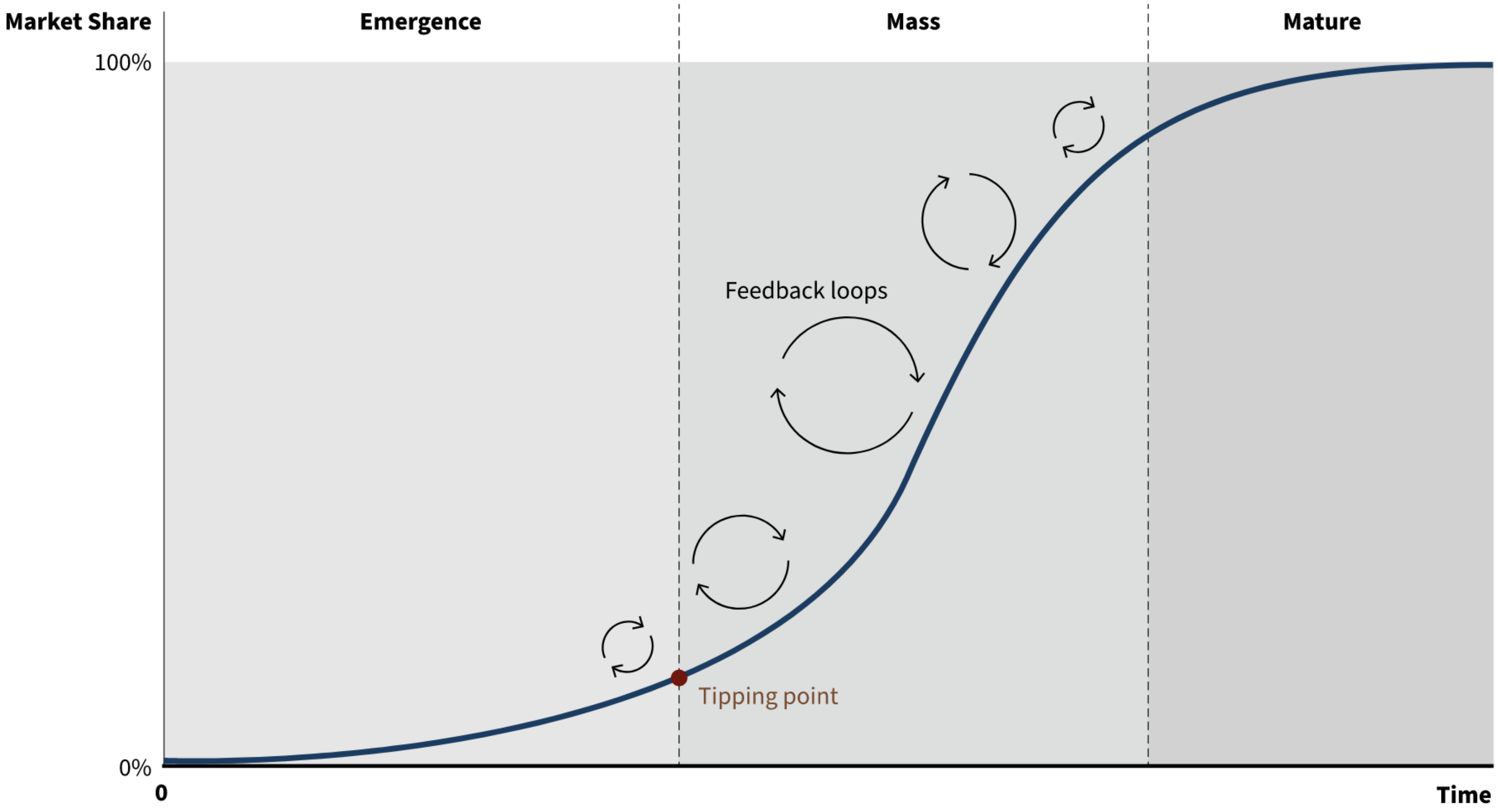
- Leaving the Dark Ages?
- Learning from What Went Wrong
- What Nuclear Does Well: Excellence in Operations and Clean Firm Power
- The imperative of finance

Topic 1:

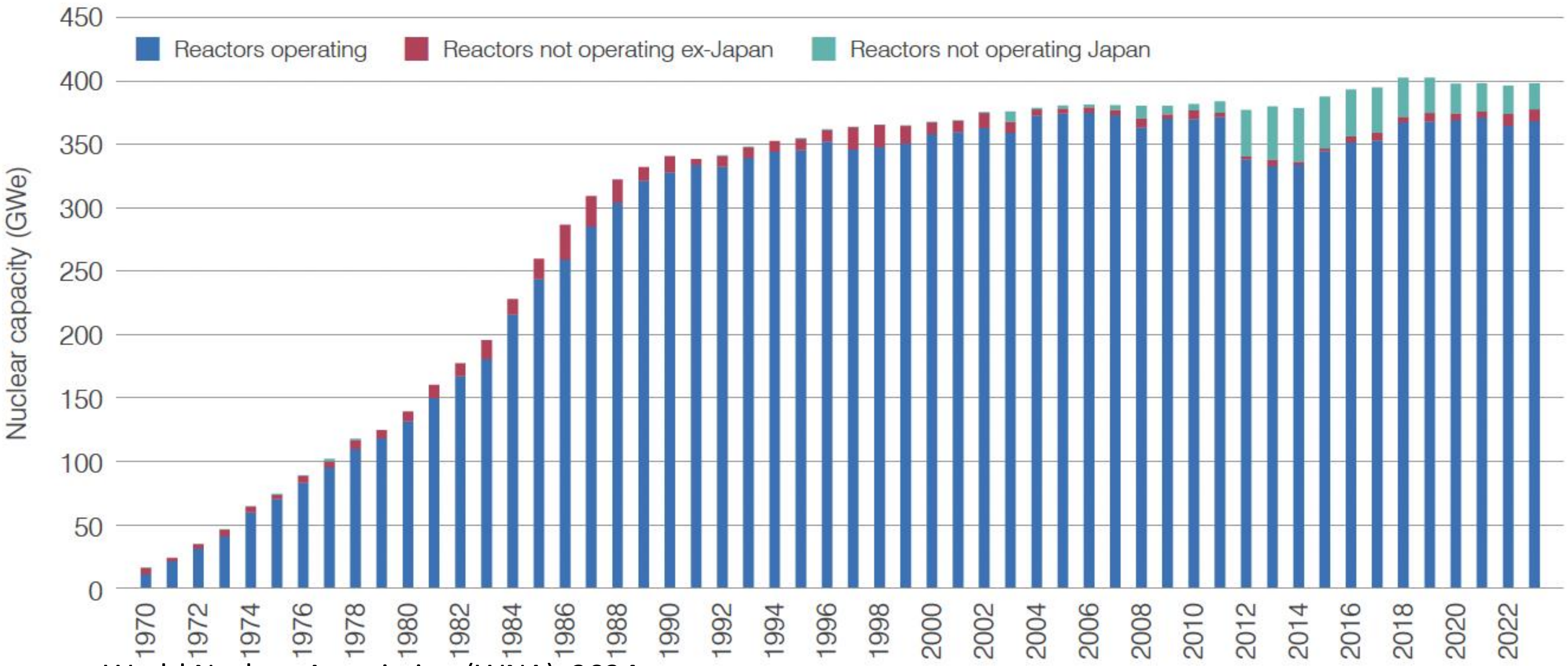
Leaving the Dark Ages?

A Shift in Nuclear Geography

How to Think About New Technologies

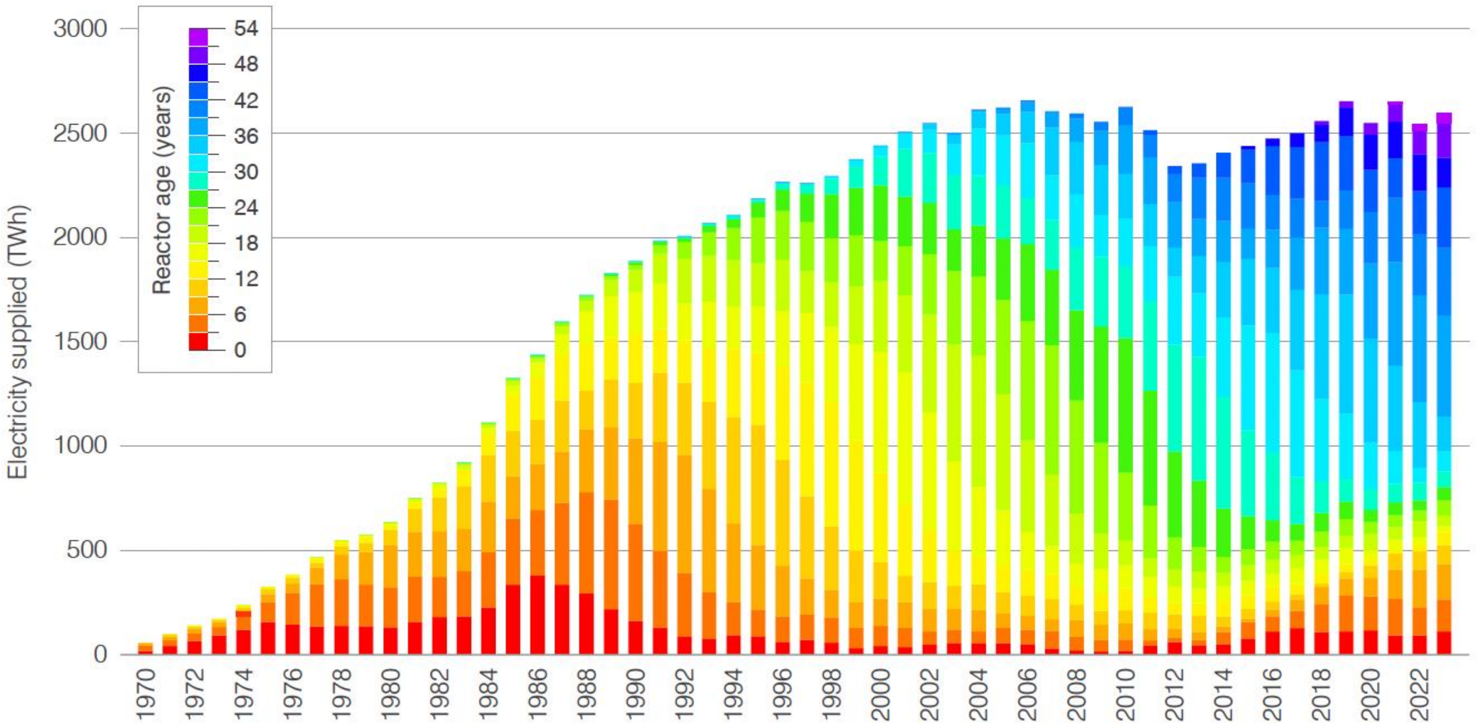


Did the Renaissance End in the 1980s?



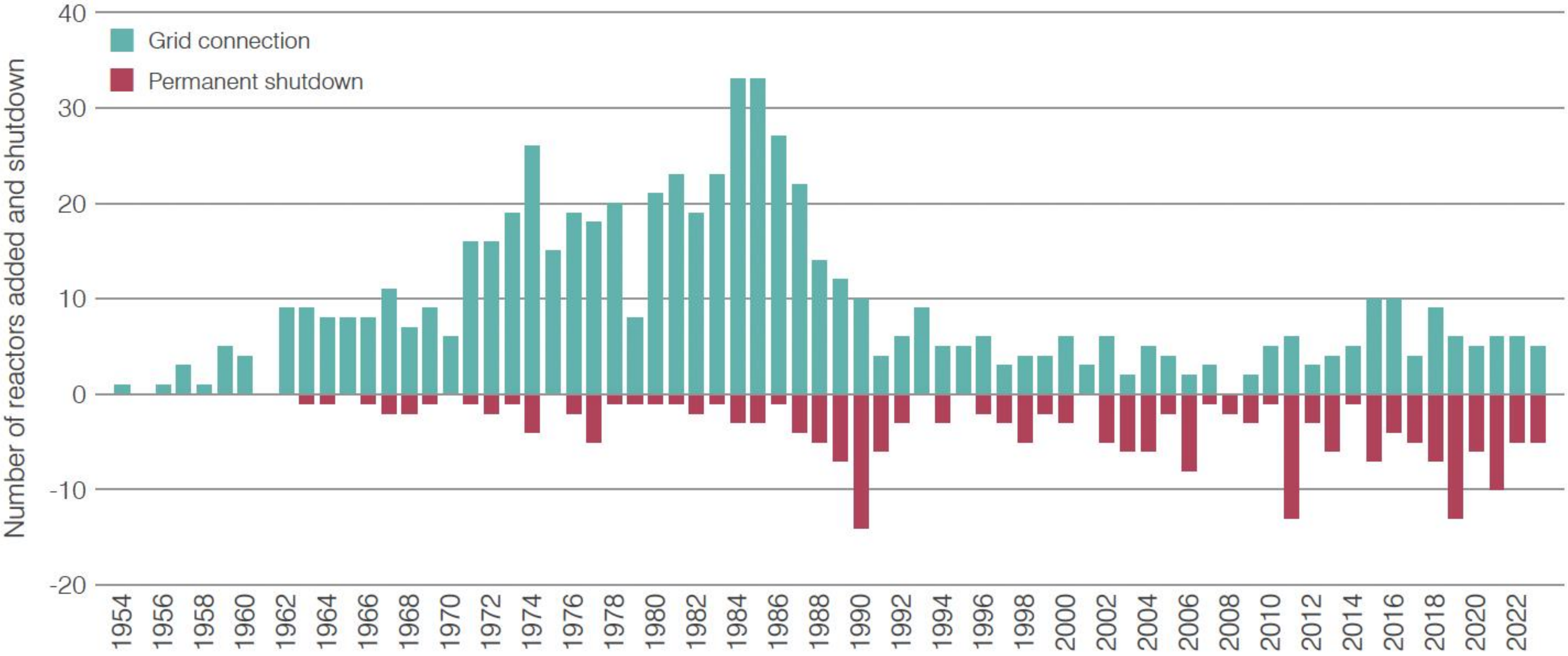
Sources: World Nuclear Association (WNA), 2024;
IAEA PRIS Database

Two Fleets: Geriatrics and Adolescents



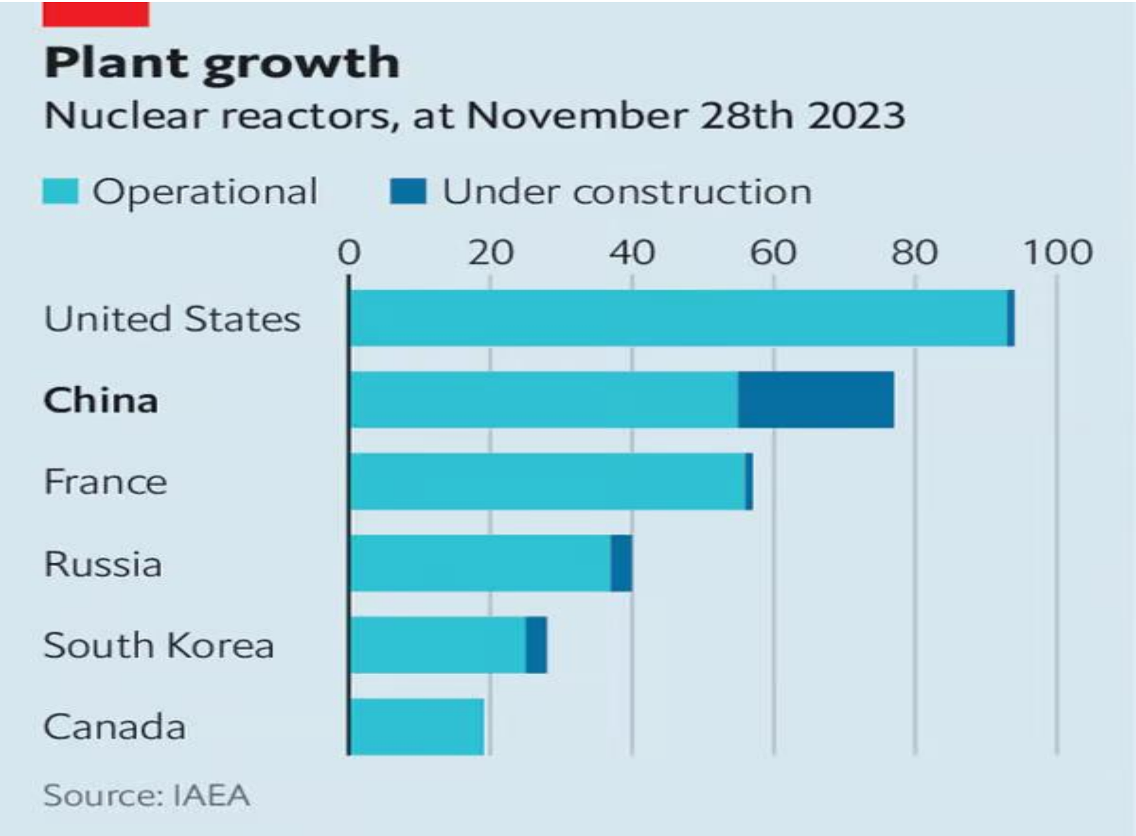
Sources: World Nuclear Association (WNA), 2024;
IAEA PRIS Database

Grid Connections: First (green) and Last (Red)



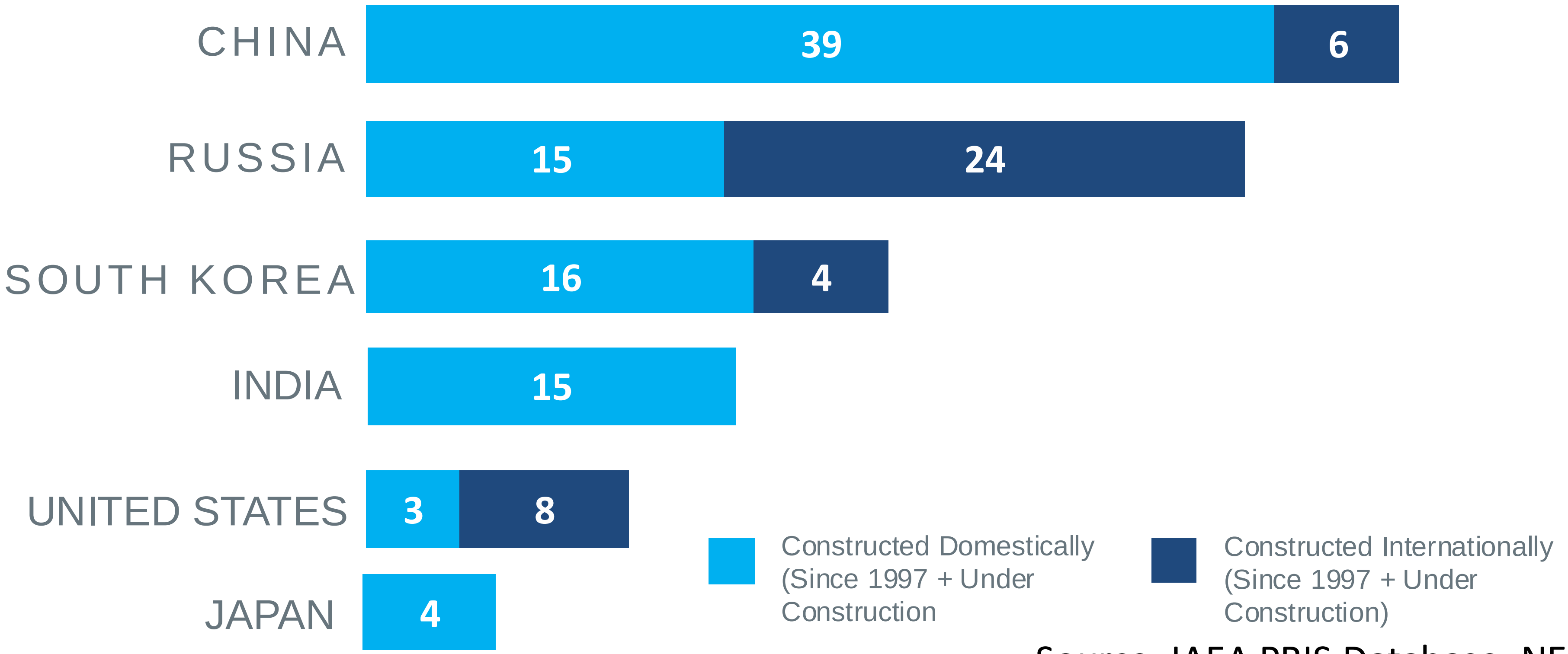
Sources: World Nuclear Association (WNA), 2024;
IAEA PRIS Database

The Rapid Rise in China



Source: The Economist

The Other Geographical Shift: Overseas Construction



Source: IAEA PRIS Database; NEI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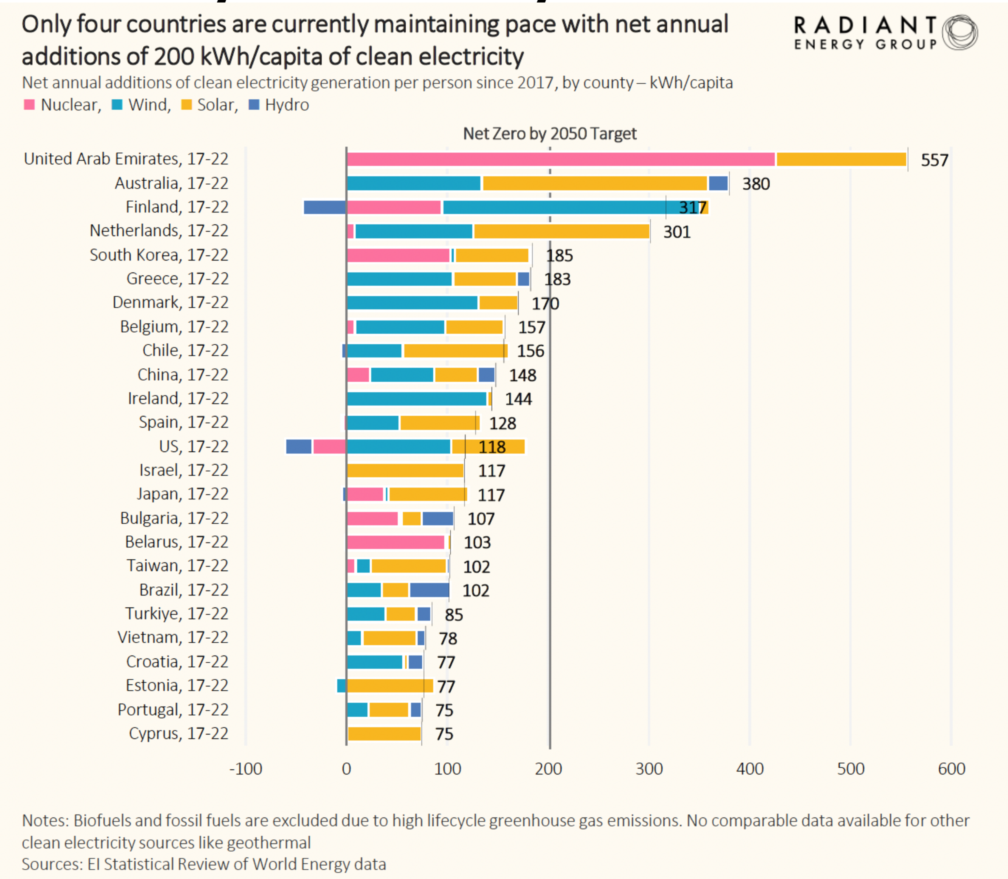
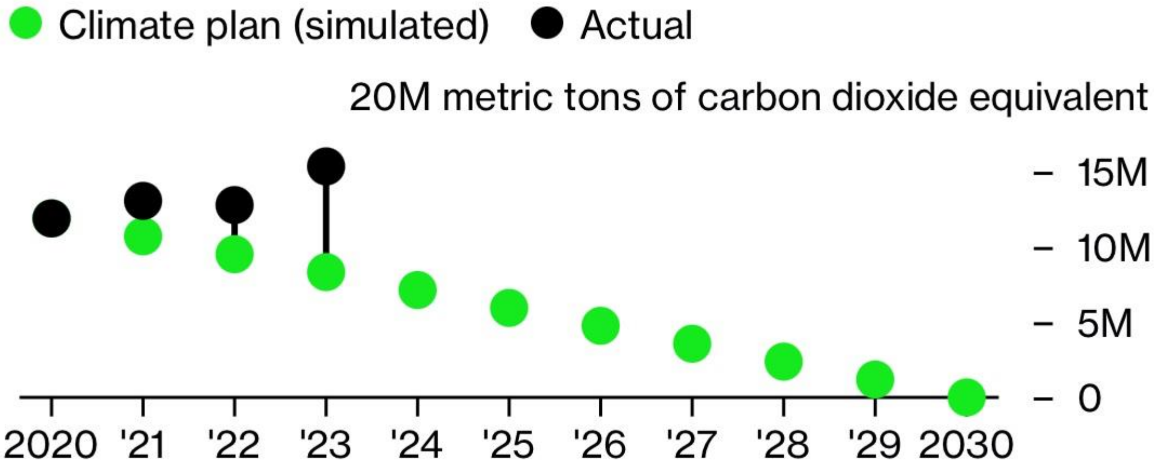
Clean electrons scaling is happening, but every country is different



Microsoft's Emissions

Artificial intelligence is putting the tech giant's climate goals in peril

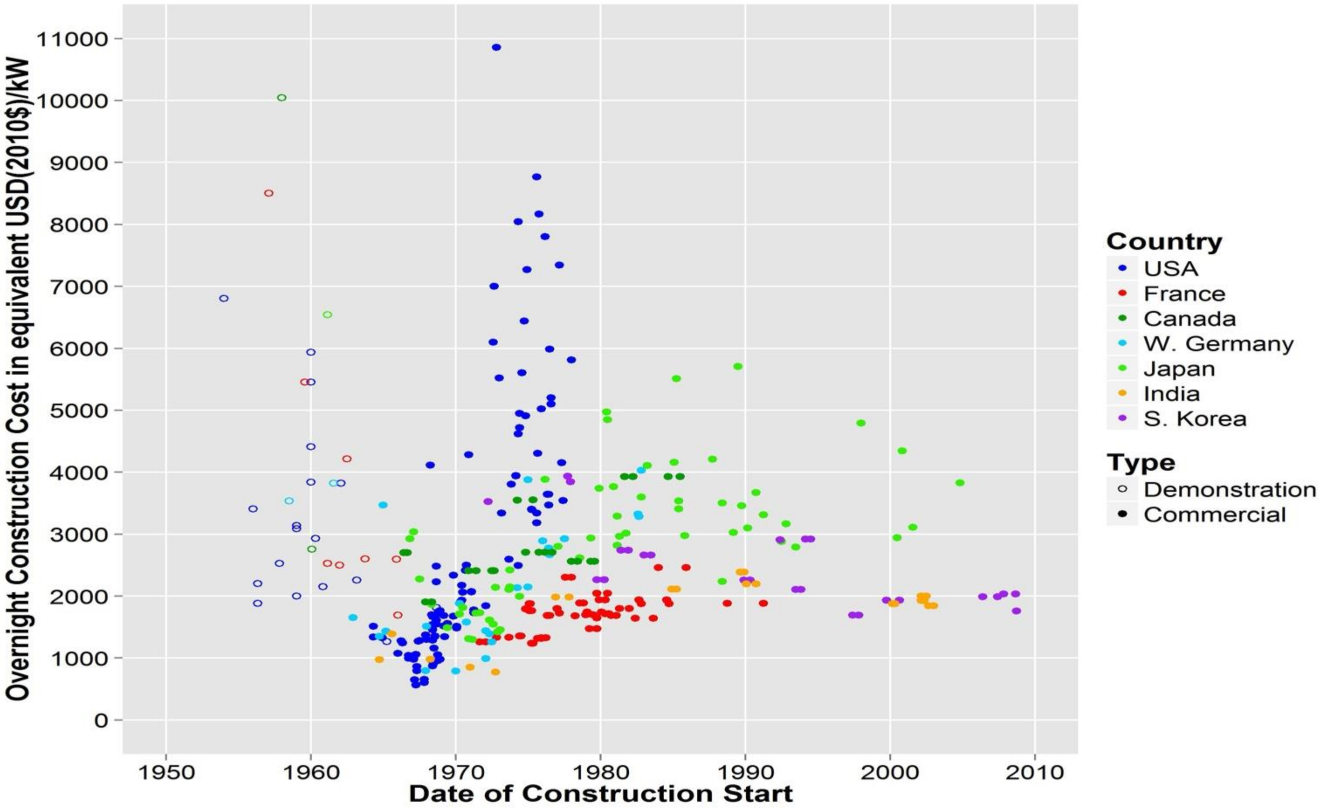


Source: Microsoft (Scope 1, 2 and 3 "management criteria" data)
Note: Green dots represent linear decline to carbon negative goal.

Topic #2:

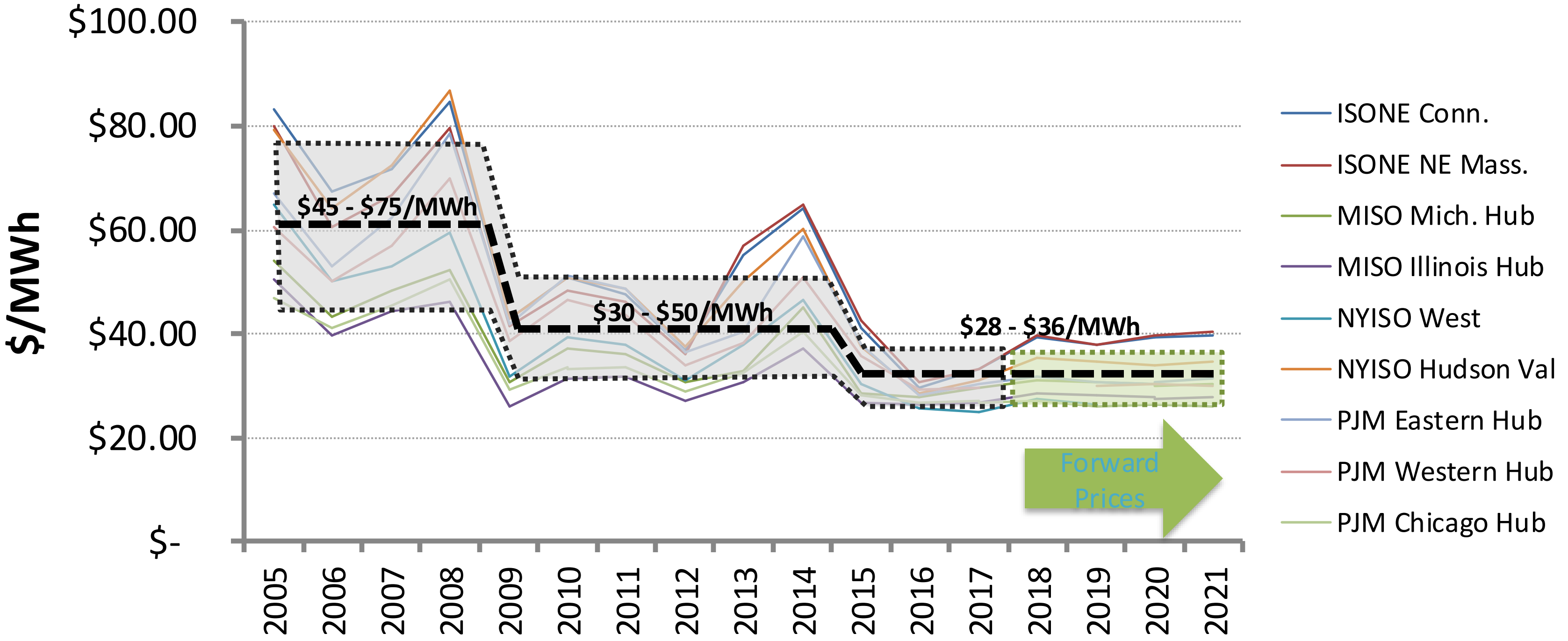
Learning from What Went Wrong

Overnight Capex for Nuclear Reactors by Country



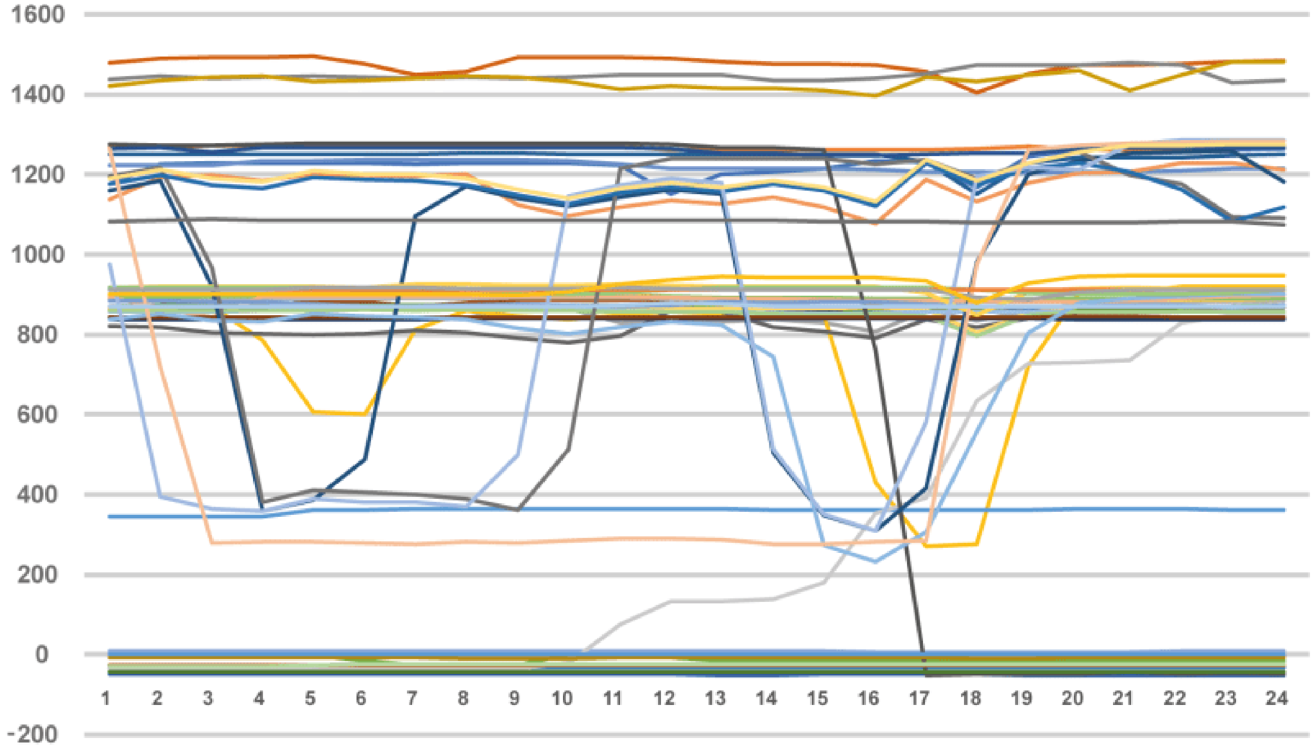
Source: Lovering et al (2016)

U.S. Wholesale Power Prices: The Gas Revolution



Source: NEI

Looking to the Future: Performance While Rapidly Ramping with Grid connected renewables



Source: RTE output for French nuclear reactors on 13 Sept 2015, via Morris (2018)

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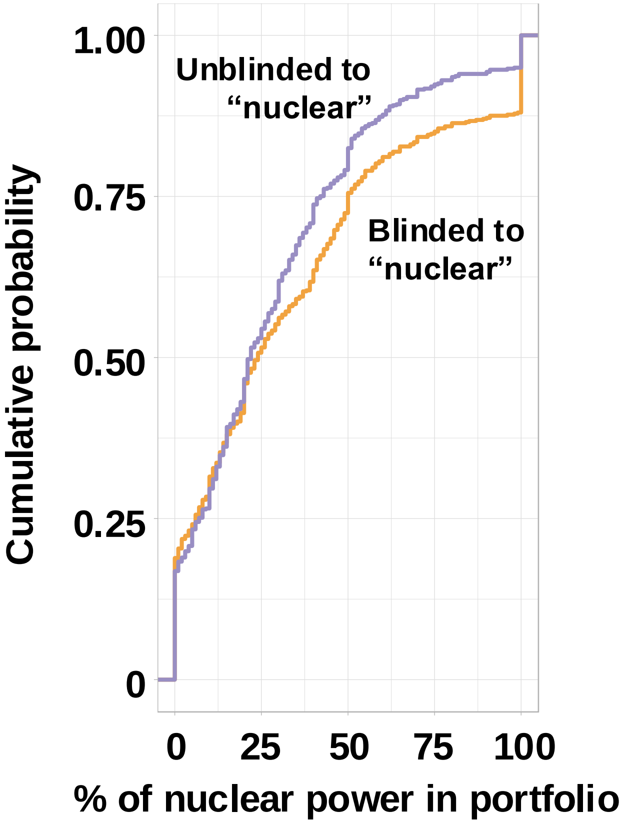
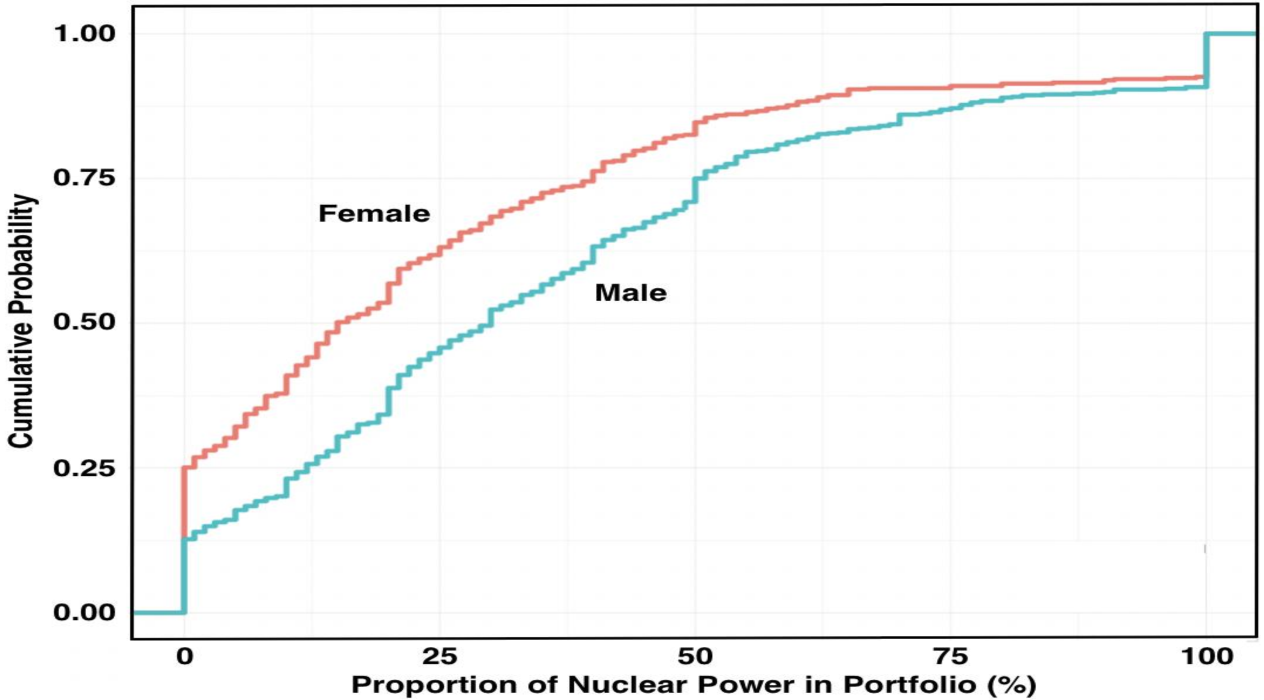
Political Support for Nuclear: “Dread Risk”



- “Even after accounting for the risk of nuclear power, the role that dread plays in opposition is large
- Without dread, U.S. sample might support 40% more nuclear
- Safer reactors not enough. Increased deployment requires strategies to reduce “dread risk”

Source: Abdulla *et al* (2019) Energy Policy

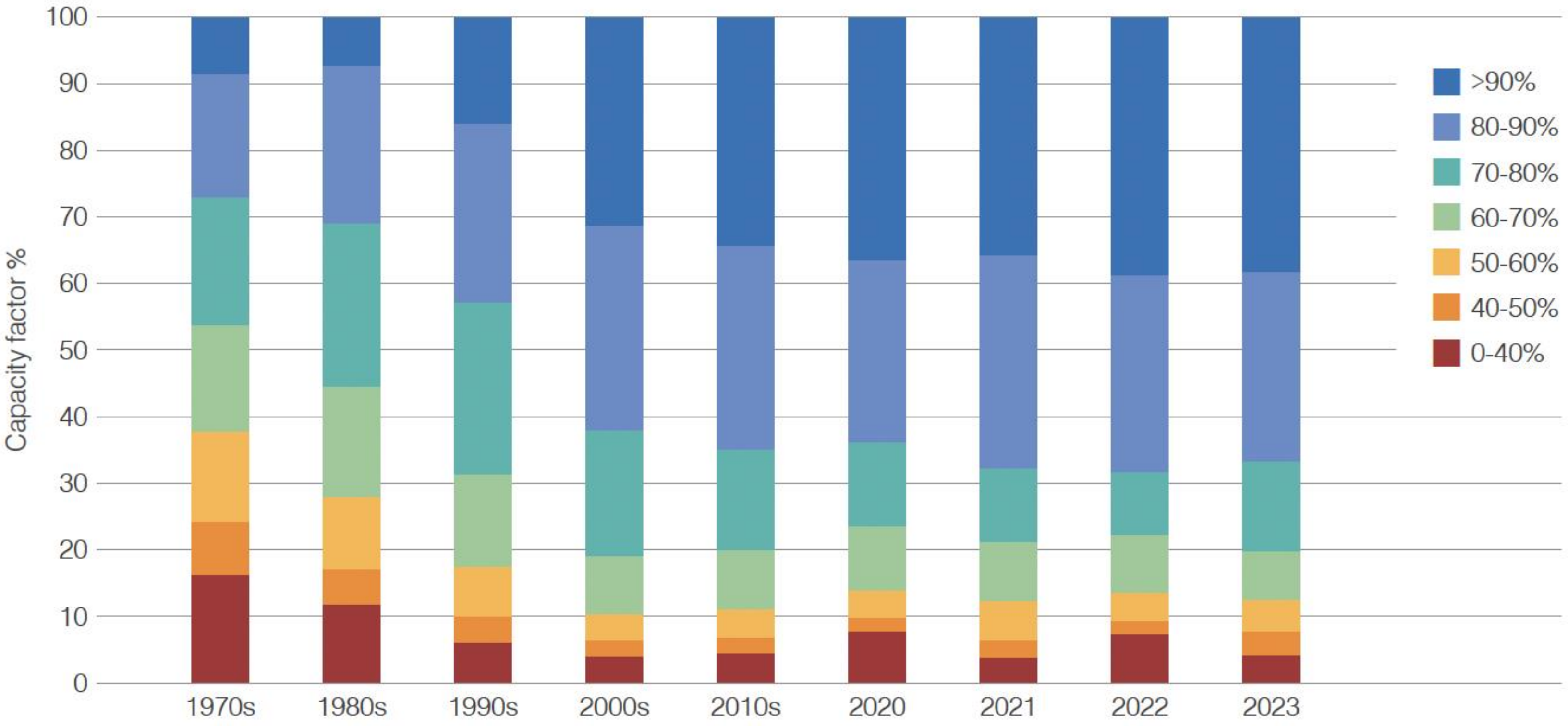
Political Support for Nuclear: Gender Differentiation



Source: Abdulla *et al* (2019) Energy Policy

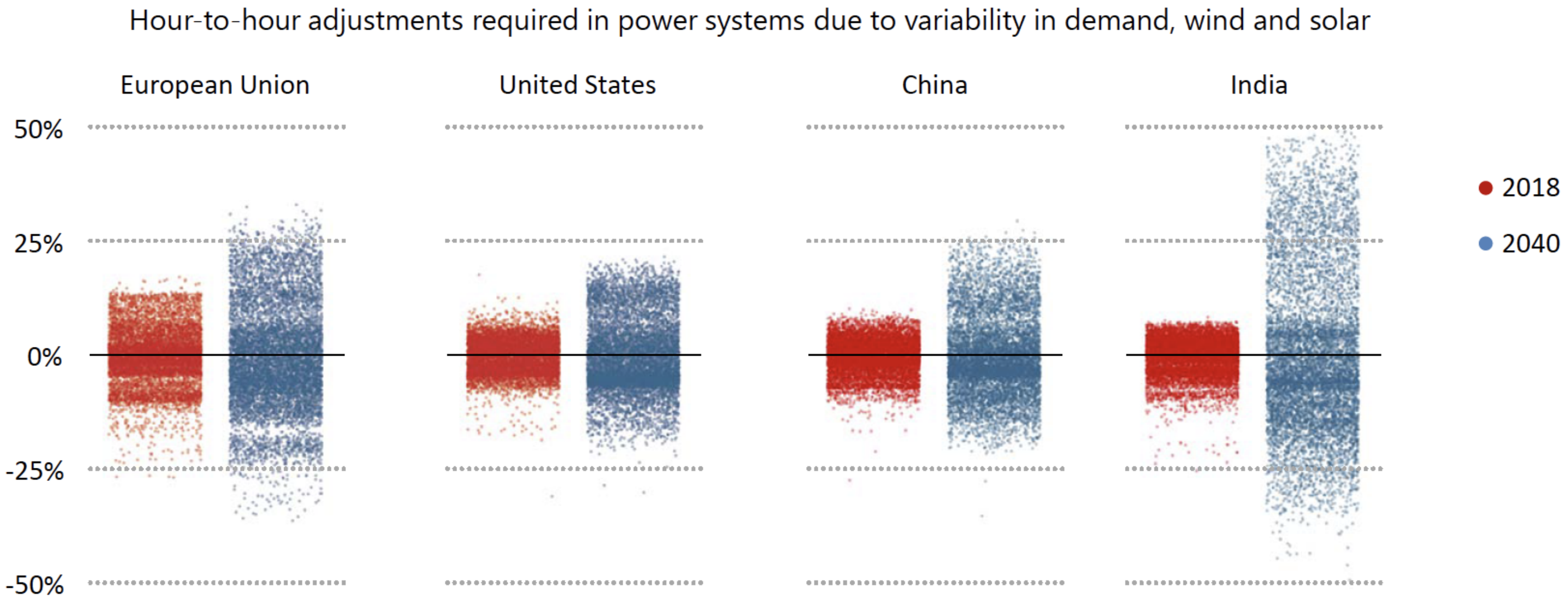
Topic 3:
What Nuclear Does Well: Excellence in Operations and Clean Firm Power

Capacity Factors for Global Nuclear Fleet, by decade



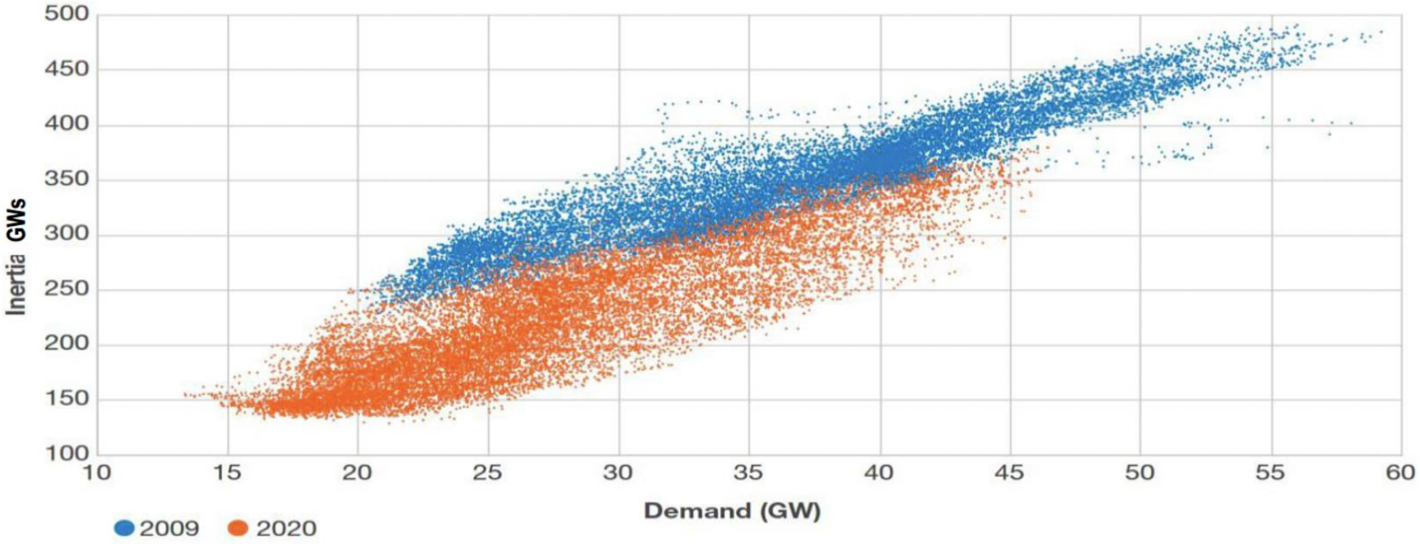
Sources: World Nuclear Association (WNA), 2024;
IAEA PRIS Database

Electricity moves to the heart of modern energy security



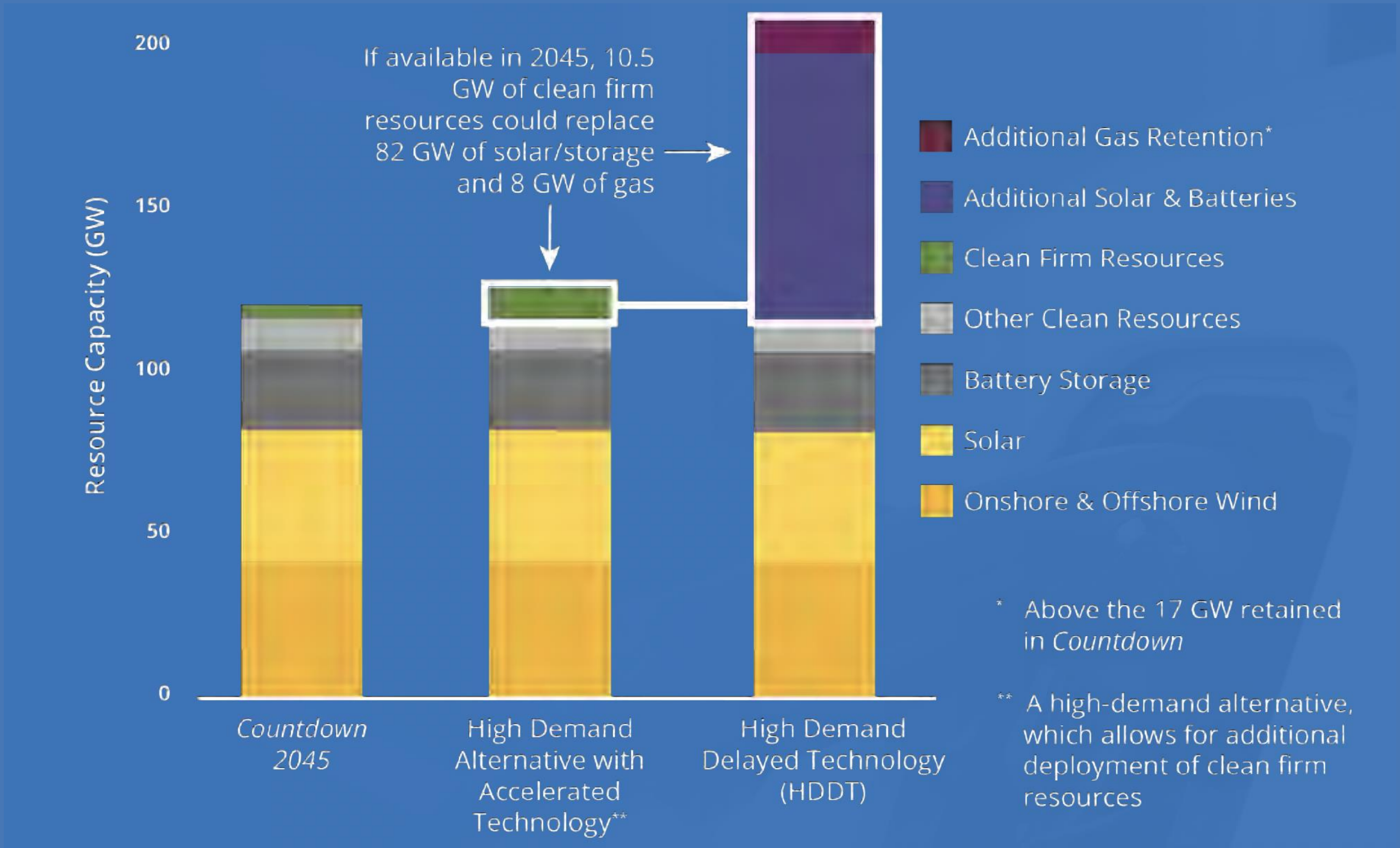
Global needs for flexibility double to 2040, but today's market designs may not bring sufficient investment to deliver it, e.g. in power plants, networks, demand-side response and energy storage, including batteries

Grid Stability and Inertia



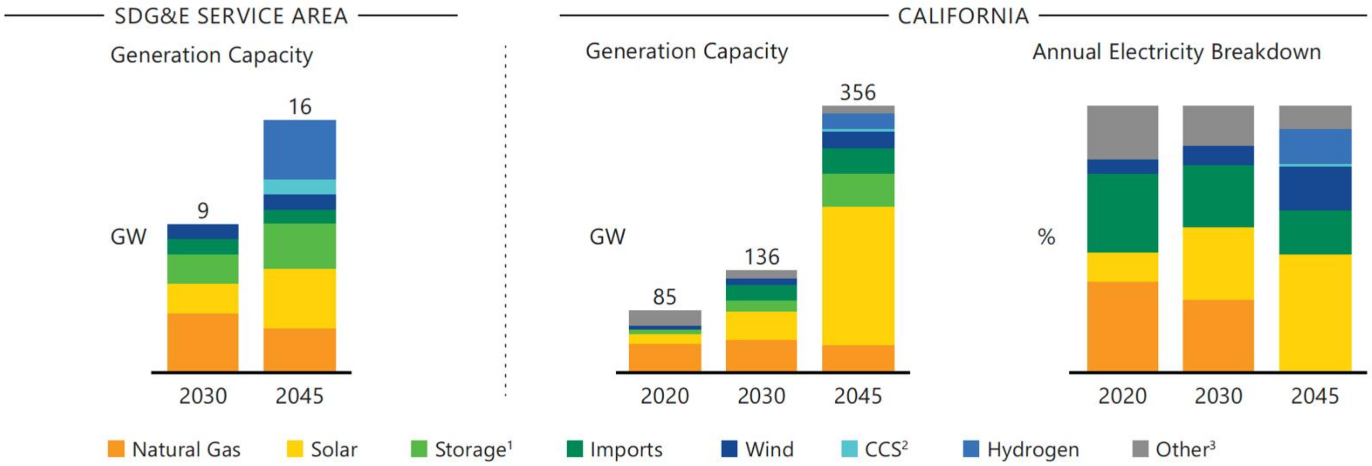
Source: Quist, Hammadi and Victor (2023) Oxford Institute for Energy Studies

The Imperative of Clean Firm Power



Source: SCE "Reaching Net Zero" (Sept 2024)

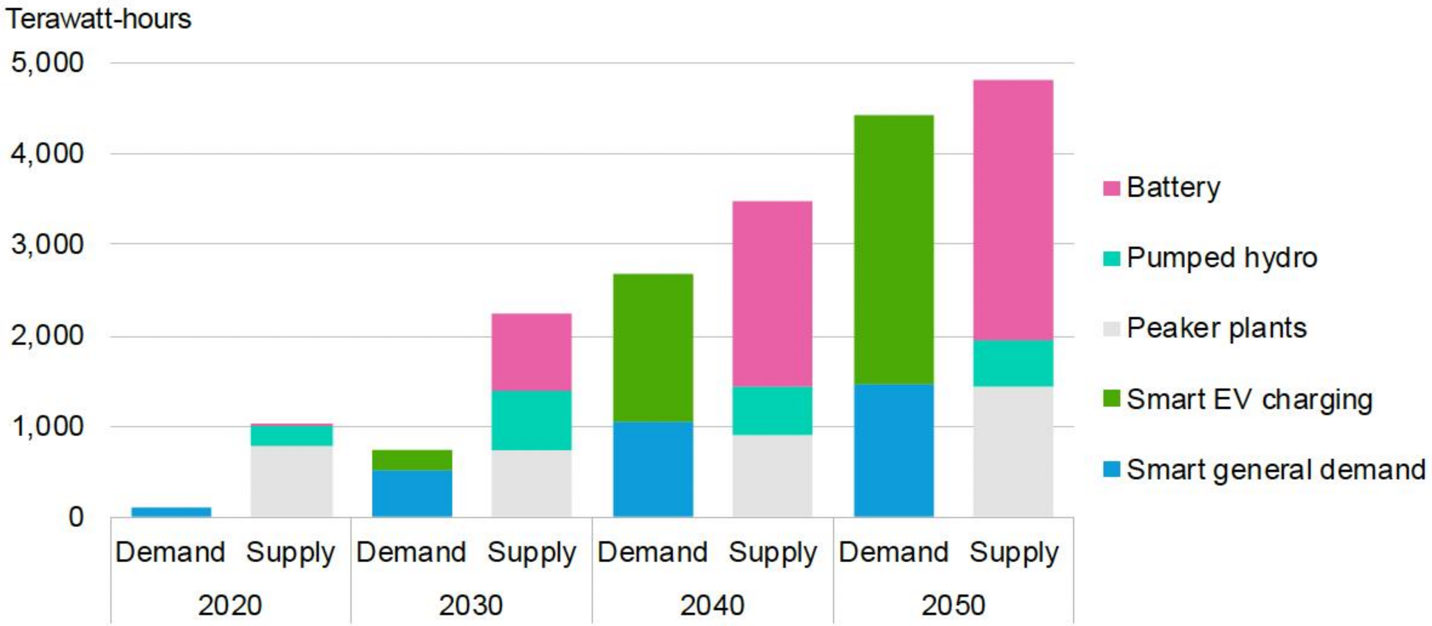
Eliminating Emissions in California



Source: SDG&E "Net Zero" (April '22)

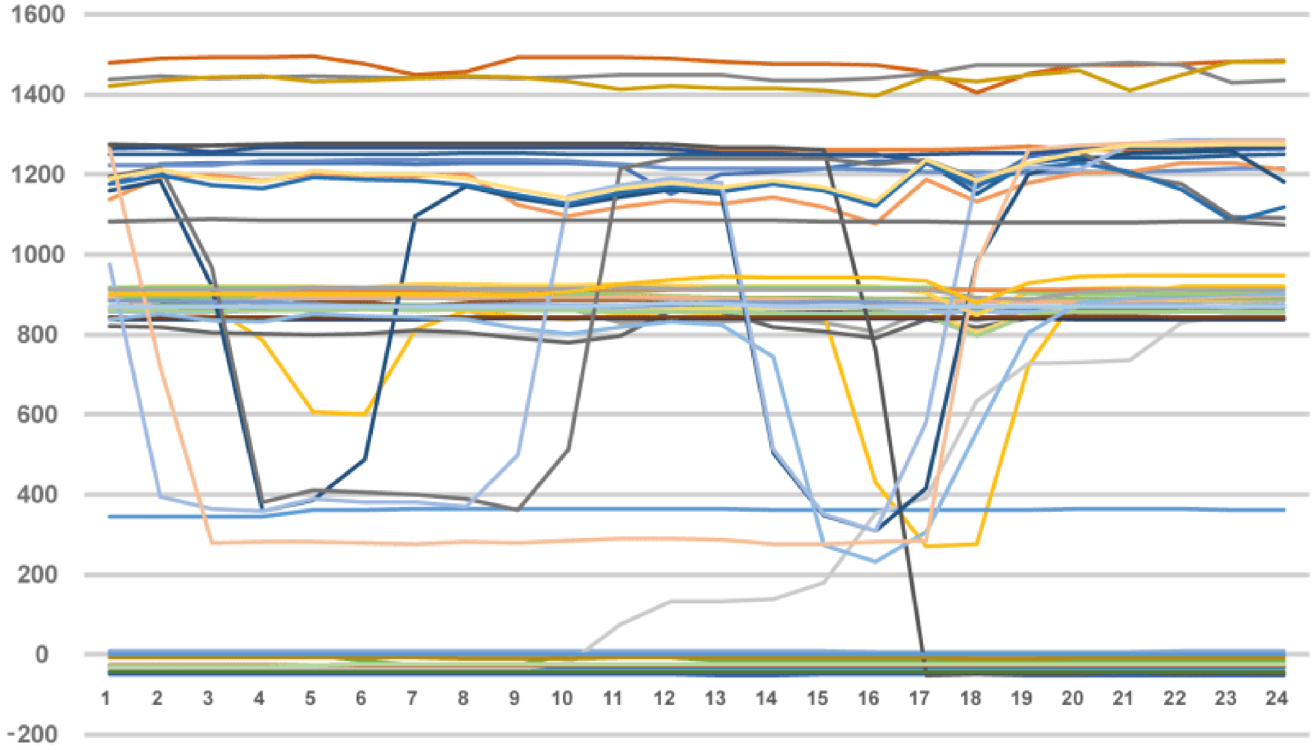
How Much Supply Flexibility is Needed Depends on Demand Flexibility

Figure 6: Power system flexibility sources, Economic Transition Scenario



Source: BloombergNEF *New Energy Outlook* (May 2024)

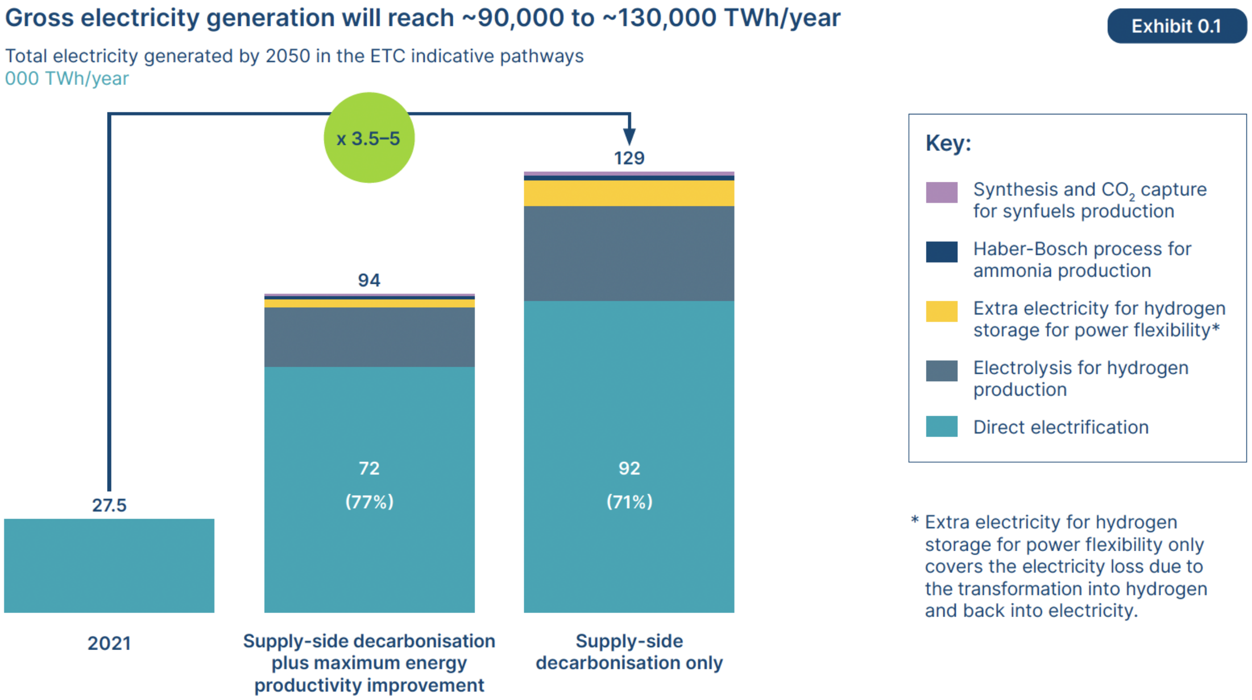
Looking to the Future: Performance While Rapidly Ramping with Grid connected renewables



Source: RTE output for French nuclear reactors on 13 Sept 2015, via Morris (2018)

Topic 4:
The Imperative of Finance

Clean electricity supply poised for massive growth



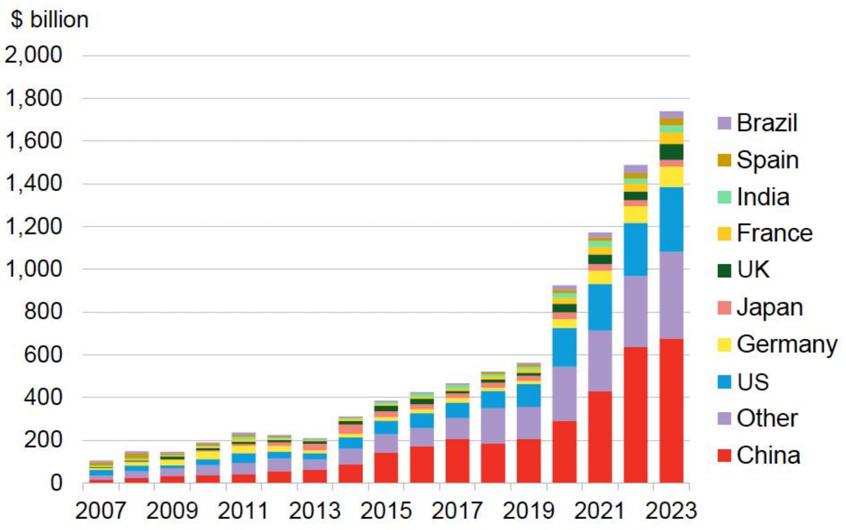
Note: Assumes 85% green hydrogen production in 2050.

Source: Systemiq analysis for the Energy Transitions Commission (2021); EMBER (2022), *Global Electricity Review* (2022).

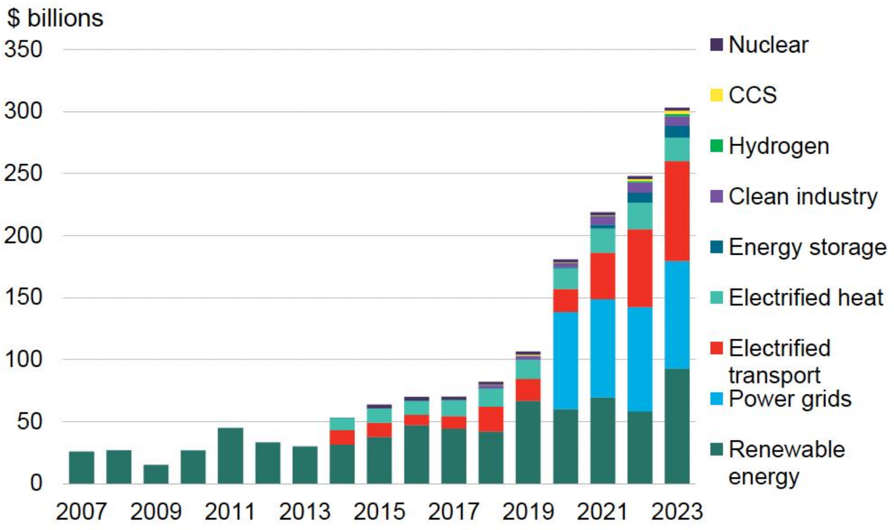
Source: ETC "Streaming planning and permitting…" (Jan 2023)

Surge in “energy transition” investment

Energy transition investment, by market



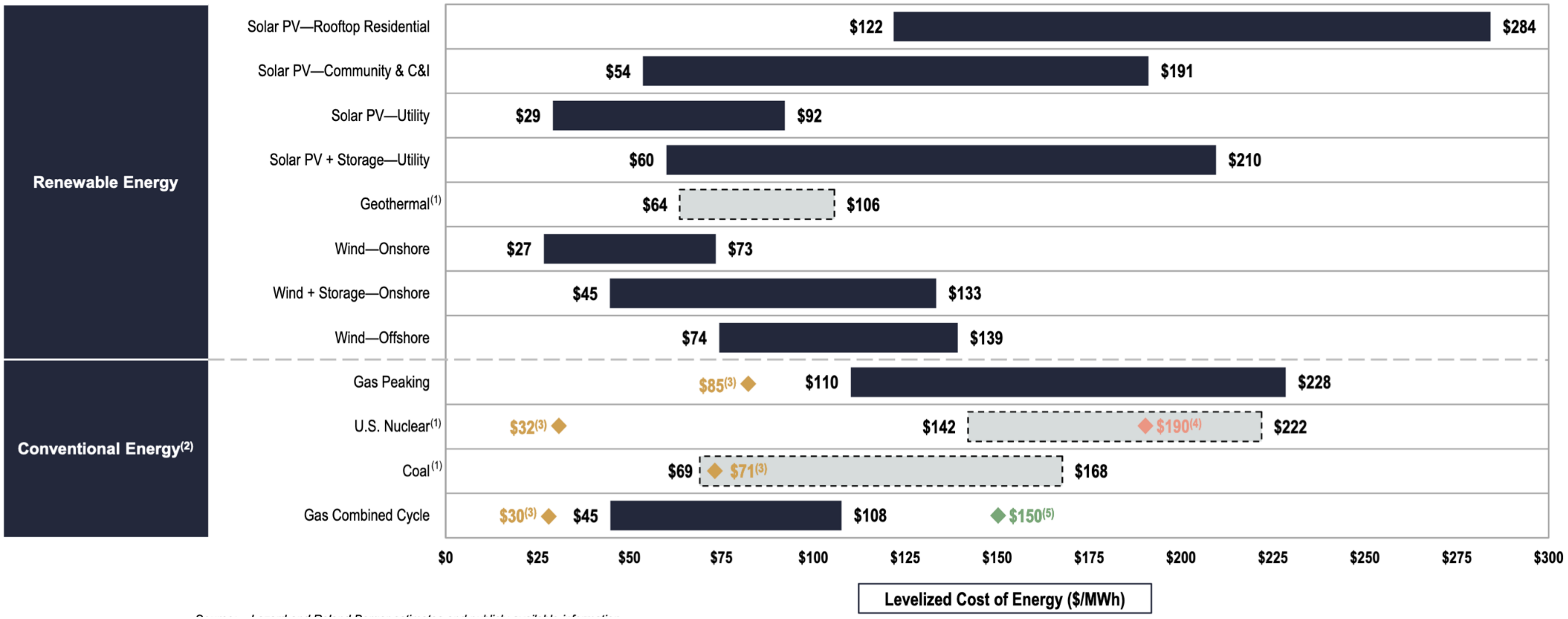
US energy transition investment, by sector



Source: BNEF *Sustainable Energy in America* (2024)

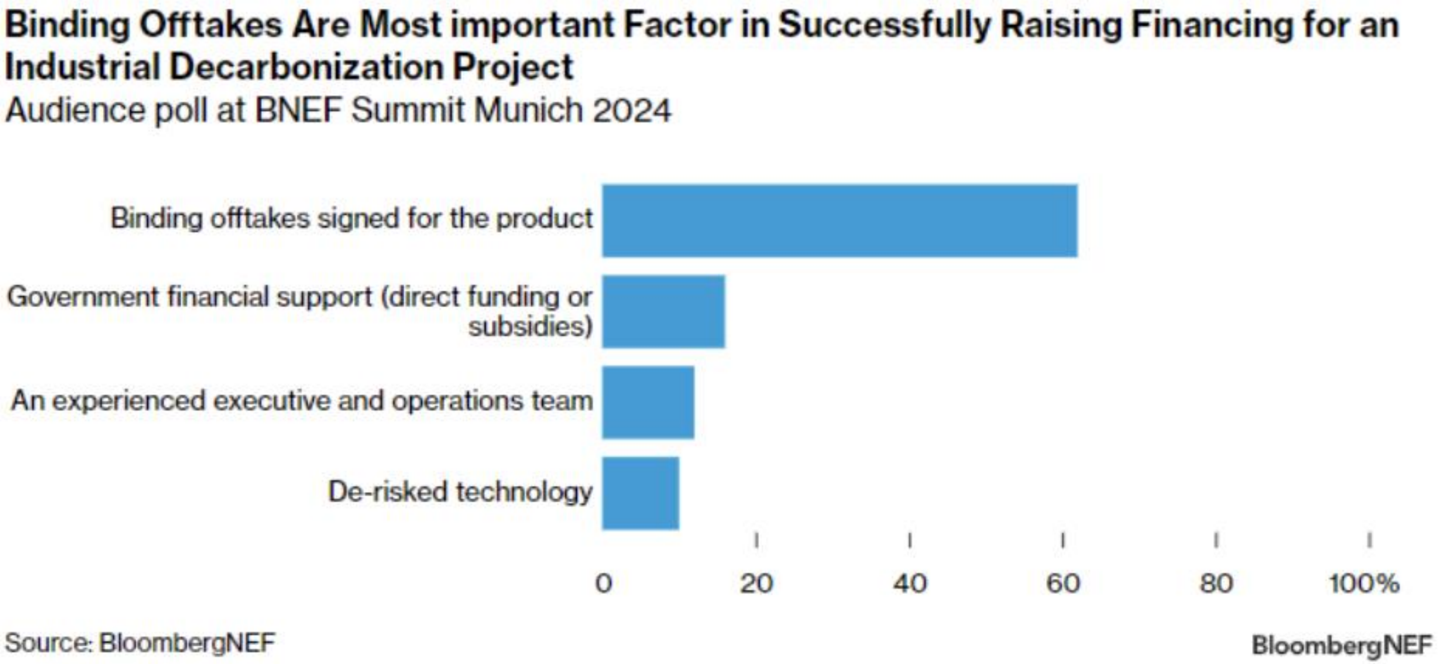

FINANCING THE TRIPLING OF NUCLEAR ENERGY
New York
23 September 2024

The Cost of Electric Generators



Source: Lazard and Berger (2024)

Lots of interesting ideas for clean industrial projects, but will someone pay for it?



Notes for Lazard LCOE

Source: *Lazard and Roland Berger estimates and publicly available information.*

Note: Here and throughout this analysis, unless otherwise indicated, the analysis assumes 60% debt at an 8% interest rate and 40% equity at a 12% cost. See page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital sensitivities.

(1) Given the limited public and/or observable data available for new-build geothermal, coal and nuclear projects the LCOE presented herein reflects Lazard's LCOE v14.0 results adjusted for inflation and, for nuclear, are based on then-estimated costs of the Vogtle Plant. Coal LCOE does not include cost of transportation and storage.

(2) The fuel cost assumptions for Lazard's LCOE analysis of gas-fired generation, coal-fired generation and nuclear generation resources are \$3.45/MMBTU, \$1.47/MMBTU and \$0.85/MMBTU respectively, for year-over-year comparison purposes. See page titled "Levelized Cost of Energy Comparison—Sensitivity to Fuel Prices" for fuel price sensitivities.

(3) Reflects the average of the high and low LCOE marginal cost of operating fully depreciated gas peaking, gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper- and lower-quartile estimates derived from Lazard's research. See page titled "Levelized Cost of Energy Comparison—New Build Renewable Energy vs. Marginal Cost of Existing Conventional Generation" for additional details.

(4) Represents the illustrative midpoint LCOE for Vogtle nuclear plant units 3 and 4 based on publicly available estimates. Total operating capacity of ~2.2 GW, total capital cost of ~\$31.5 billion, capacity factor of ~97%, operating life of 60 – 80 years and other operating parameters estimated by Lazard's LCOE v14.0 results adjusted for inflation. See Appendix for more details.

(5) Reflects the LCOE of the observed high case gas combined cycle inputs using a 20% blend of green hydrogen by volume (i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern). No plant modifications are assumed beyond a 2% increase to the plant's heat rate. The corresponding fuel cost is \$6.66/MMBTU, assuming ~\$5.25/kg for green hydrogen (unsubsidized PEM). See LCOH—Version 4.0 for additional information.