Nuclear Technologies Today & Tomorrow

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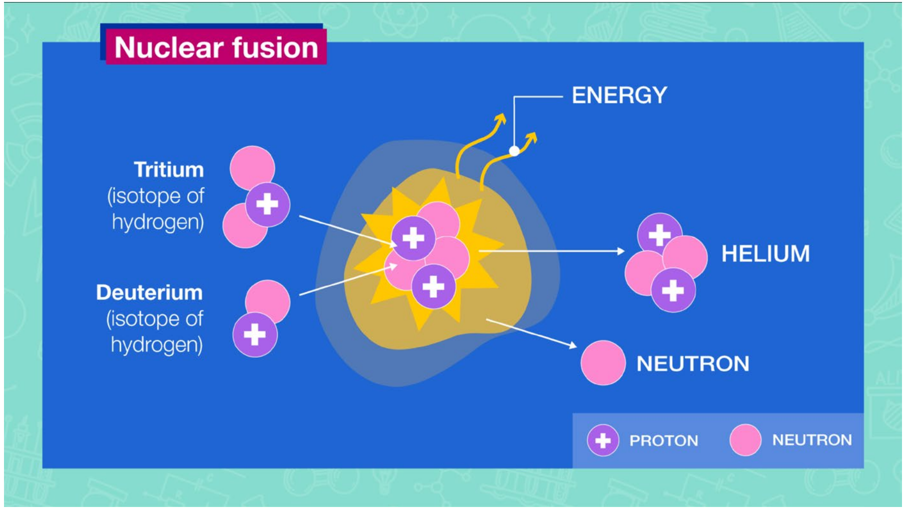
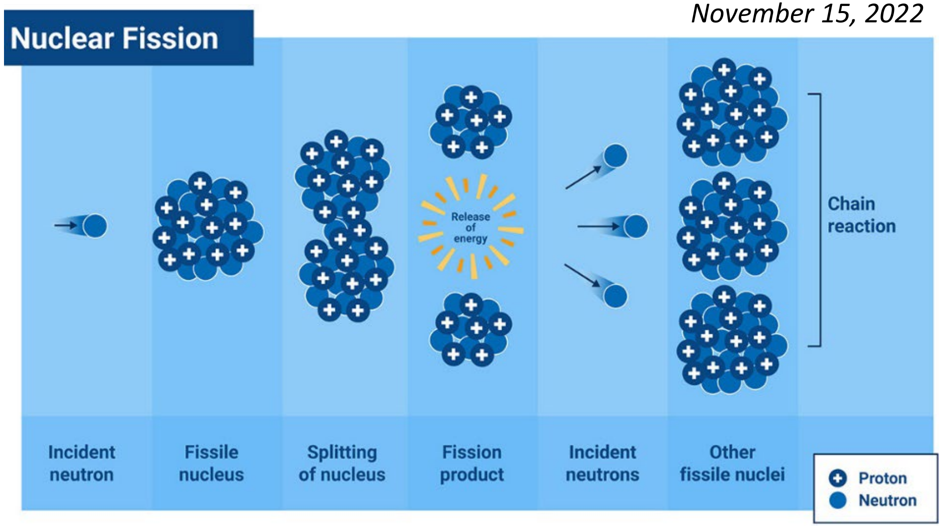
Nuclear Energy, Fusion and Fission

"What is nuclear fusion" @IAEA, August 3, 2023



Nuclear fusion is a reaction that combines atoms and is in the research and development stages as a power generating technology.

"What is nuclear energy? The Science of Nuclear Power" @AEA, November 15, 2022



Nuclear fission is a reaction where the nucleus of an atom splits into two or more smaller nuclei, while releasing energy. Nuclear fission is widely used today as a power generating technology.

Types of Nuclear Reactors

Large Light Water-Cooled Reactors (LLWRs)

- ~1,000+ MWe
- 95 in the U.S.
- Owned and operated by utilities for on-grid applications

Small Modular Reactors (SMRs)

- 50-300 MWe
- Some deployed in China and Russia
- Currently under development by numerous companies across the globe

Microreactors

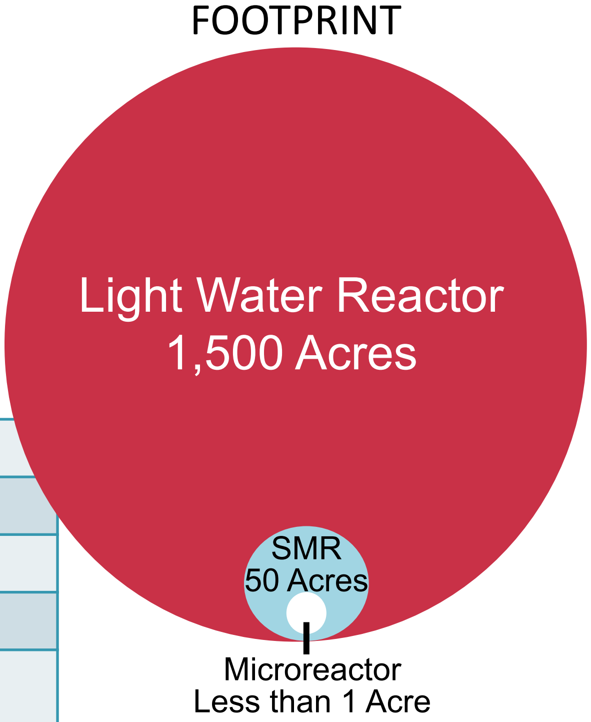
- 1-20 MWe
- Factory-built and transportable
- Currently under development by numerous companies, including BWXT

Can be smaller version of *Large Light Water Reactors* or any of the ***Advanced Reactors***: Molten Salt, High Temperature Gas, or Liquid Metal

Large Scale Reactors: Light Water-Cooled Reactors

Vogel, Georgia
Photo courtesy of Robert Myers, US Department of Energy

Number in Operation	95 in U.S
Timeframe	Built in the 1950s-1980s
Products	Electricity
Megawatts	1,000+ megawatts
Customers	Large utilities
Construction	Custom built on site
Scalability	Only with a new reactor



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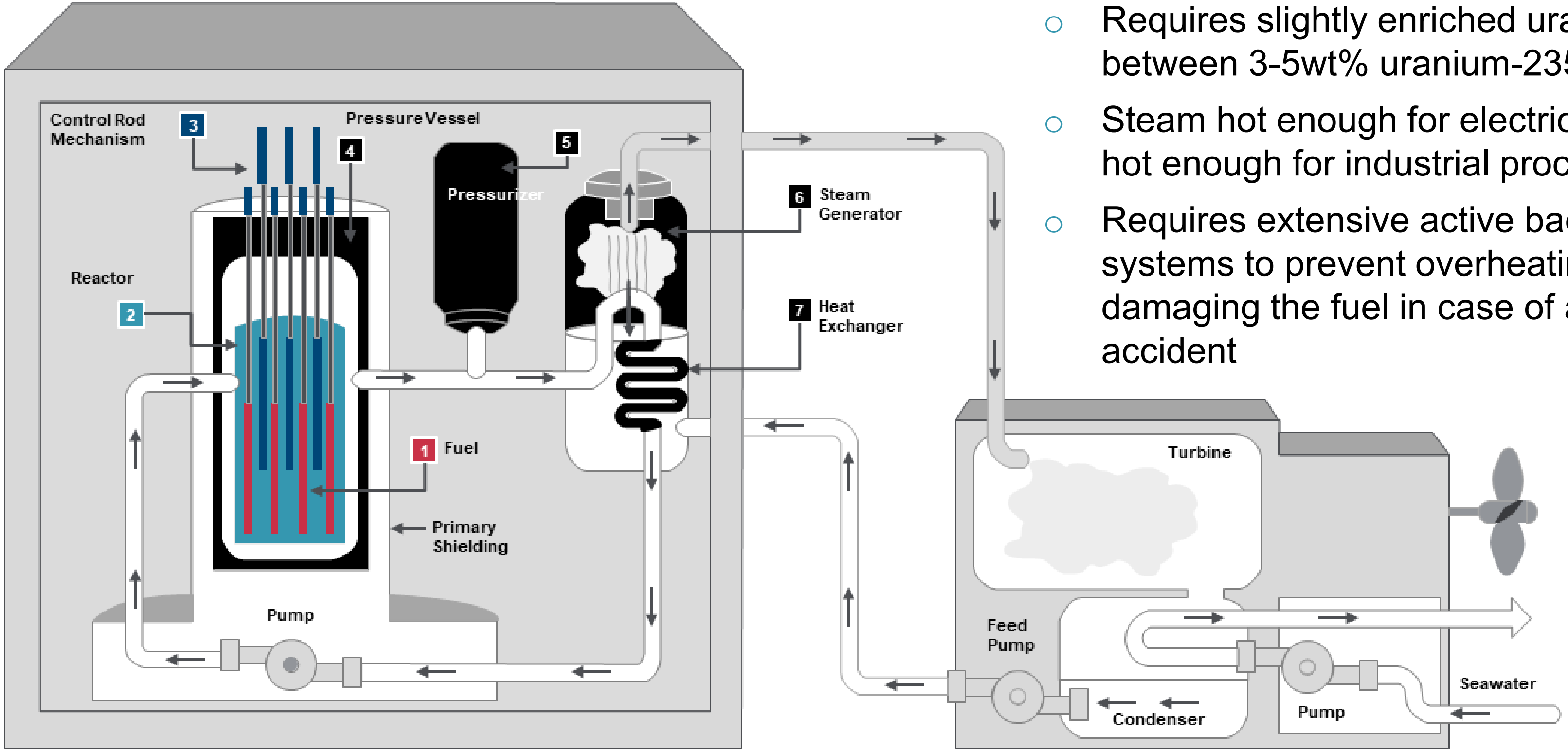
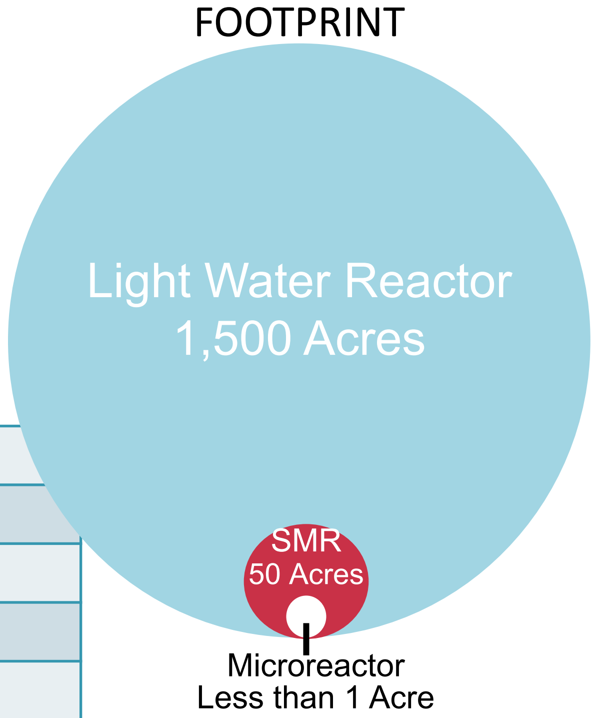
Light Water-Cooled Reactor

Type of **Thermal Reactor** both Boiling and Pressurized Water Reactors (BWR and PWR)



- Requires slightly enriched uranium: between 3-5wt% uranium-235
- Steam hot enough for electricity (not hot enough for industrial processing)
- Requires extensive active backup systems to prevent overheating and damaging the fuel in case of an accident

Mid-Sized: Small Modular Reactors (SMRs)



Number in Operation	China and Russia; plus others under development
Timeframe	First U.S. reactors expected by 2029
Products	Electricity, heat, and steam
Megawatts	50-300 MWe per module
Customers	Large utilities; municipalities; industry
Construction	Factory built, assembled on site
Scalability	Reactor modules added as demand increases

Fuel: Salt and Sodium Cooled Reactors

Molten Salt

- Salt heated into a liquid. In some designs, fuel dissolves in the salt; in others the fuel is a solid that will have its heat transferred away by the salt.
- A variety of salts can be used, including fluoride and chloride salts.
- Salt **allows ready absorption of fission products**, a safety feature, and molten salt can ease the online refueling process.
- As a coolant, it **can reach very high temperatures at low pressures**, a design advantage compared to water cooled reactors (but comes with tradeoffs).

Sodium Reactor

- Liquid Sodium is a weak neutron moderator. These unmoderated neutrons are referred to as fast neutrons.
- A large "liquid temperature range," meaning that it does not expand much; hence it can move heat at very high temperatures but low pressures, **simplifying design and construction** of the reactor.

Technical and manufacturing readiness is evolving. Demonstration plants are expected to be on-line in the next 5-10 years.

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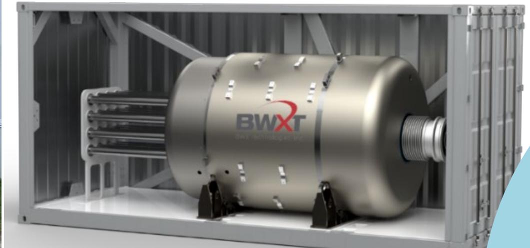
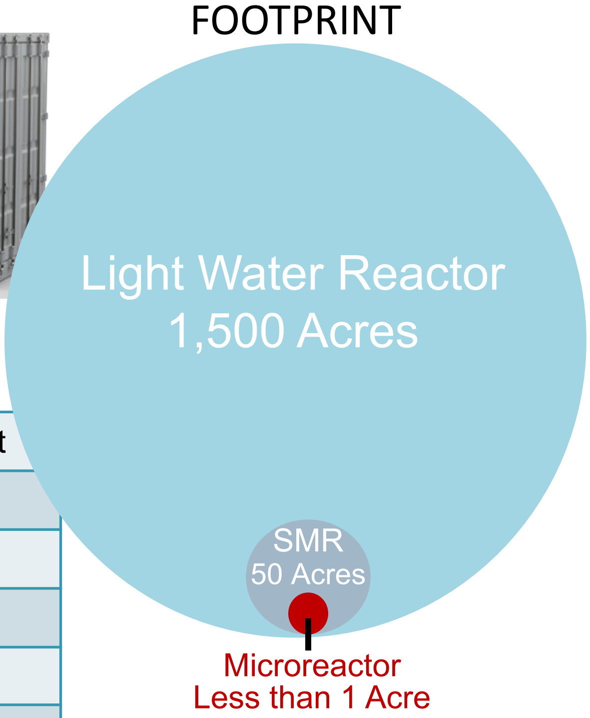
Small & Transportable: Microreactors

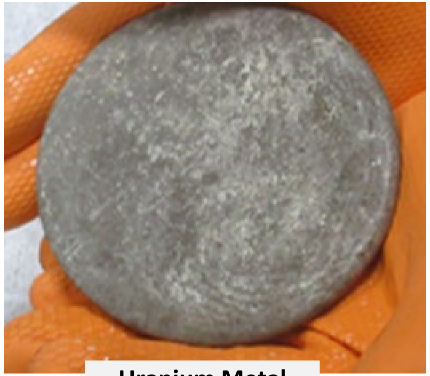


Design abstract

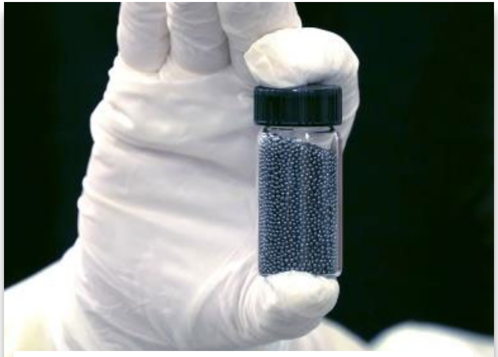


Number in Operation	Numerous companies have them under development
Timeframe	First reactors expected by 2027
Products	Electricity, heat, and steam
Megawatts	20 MWe or less
Customers	Military; municipalities; industry
Construction	Factory built then assembled on site
Scalability	Reactor module added as demand increases

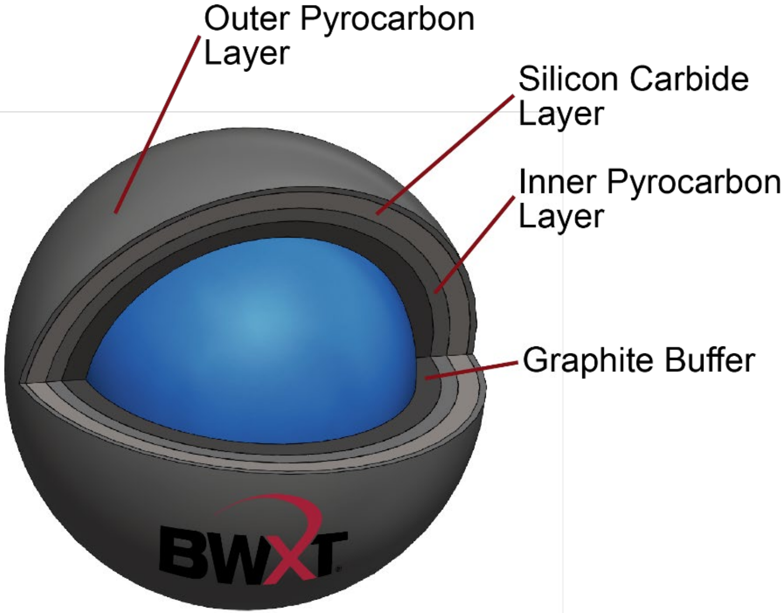
Fuel Enrichment & TRISO



Uranium Metal



BWXT produced TRISO particles



HALEU

- High-Assay Low-Enriched Uranium
- 10% up to 20% enriched
- Most SMRs and advanced reactors
- TRISO

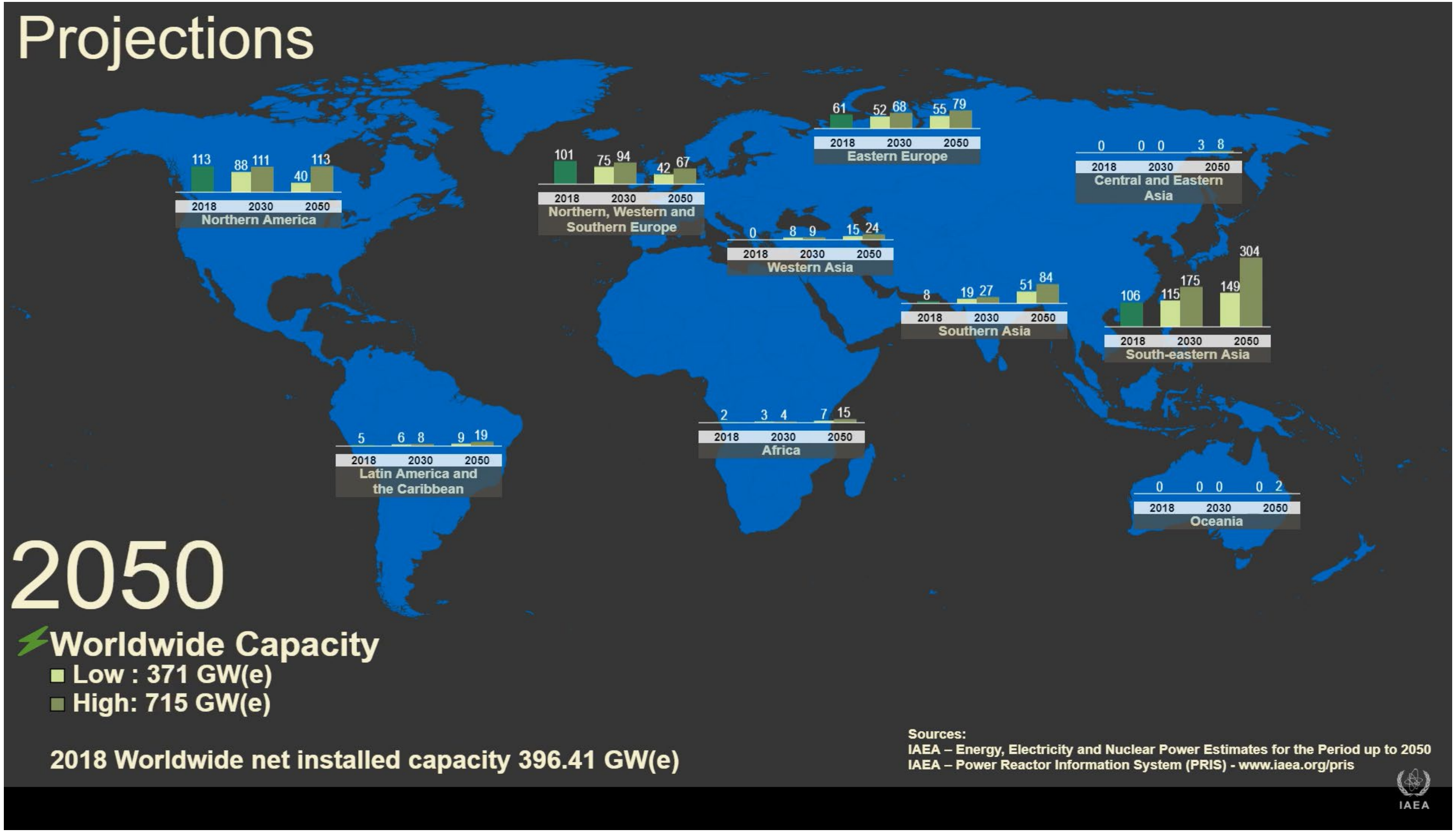
LEU+

- Low-Enriched Uranium
- 5% up to 10% enriched
- Some SMRs

LEU

- Low-Enriched Uranium
- 5% or less enriched
- Commercial Light Water reactors

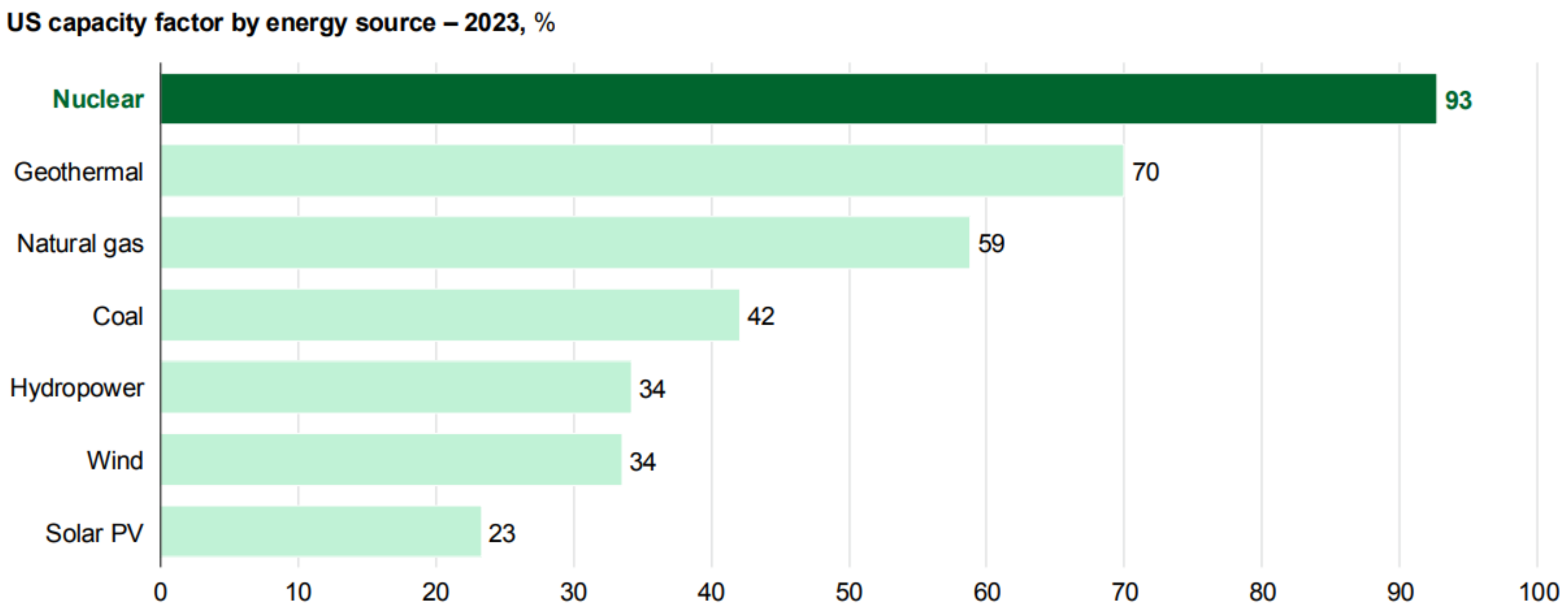
Global Nuclear Capacity Projection



"IAEA Projects for Nuclear Power Through 2050" @IAEA, October 2, 2019)

Energy Produced versus Carbon Emissions

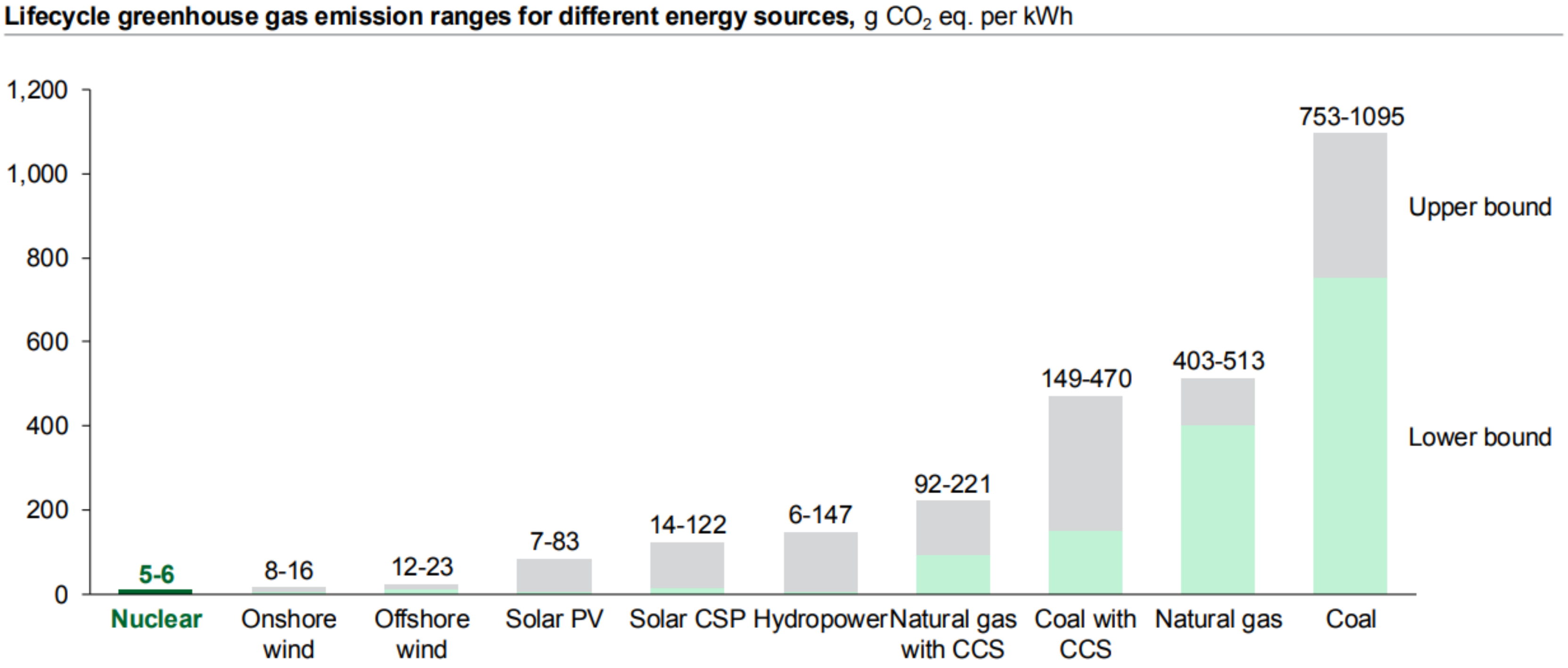
Figure 12: Nuclear has the highest capacity factor of any energy source[ii,36]



Courtesy of Department of Energy “Pathways to Commercial Liftoff: Advanced Nuclear” September 2024

Energy Produced versus Carbon Emissions

Figure 11: Nuclear generates clean electricity with very low lifecycle emissions[30]



Courtesy of Department of Energy [“Pathways to Commercial Liftoff: Advanced Nuclear”] September 2024

Commercial Challenges of SMRs

Affordability

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- Must achieve an attractive price point for end users to adopt and deploy the technology
- Mass production will drive down per-unit and per-MW costs across the supply chain

Predictability

- Building in a factory then delivering to site improves the historic uncertainty in new nuclear projects
- Highly standardized reactors for a wide range of end use applications
- Once up and running, nuclear's high capacity factor brings predictability and cost certainty

First-of-a-Kind

- Today's advanced reactors are based on proven technologies, though specific use cases make aspects first-of-a-kind
- Institutional knowledge and lessons learned will bring more rapid deployment

Regulatory Challenges for SMR Commercialization

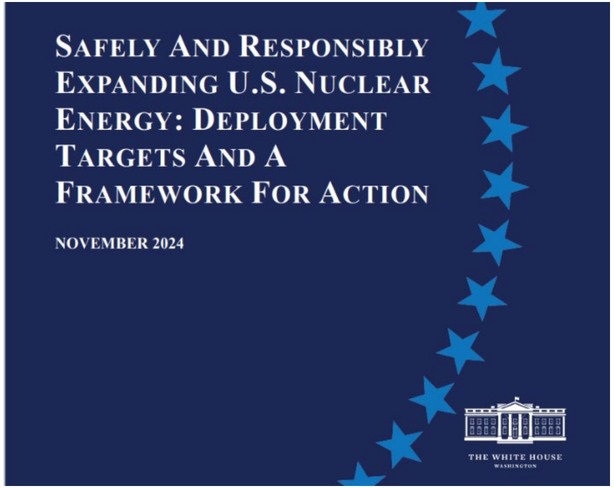
First-of-a-Kind

- Each technology represents a potentially new safety case for regulatory review
- Improved safety characteristics bring benefits like reduced staffing, smaller emergency planning zones and remote operations
- Demonstration programs like Pele and ARDP provide opportunities to show these capabilities and establish the basis for acceptance.

Speed

- To deploy at scale, the regulatory framework must accommodate a significantly improved schedule for approvals of NOAK projects.
- Regulatory approvals focused on the standard plant as a product, rapid site assessment, and fleet operation management.
- Recent experience shows potential for subsequent licensing efficiency gains for advanced reactors.

Conclusion



"Investment in the safe and responsible deployment of nuclear energy and associated supply chains will ***strengthen our national security, increase energy reliability and resilience, grow America's economy***, and restore American leadership in this critical industry"

Expanding market demand

COP29
Baku
Azerbaijan
UN CLIMATE CHANGE CONFERENCE

Six more countries joined the declaration to triple nuclear energy by 2050 during the World Climate Action Summit November 13, 2024, at COP29.

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Thank you