NUCLEAR ECONOMICS
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The future of U.S. nuclear power

Investable Nuclear Energy
GW Law School – 9 to 12 May 2022

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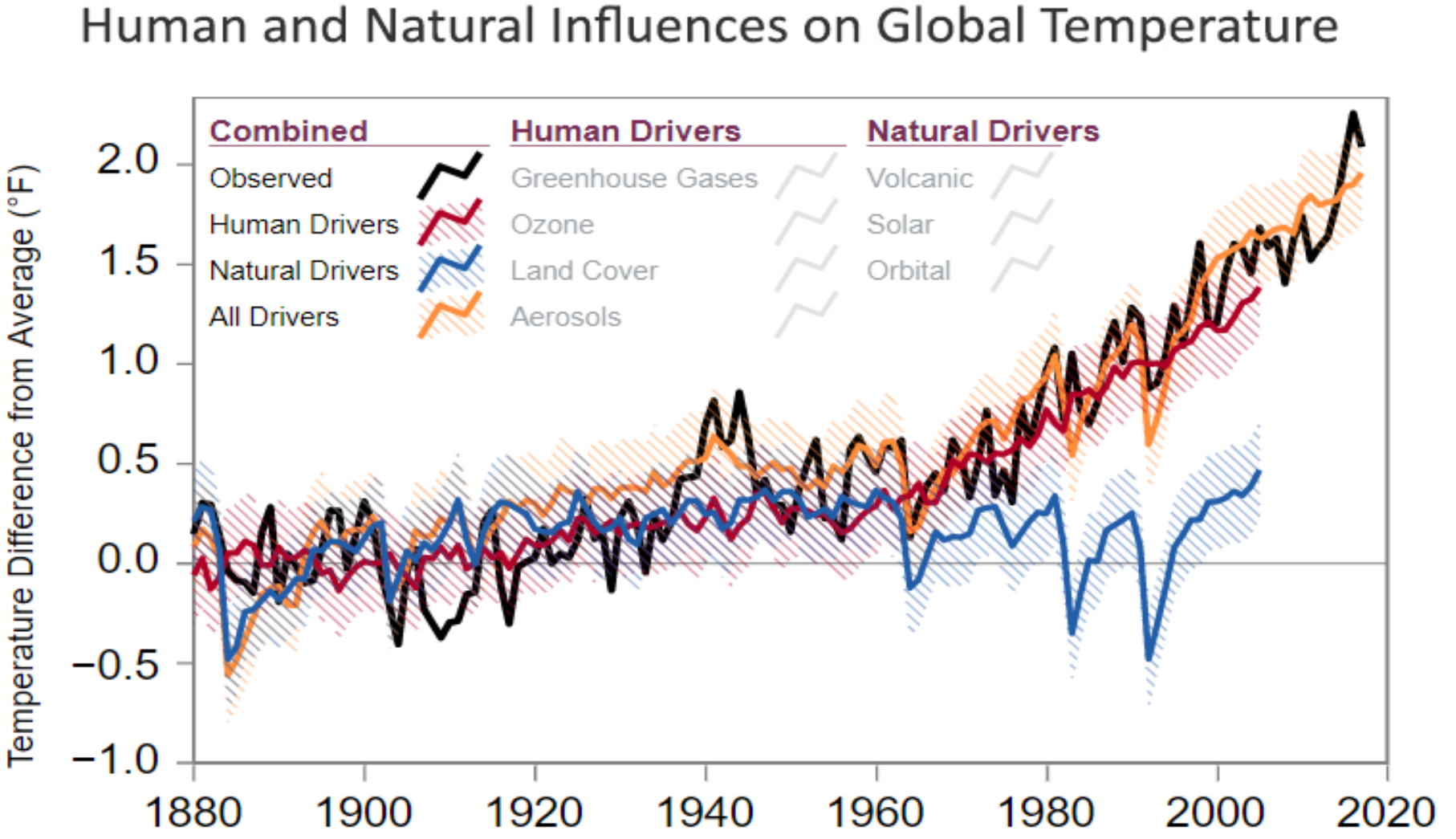
Preview

More nuclear power is needed in the U.S. (and in the world) to reduce electricity sector emissions, but U.S. nuclear power is declining

U.S. nuclear power is declining due to market-based nuclear power operating in markets with low commodity wholesale electricity prices

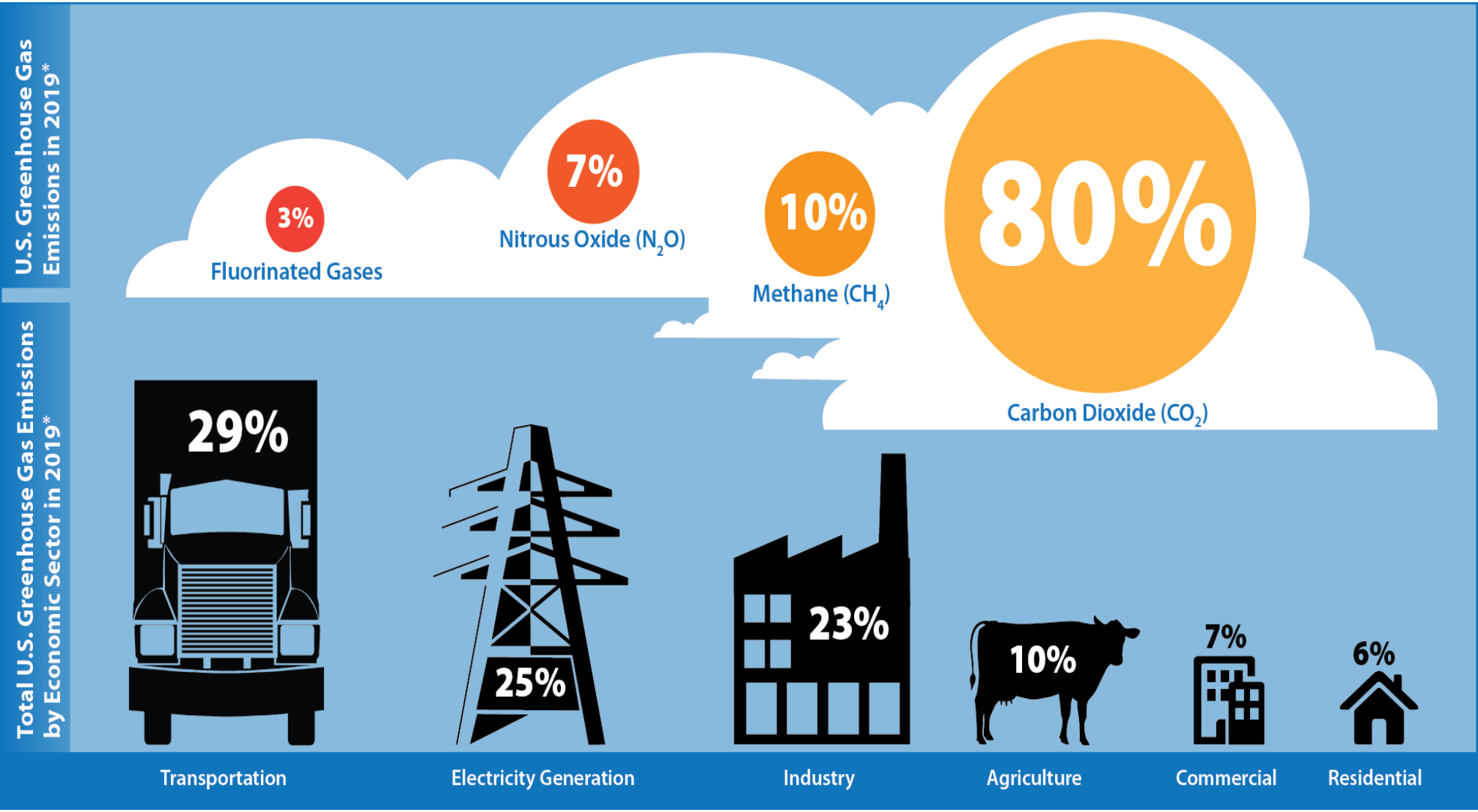
The future of U.S. nuclear power depends on reversing this decline by creating a different and stronger role for the U.S. government

Climate change is a human problem



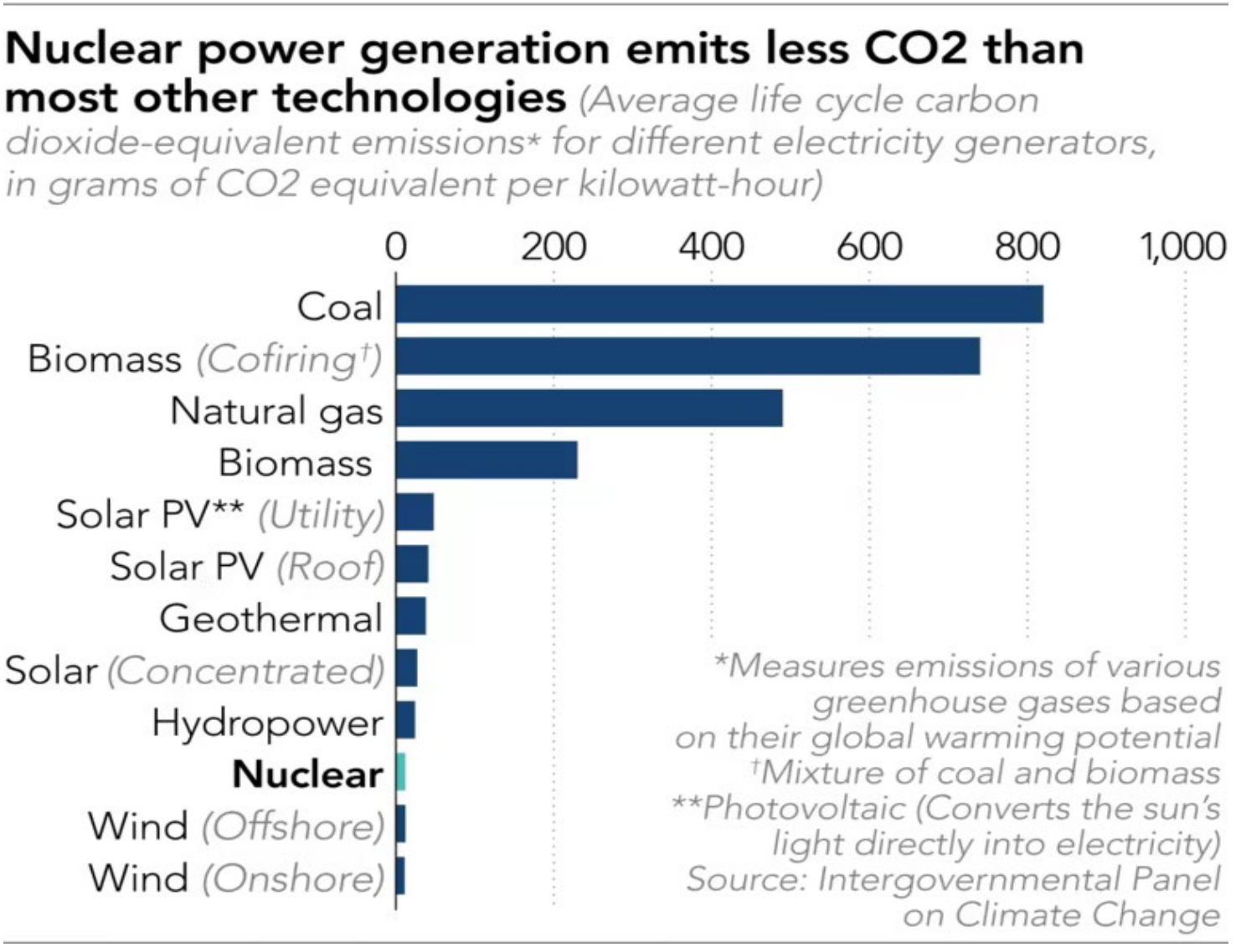
Source: U.S. Global Change Research Program, Fourth National Climate Assessment, 2017, Chapter 2: Our Changing Climate.

Electricity is large part of this problem



Source: U.S. EPA, https://cfpub.epa.gov/ghgdata/inventoryexplorer/

Nuclear electricity can help . . .



Nuclear power has very low life-cycle emissions.

When nuclear power plants replace combustion-based power plants, emissions are reduced.

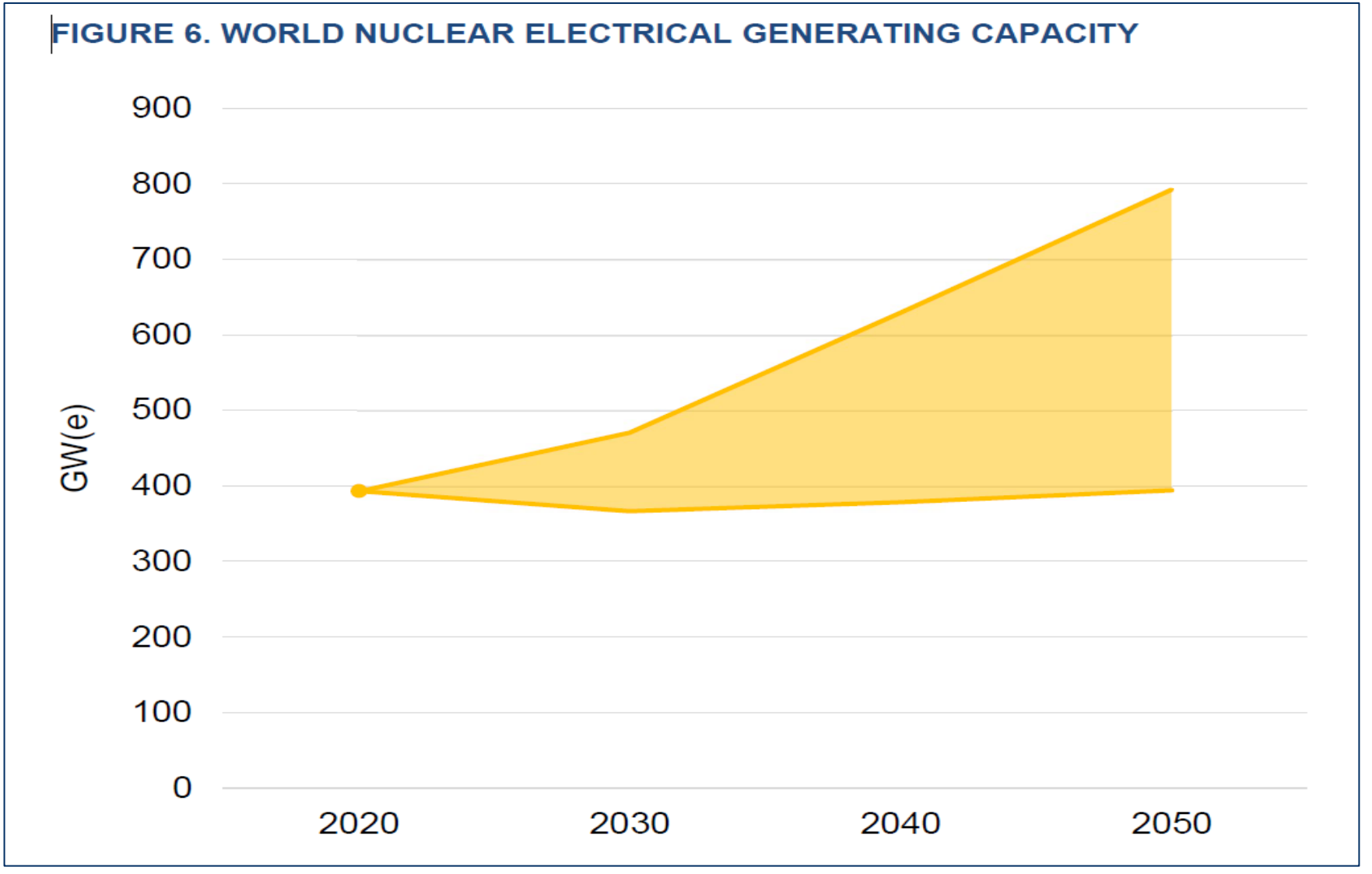
When combustion-based power plants replace nuclear power plants, emissions are increased.

Source: https://asia.nikkei.com/Spotlight/The-Big-Story/Asia-s-nuclear-power-dilemma-Ukraine-war-drives-energy-turnarounds

. . . but a lot of nuclear power needed to meet climate goals

- ***Global -*** IPCC 1.5°C pathways include, on average, 1,160 GWe of global nuclear generation by 2050 (i.e., about three times the amount in 2020)
- **U.S.** - Biden targets a carbon-free power sector by 2035 – this means replacing more than 725 GWe of fossil-fueled generation
- A massive nuclear build program, that should have started already, could help meet climate goals
- Recent projections of nuclear capacity not promising

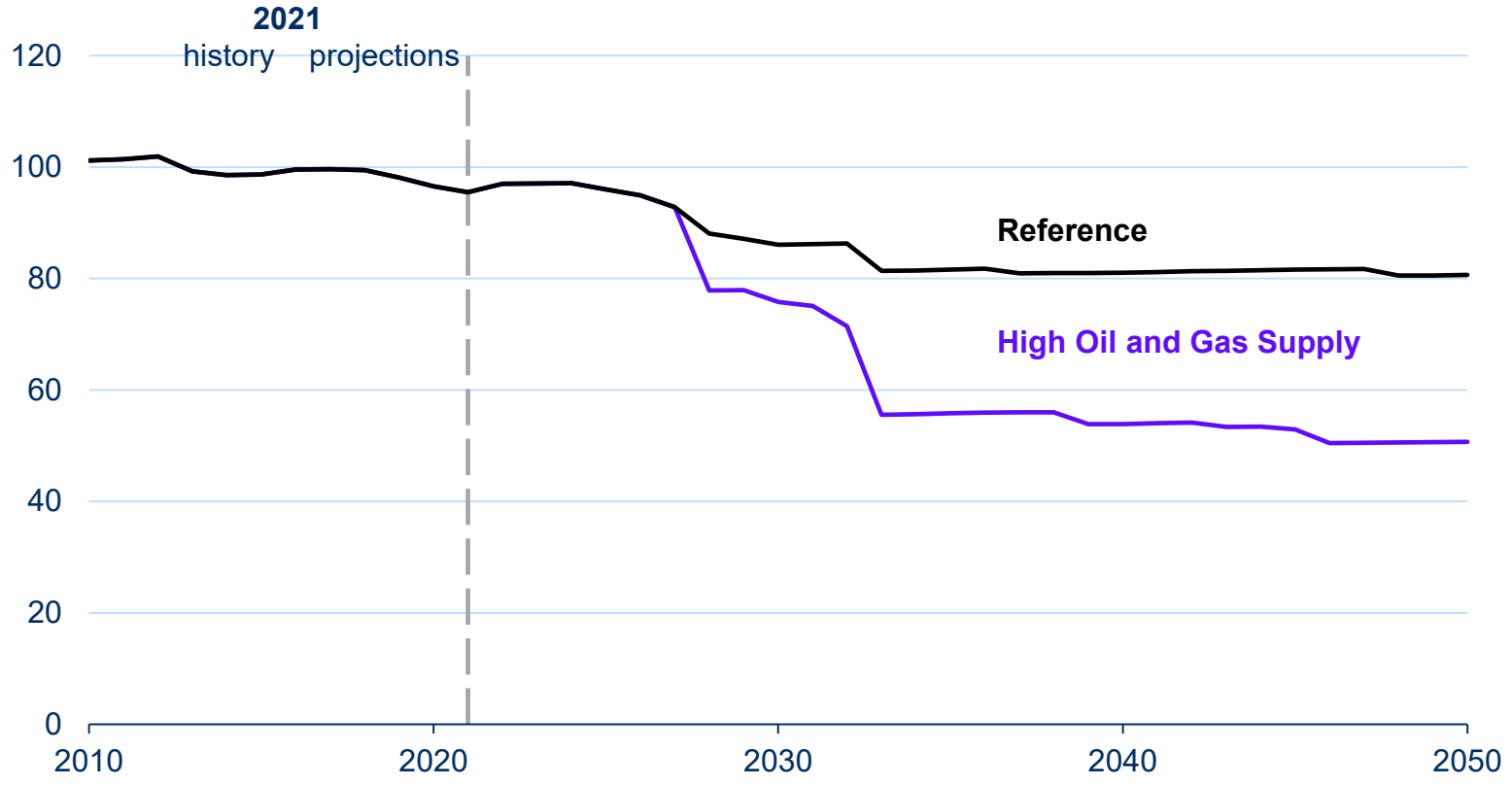
IAEA projections fall short



Source: IAEA Energy, Electricity and Nuclear Power estimates to 2050, Reference Data Series No. 1, 2021 Edition.

U.S. nuclear capacity is declining

U.S. nuclear electricity generating capacity (gigawatts)



Source:; U.S. EIA, Annual Energy Outlook (AEO) 2022; ***assumes many existing plants operate longer than 60 years****.*

Why is U.S. nuclear power declining?

U.S. market-based nuclear power is undervalued in the market

Political / legal / economic actions led to this

I am going to discuss four of these

1: Federalism

1: Federalist form of government | 2: Investor owned utilities | 3: Market nuclear power | 4: Electricity industry reform

Sharing of power between national and state governments

National energy policy applies to

- Interstate transmission of electricity;
- Wholesale electricity markets that cover more than one state; and

States retain control of

- Regulated electricity companies and retail electricity sales;
- Approval of electric generation facilities except hydro & nuclear; and
- Mandates on electric utilities to generate or purchase power from renewable (or nuclear power) energy resources.

Federalism and nuclear power in the courts

- PG&E v. State Energy Resources Comm'n
- Entergy Nuclear Vermont Yankee v. Shumlin
- Coalition for Competitive Electricity v. Zibelman

Different from unitary form of government in other countries

2: Investor-Owned Regulated Utilities

Entrepreneurial beginnings – selling electric lighting in cities

- Natural monopoly concept led to city franchises
- City franchises grow into state utility regulation

By 1920, most states had regulated electric utility laws

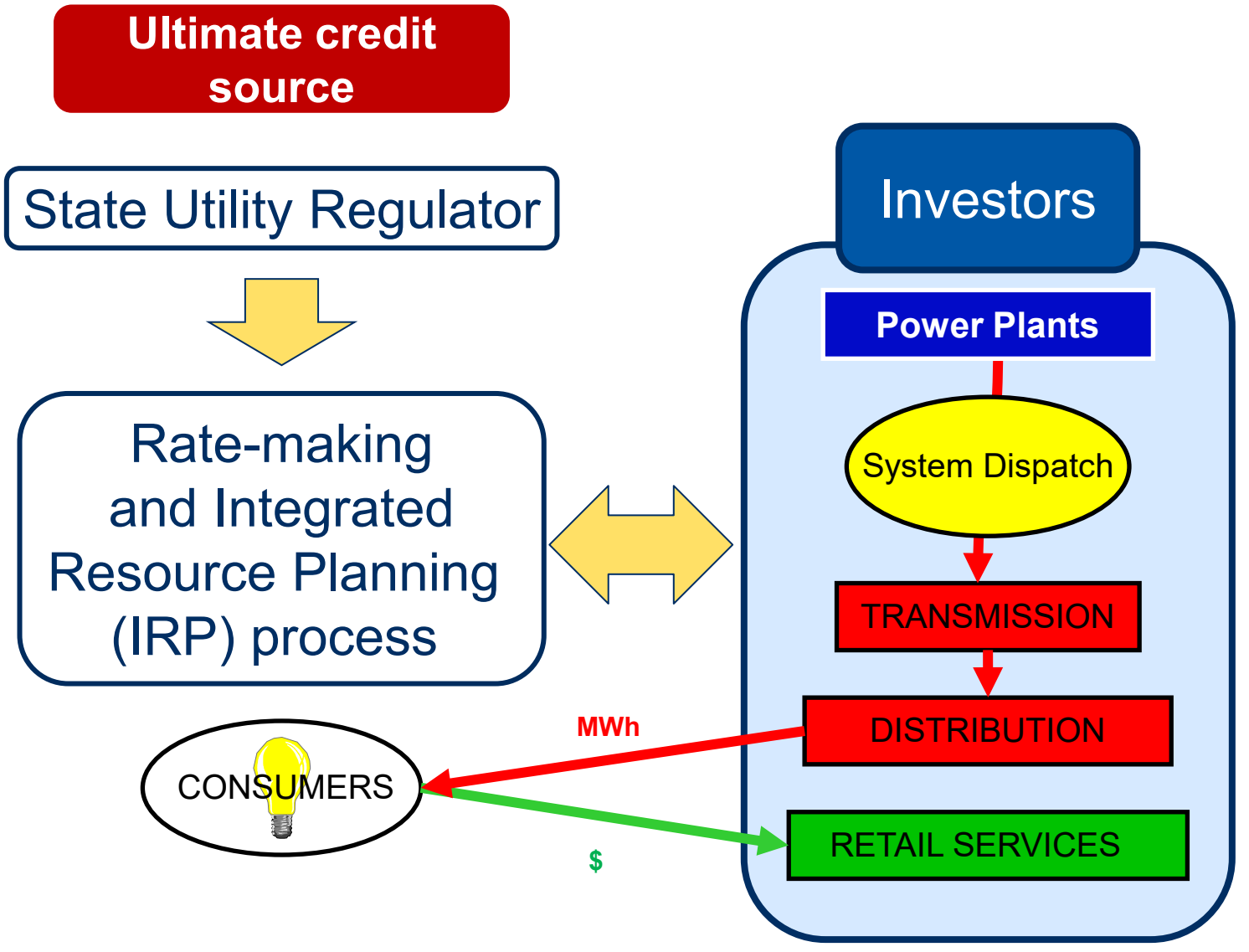
- Investor-owned regulated utilities (IOUs) under traditional model (i.e., obligation to serve, cost recovery, monopoly service area, and vertical integration)

Today, the U.S. has a well-developed electricity industry

- Enormous amount of capital deployed to develop national grid
- IOUs under state regulation plus public and federal power

Other countries (and some U.S. states) did this with a government-owned electricity sector (Nebraska, France, UK, Russia, China, etc.)

Traditional utility model



- All costs, fixed and marginal, plus returns on equity recovered in rates set by the regulator and recovered from customers
- Regulator oversees utility planning and long-term investments
- Goal is to minimize long-term customer rates while maintaining reliable service

3: Market-Based Nuclear Power

Manhattan Project (under U.S. Army) - 1942

Atomic Energy Act of 1946

- Government control of nuclear power under Atomic Energy Commission

Atomic Energy Act of 1954

- Created a role for private utilities and vendors in market-based nuclear power

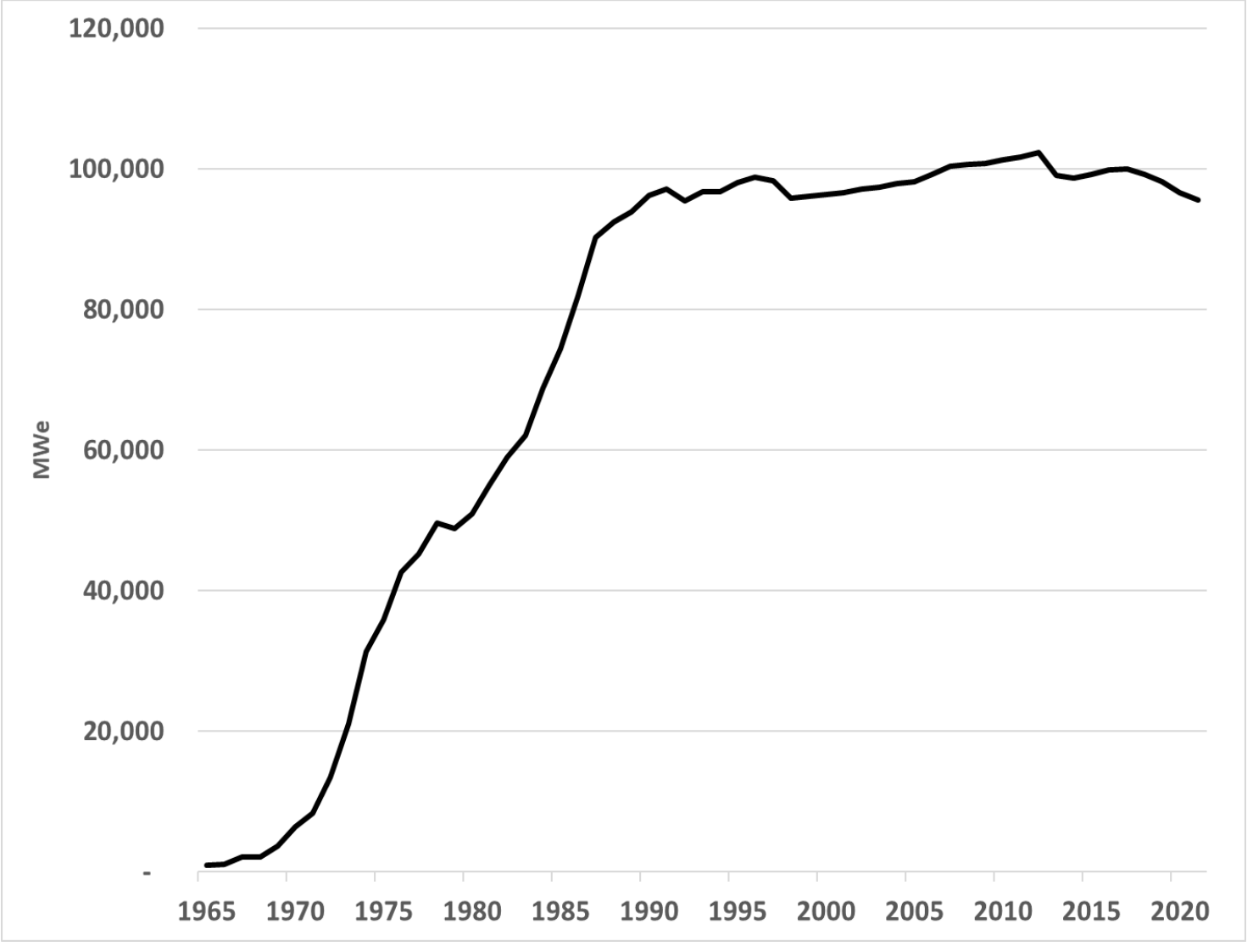
Private *owners* and *builders* of nuclear power plants

Massive U.S. nuclear build, but with some issues

- Only about 1/3 of planned nuclear projects were placed into commercial operation
- Cost overruns. delays, projects canceled and abandoned
- Shareholder disallowances
- One-off plants & multiple vendors (i.e., not standard design & fleet build)

Different from government-owned nuclear industry in other countries

U.S. nuclear capacity



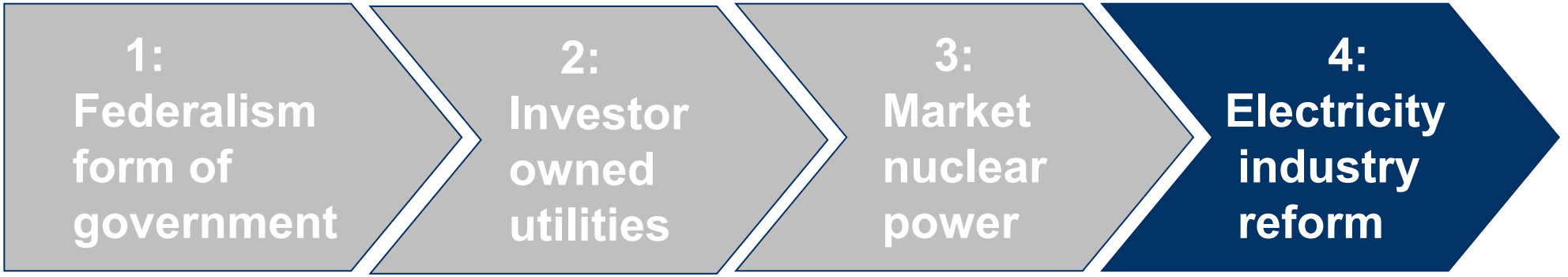
Source: International Atomic Energy Agency Power Reactor Information System data, with NECG analysis.

Nuclear power plant build was driven by high demand growth, high oil and gas prices, and early project success. Later, there were multiple closures:

- TMI-2 (1979)
- Shoreham (1989)
- Trojan (1992)
- Zion (1998)
- Kewaunee (2013)
- Vermont Yankee (2014)
- Fort Calhoun (2016)
- TMI-1 (2019)
- Duane Arnold (2020)

+107,855 MWe - new plants
+ 8,927 MWe - uprates
- 21,177 MWe - closures
95,605 MWe

4: Electricity Industry Reform



Electricity Reform and Restructuring

- Started in UK in about 1990
- New wholesale electricity markets with competition in generation
- FERC led U.S. effort

U.S. has mix of Traditional & Market States

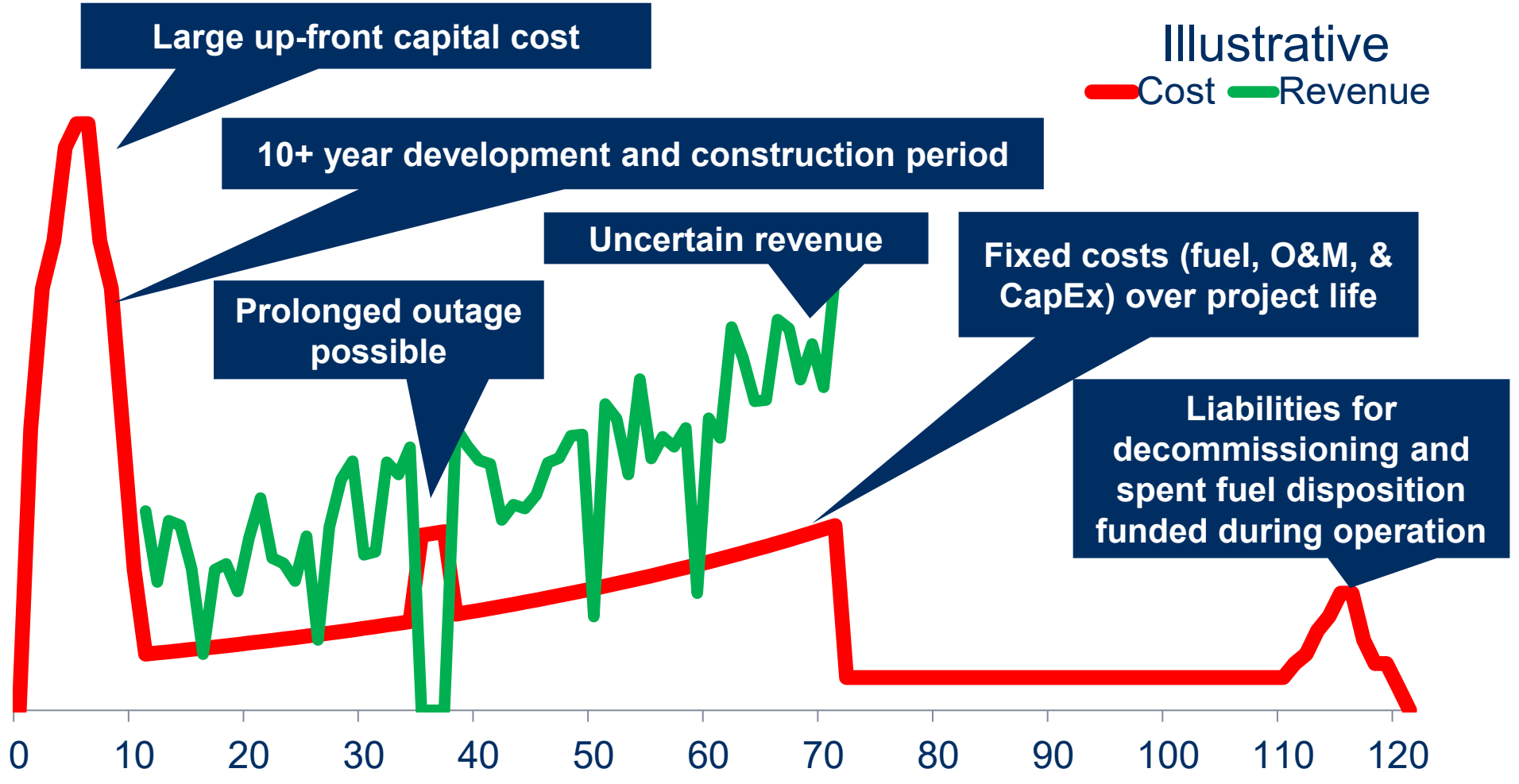
- U.S. nuclear fleet is mix of regulated, public power, and merchant plants

Nuclear power decline in U.S. due to economics

- Merchant nuclear closures are primary cause of decline
- Low (and even negative) prices in bid-based wholesale electricity markets
  - low natural gas prices,
  - low demand growth, and
  - increased renewable penetration

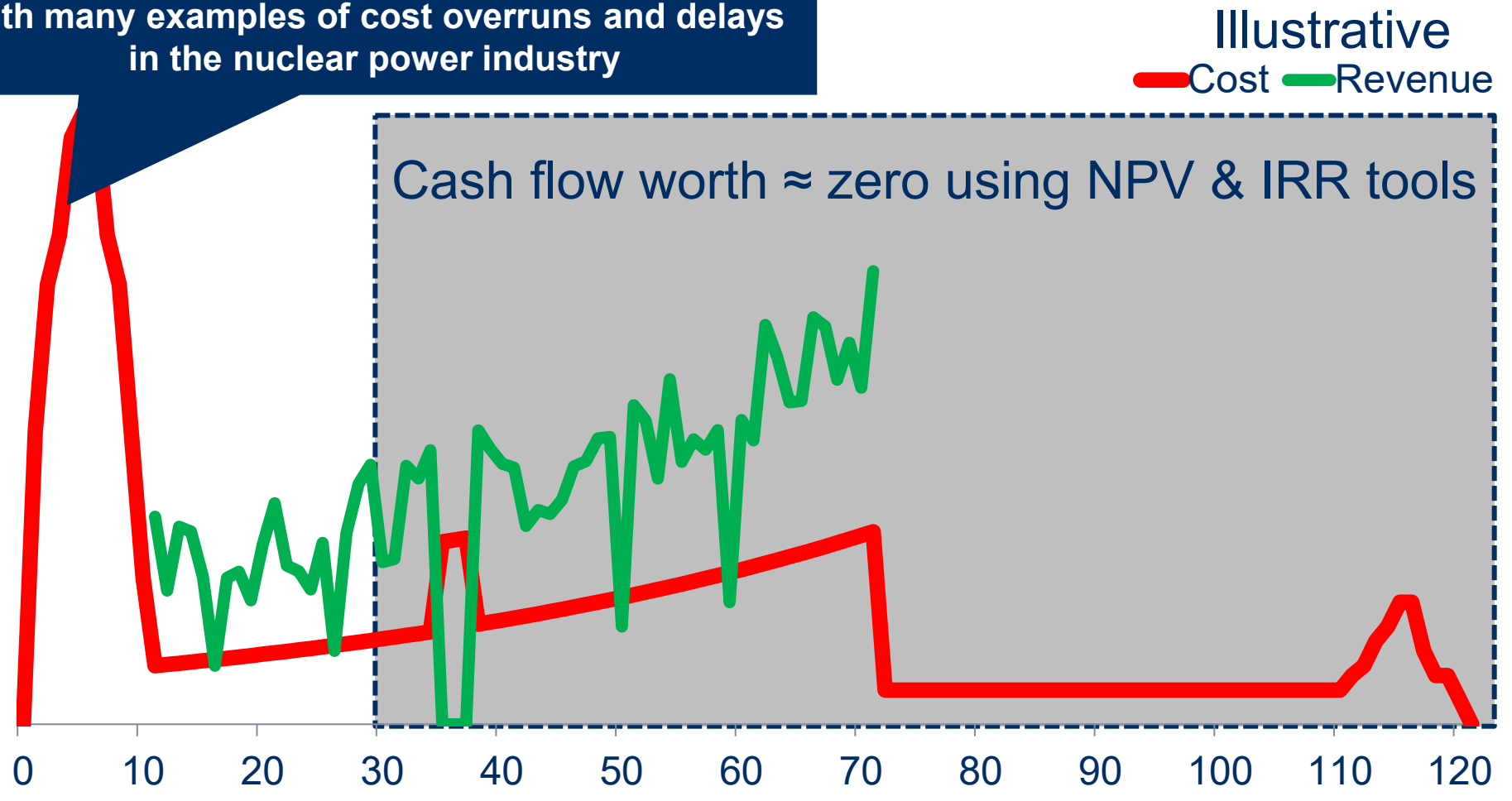
Private development of new nuclear power plants, either as merchants or as regulated IOU projects, is not likely without changes

New nuclear project cash flow

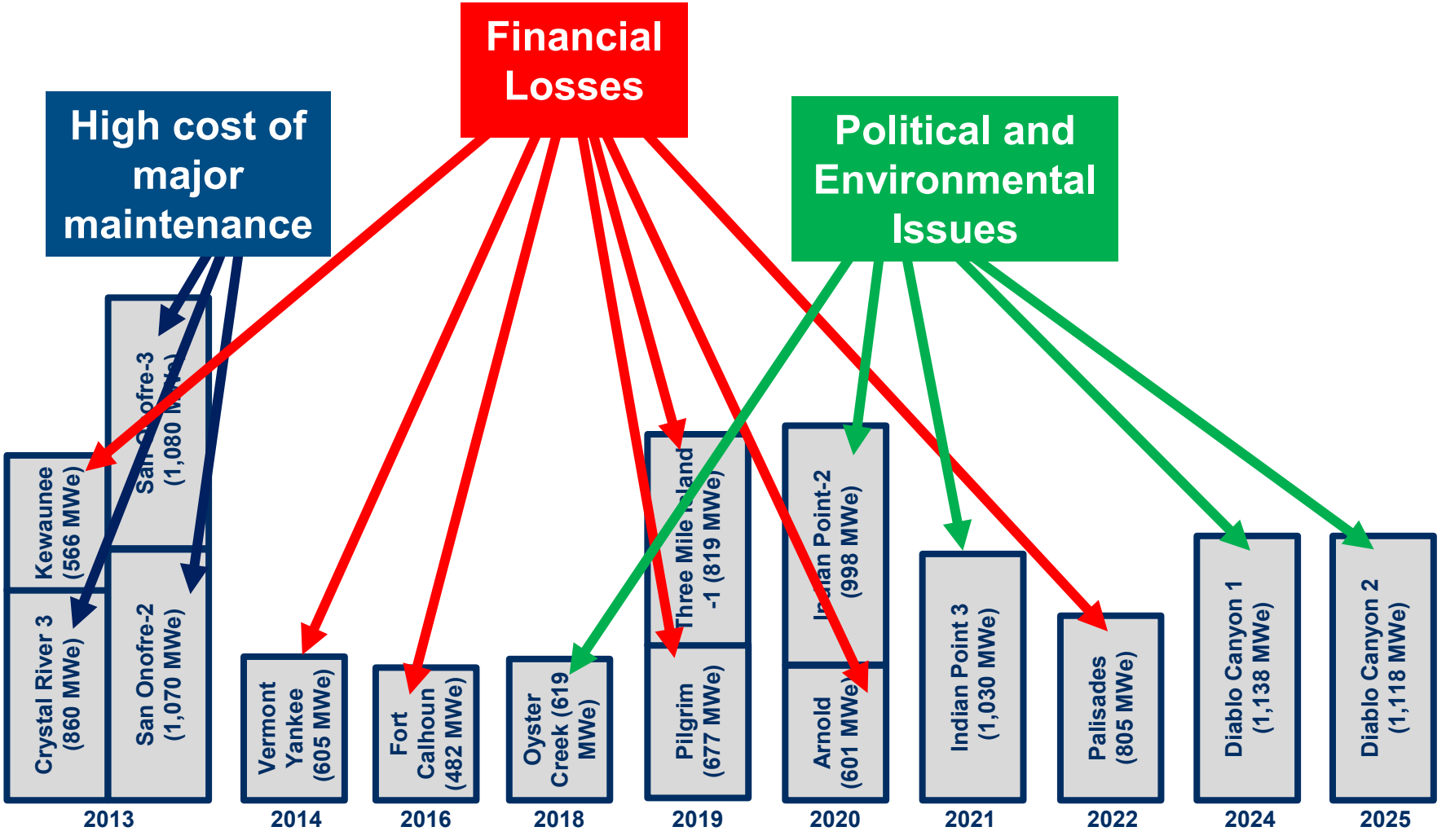


Market nuclear project hard to finance

Primary project financial impact is capital cost, with many examples of cost overruns and delays in the nuclear power industry



Recent U.S. nuclear power closures



More merchant nuclear closures stopped by ZEC payments

- Zero Emission Credits (ZECs) in New York, Illinois, New Jersey compensate for positive externalities
  - Commodity electricity prices do not reflect emissions
  - ZEC payments for value of clean nuclear electricity
- ZEC costs passed to electricity end use customers by state allocation of ZEC costs to ***state-regulated retail electricity companies***
- ZECs are out-of-market incentives similar to renewable energy credits and state mandates

Future of nuclear power

Electricity Shortage Warnings Grow Across U.S.

Power-grid operators caution that electricity supplies aren't keeping up with demand amid transition to cleaner forms of energy

Wall Street Journal, 8 May 2022

Urgent need for increased nuclear power

Nuclear power is carbon-free, technologically feasible, scalable, and economical.

MIT, 2008

U.S. should double nuclear energy by 2050

NIA Fission Vision calls on DOE to launch an advanced nuclear energy Earthshot to help double nuclear power plant output.

Nuclear Innovation Alliance, 14 Apr 2022

EU needs 'colossal' investment in new nuclear

Investment in nuclear power of about €500 billion by 2050 will be needed to meet the European Union's carbon neutrality goal.

WNA World Nuclear News, 10 Jan 2022

Dire future for US nuclear power

If the US keeps closing nuclear power plants and fails to build new ones, we will cede our ability to compete with the Russians and Chinese in building new nuclear power plants abroad, which will undermine national security and good industrial jobs at home.

Michael Shellenberger, 2020

Future of nuclear power depends on addressing market failure

- U.S. has favorable conditions for new nuclear build
  - Large need for capacity, especially if fossil units closed
  - Proven nuclear safety regulatory regime
  - Long and positive experience with nuclear power
  - Established and experienced vendors and operators
- Market investment in nuclear power by merchant, regulated, and public power utilities is not likely because market value of nuclear is low
- This is market failure – government has a role to resolve that market failure

New support for nuclear power

- 2016 to 2019 - ZEC programs in New York, Illinois, and New Jersey plus Connecticut power contracts
- 2021 - 2nd ZEC program in Illinois (Byron and Dresden)
- 2021 Build Back Better Act (not passed) included a Production Tax Credit (PTC) for existing nuclear power
- Infrastructure Investment and Jobs Act ("IIJA") signed into law in Nov 2021 includes $6 billion Civil Nuclear Credit program now being implemented by DOE
- But these efforts are not aimed at new nuclear build

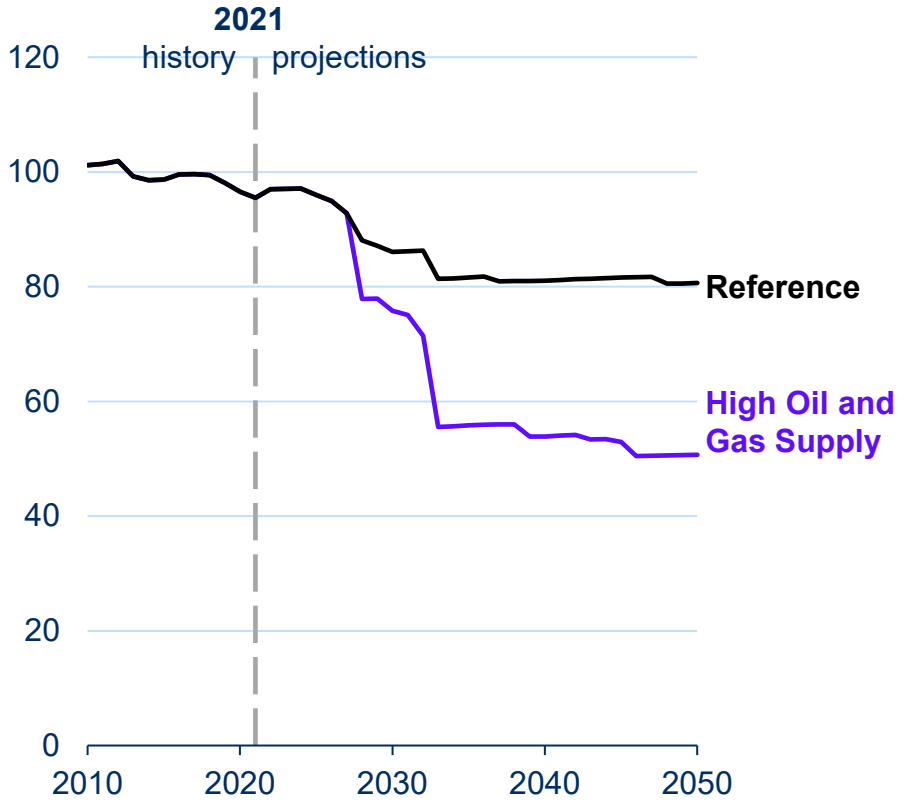
Three scenarios for future U.S. nuclear power

1 – Business as usual

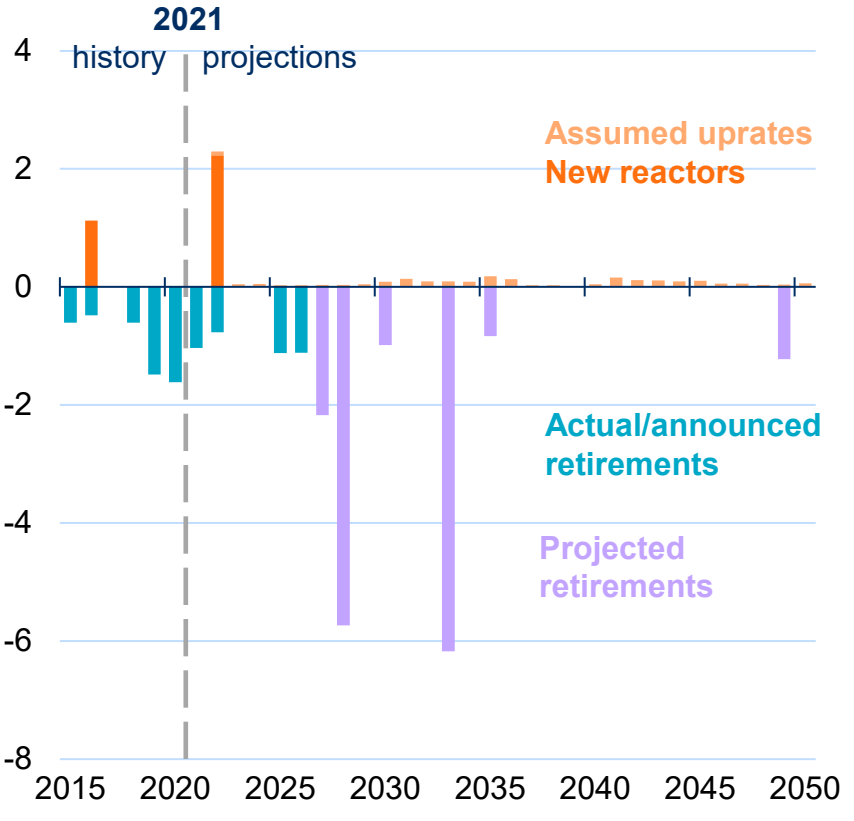
- No major changes in U.S. federal policy
- U.S. nuclear power declines as existing nuclear power plants close; decline shaped by
  - State ZEC programs + Federal CNC/PTC programs
  - 80 year and even 100 year NRC license life
- Little or no new nuclear power capacity built
- U.S. electricity generation will be dominated by natural gas and renewable generation

1 – EIA projections details

U.S. nuclear electricity generating capacity (gigawatts)



Year-over-year nuclear capacity change - Reference case (gigawatts)



Source:; U.S. EIA, Annual Energy Outlook (AEO) 2022; assumes many existing plants operate longer than 60 years.

2 – New nuclear incentives

- A lot needed to convince investors in nuclear power plant projects
  - IOUs (and their state regulators) and public power
  - Merchant nuclear will need even more
- EPAct of 2005 was good start; more needed
  - Long-term power contracts
  - Government equity
  - Completion risk (i.e., cost overruns and delays)
- Revenue and cost recovery issues
  - Federal vs State regulation of retail electricity

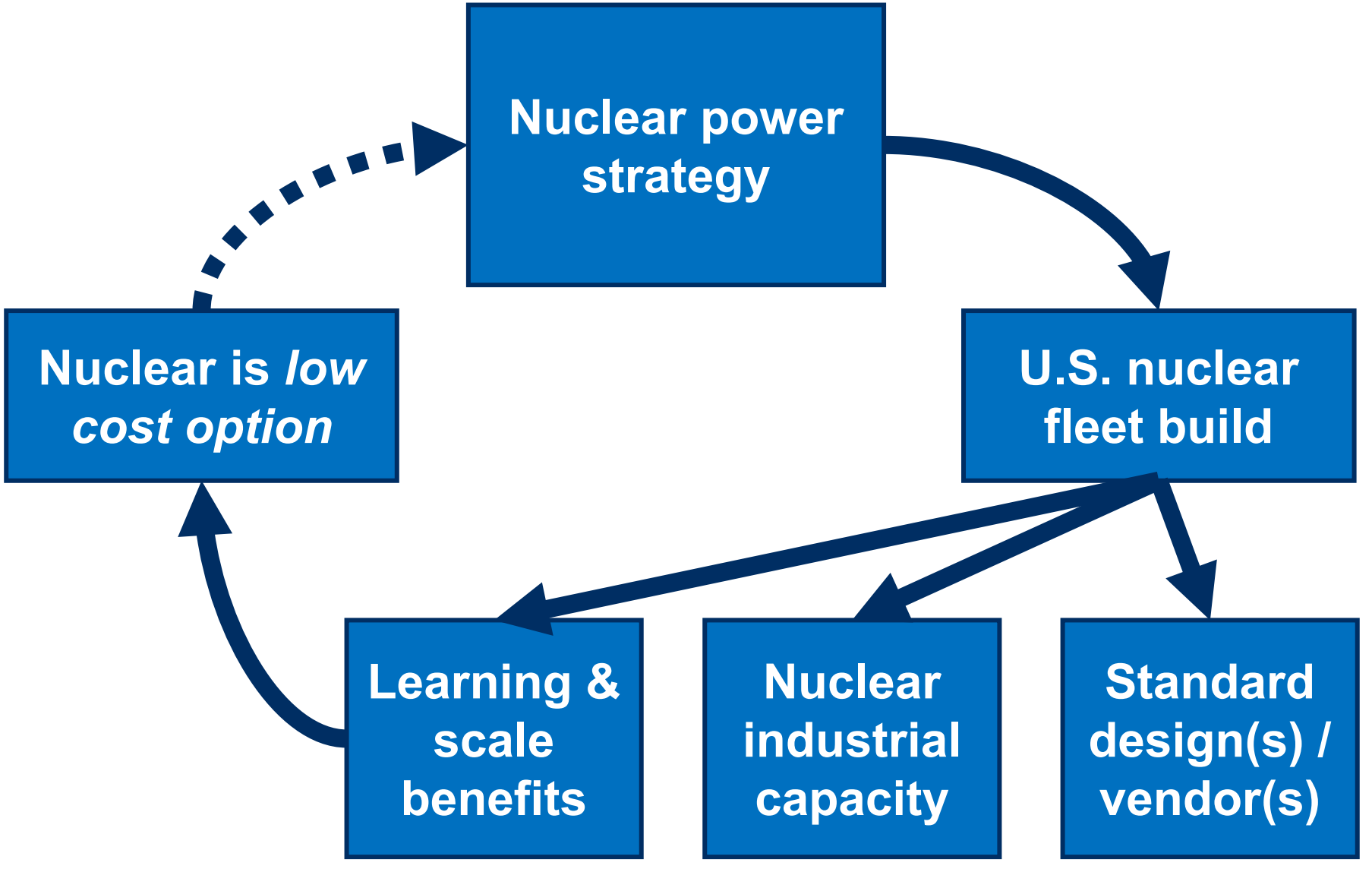
2 – Lessons from the UK

- Hinkley Point C project incentives (Electricity Market Reform process)
  - Long-term power contract
  - Other incentives
  - Financial Investment Decision by foreign state-owned nuclear utility owners (EDF & CGN)
  - Not enough for private projects (Horizon & NuGen) or next EDF project (Sizewell C)
- Sizewell C is expected to get new Regulated Asset Base (RAB) model with gov't equity

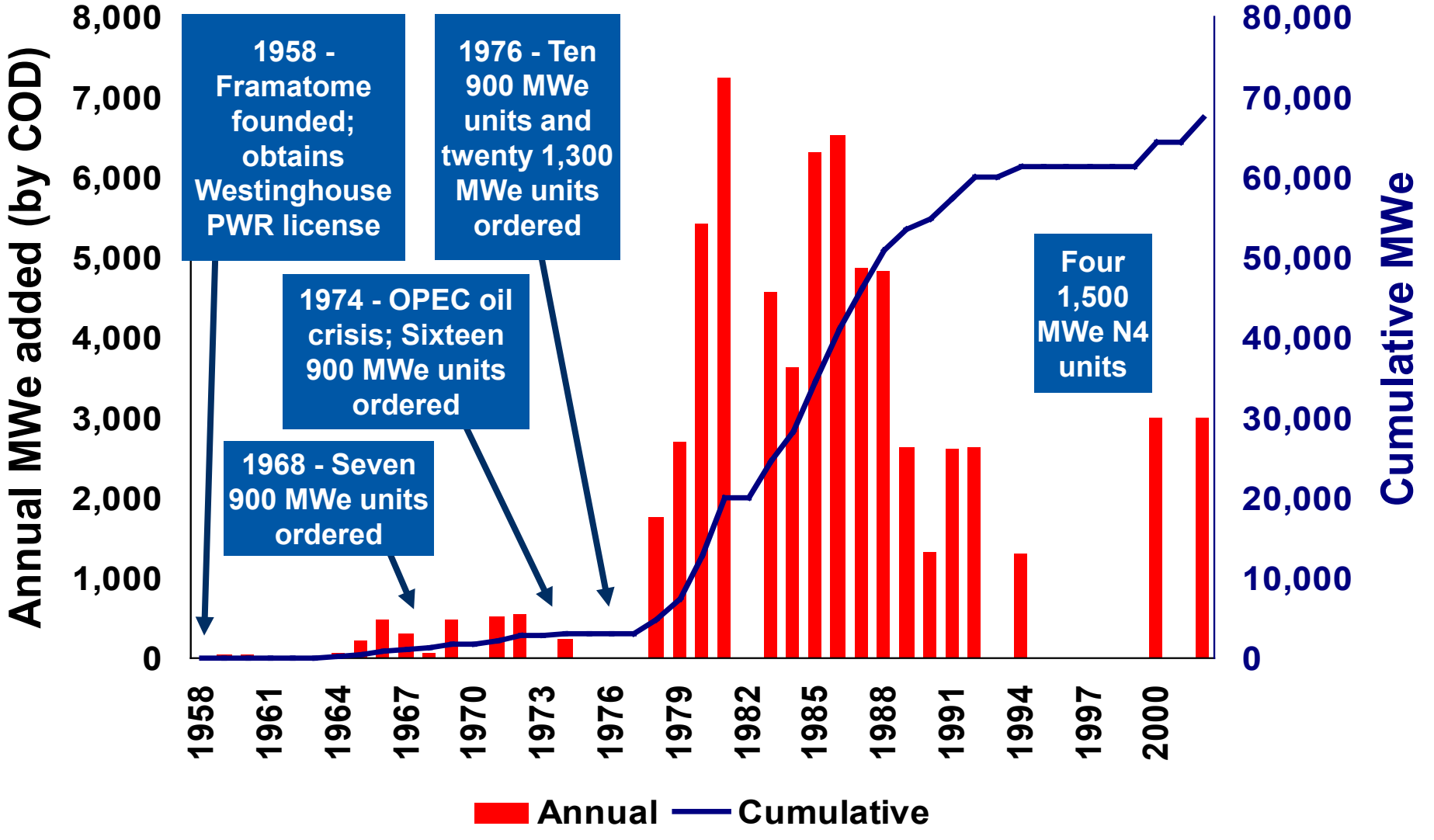
3 – New U.S. nuclear power strategy

- Nuclear power as critical national infrastructure
  - Federal government builds and owns nuclear power
  - Replicate the French/Chinese fleet build approach
- Requires hard-to-implement changes to U.S. system to overcome the four actions/choices, including revenue and cost recovery issues
- Will require strong bipartisan support
  - To pass new laws changing the U.S. system
  - To approve budgets for government nuclear build

3 – New U.S. nuclear power strategy



3 – French nuclear fleet build



Source: NECG analysis

Summary

More nuclear power is needed to reduce electricity sector emissions, but U.S. nuclear power is declining

U.S. nuclear power is declining due to market-based nuclear power and the U.S. electricity industry

Three scenarios for the future of U.S. nuclear power with differing outcomes, levels of difficulty, and roles for the U.S. federal government

Action is needed to move away from Business as Usual (i.e., managing the decline of existing nuclear)

https://nuclear-economics.com/market-failure-book-pdf/

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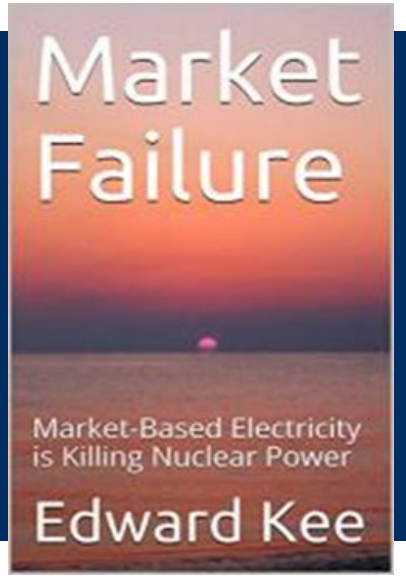

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