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FUTURE OF NUCLEAR POWER IN THE U.S.

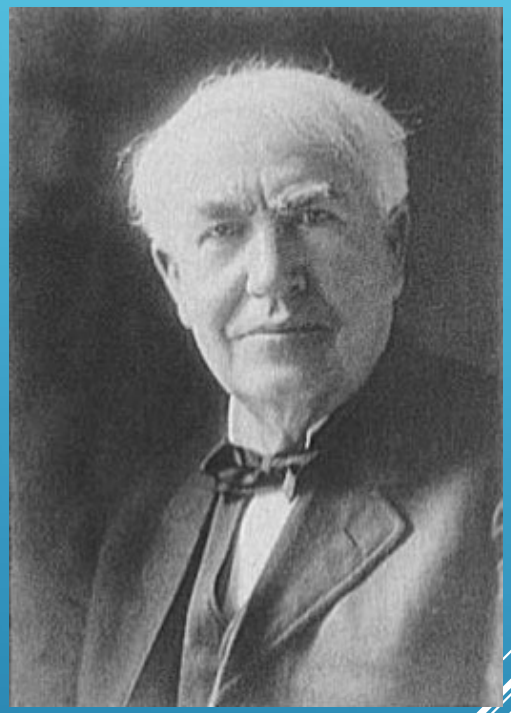
Presented by: Robert Kalantari, EPM

January 10, 2024

2024 Annual Energy Outlook (organized by Associations of Energy Engineers)

Quick Introduction to Power Generation from Nuclear Power

- Need motive power to turn turbine and the generator
  - Turbine can be turned by the force of steam, hydro or wind power
  - Steam can be produced by fossil fuel or nuclear reaction



Thomas Edison
www.americaslibrary.gov/assets/jb/recon/jb_recon_phongrph_2_e.jpg

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Hydro Plants

- Dams are built to collect water
- Water is collected in the reservoirs
- Water is released through openings at the bottom of the reservoir
- Water is routed through hydro turbines
- Turbine turn the generator
- Generator makes electricity

Hoover Dam
www.usbr.gov/lc/hooverdam/

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Wind Farms

- Wind farms are becoming popular
- Very long blades (some over 150) mounted on the top of a tower (100 meters up)
- Usually several wind turbines are installed in a wind farm (can be several hundred units)
- New large units in an ideal location should be able to produce up to 15MW of electricity
- Limitations, no wind no electricity generation

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Thermal Power Plants

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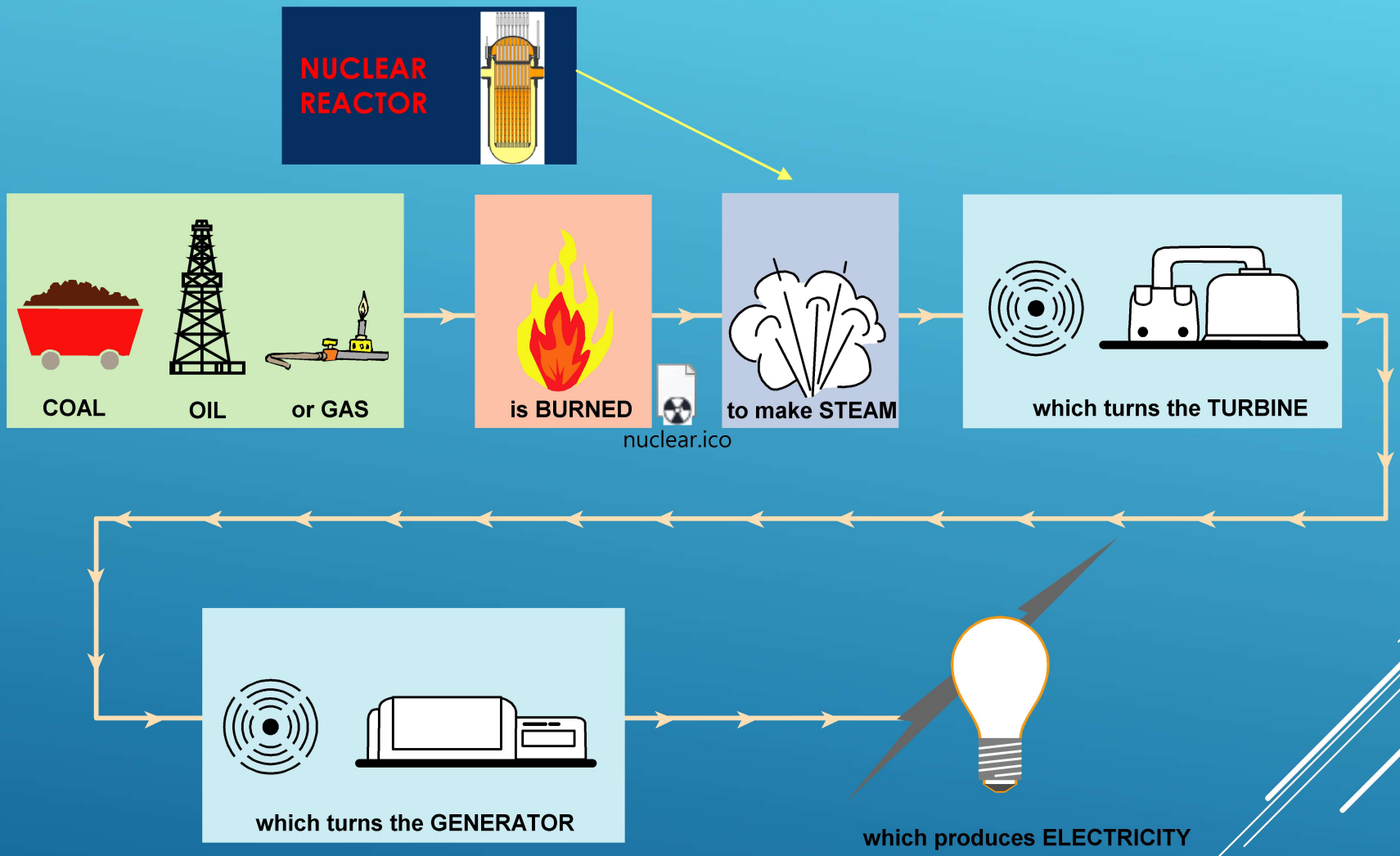

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How does nuclear power plant work?

- By splitting atoms in slightly enriched uranium
- In process of splitting the atoms, heat is generated
- This results in heating/boiling the water, creating steam
- Steam is piped to a turbine, like fossil steam plants

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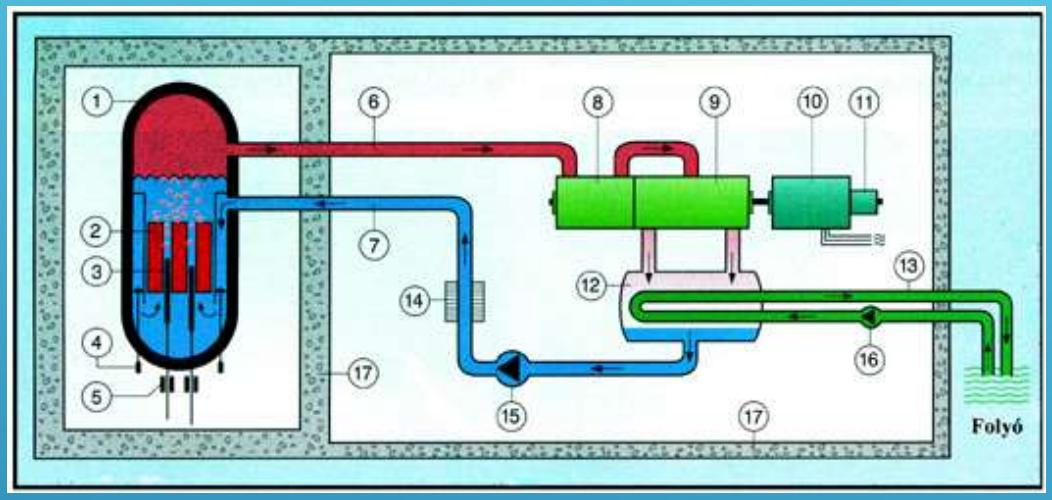
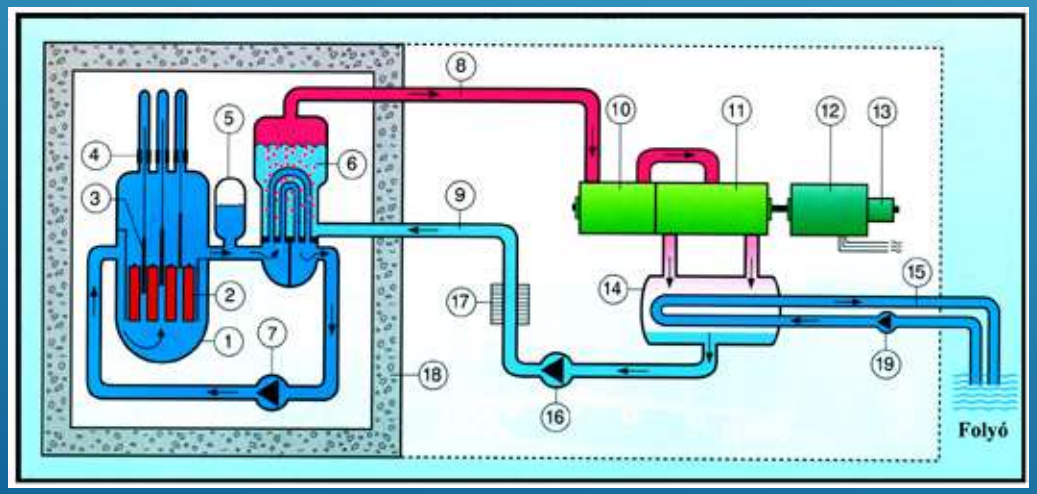
Current Nuclear Reactor Designs

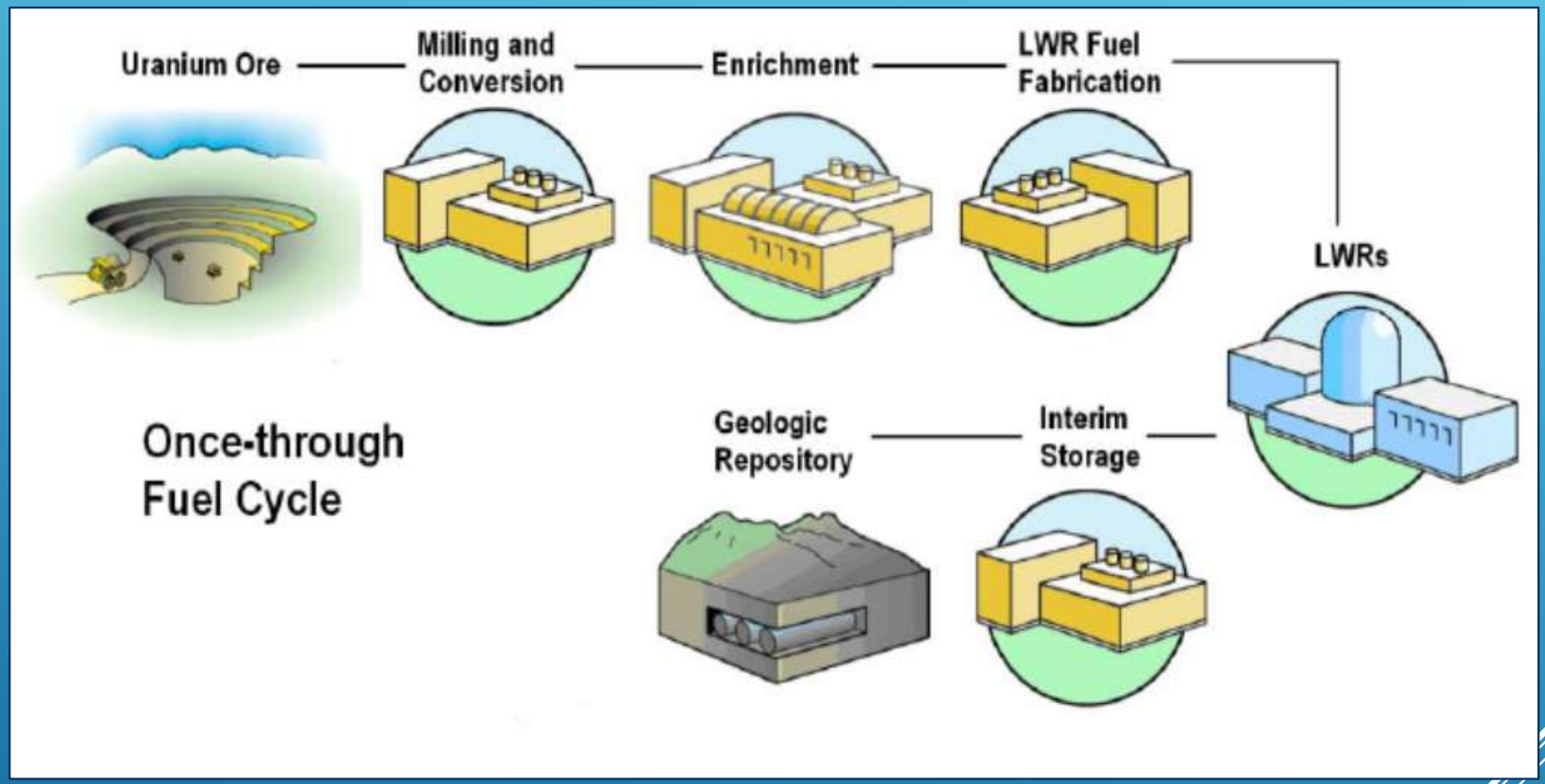
Boiling Water Reactor





Pressurized Water Reactor

Current Nuclear Reactor Designs



Source: Wigeland, R & Dixon, Brent. (2020). Identification, Description, and Characterization of Existing and Alternative Nuclear Energy Systems.

Public Misconceptions

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Misconception	Truth
Nuclear is NOT Safe	It is far safer than other power plants, industrial facilities transportation and even office workers
Nuclear Waste disposal is an unresolved problem.	There are no unresolved technical waste issues. It is purely a political issue. Currently spent fuel is stored on site in safe, guarded storage facilities which provide protection from a conceivable threat.
Nuclear accidents at Three Mile Island, Chernobyl and Fukushima produced significant radioactivity and killed people.	No public fatalities Gov. over reaction worse than event. Off site radiation none to minimally significant. Less than many industrial failures.
Nuclear power is too expensive	Nuclear is less expensive than solar and wind, coal and gas when evaluated on an equivalent, overall basis including pollution without subsidies.
Nuclear Power is NOT reliable	It is the most reliable form of power generation. After environmental catastrophes the nuclear plants have been fully operational.

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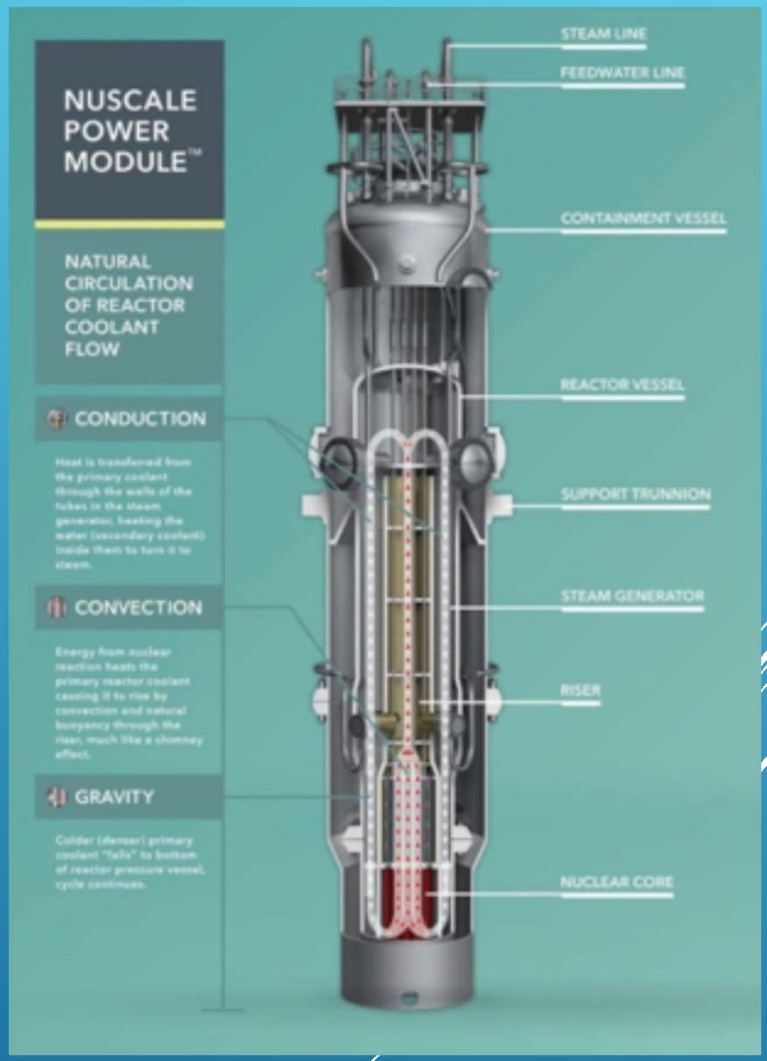
Advanced Nuclear Reactors

- Most Operating Reactors are based on designs developed in the 1960-1970s.
- Challenges to the current designs have sparked an interest in new, innovative designs.
- Large Reactors, >1000MW
- Small Reactors, 5MW to 300MW

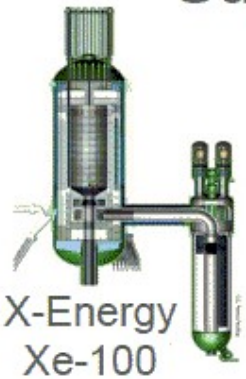
Small Modular Reactors

- Off site construction, Compact
- Modular, smaller per unit
- Integrated steam generator
- Fixed fuel utilization
- Passive safety systems
- strategy (5, 10, 20 year)

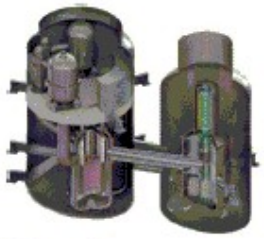


Non-Water Advanced Reactors

Gas Reactors



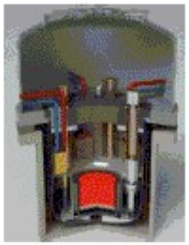
X-Energy
Xe-100



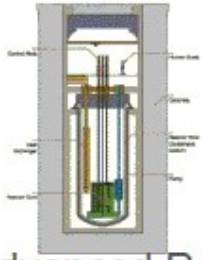
General Atomics
Energy Multiplier Module, EM2

Fast Reactors

GE Hitachi
PRISM

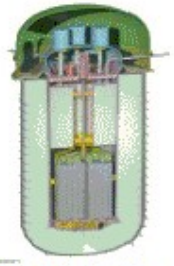


TerraPower
TWR

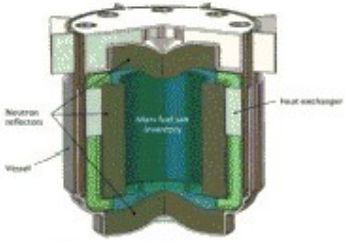


Advanced Reactor
Concepts LLC
ARC-100

Molten Salt Reactors

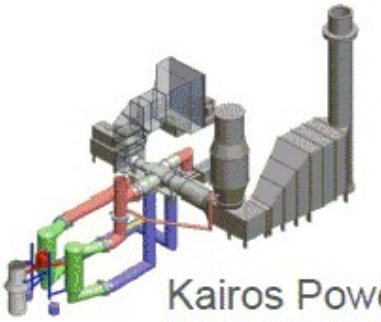


Terrestrial Energy
USA IMSR



TerraPower
MCFR

Elysium USA
MCSFR



Kairos Power
UCB PB-FHR

Advanced Nuclear Developers

ADNA Corporation
Accelerator Driven Neutron Application

ALPHA NUR

HITACHI

Muons, Inc.
Innovation in Research

TerraPower

Alpha Tech Research Corp

GENERAL ATOMICS

newcleo
Futureable Energy

TERRESTRIAL ENERGY

arc CLEAN TECHNOLOGY

HOLTEC INTERNATIONAL

USNC ULTRA•SAFE•NUCLEAR

NuGen

NUSCALE™
Power for all humankind

Westinghouse

BWXT
BWX Technologies, Inc.

Kairos Power

energy®

EXODYS ENERGY

LAST ENERGY

OKLO

framatome

moltex clean energy

RADIANT

ZENO POWER SYSTEMS

System Benefits of Advanced Reactors

Long term price stability	• Low fuel and operating costs
Reliable dispatchable generation	• 24/7, 365 days per year, years between refueling (Capacity factors >92%)
Integration with renewables and storage	• Paired with heat storage and able to quickly change power
Efficient use of transmission	• Land utilization <0.1 acre/TWh (Wind =1,125 acre/TWh; Solar 144 acre/TWh)
Environmentally friendly	• Zero-carbon emissions, one of lowest total carbon footprints • Many SMRs are being designed with ability for dry air cooling
Black-start and operate independent from the grid	• Resilience for mission critical activities • Protect against natural phenomena, cyber threats and EMP

Source: SMR Start, *SMRs in Integrated Resource Planning*

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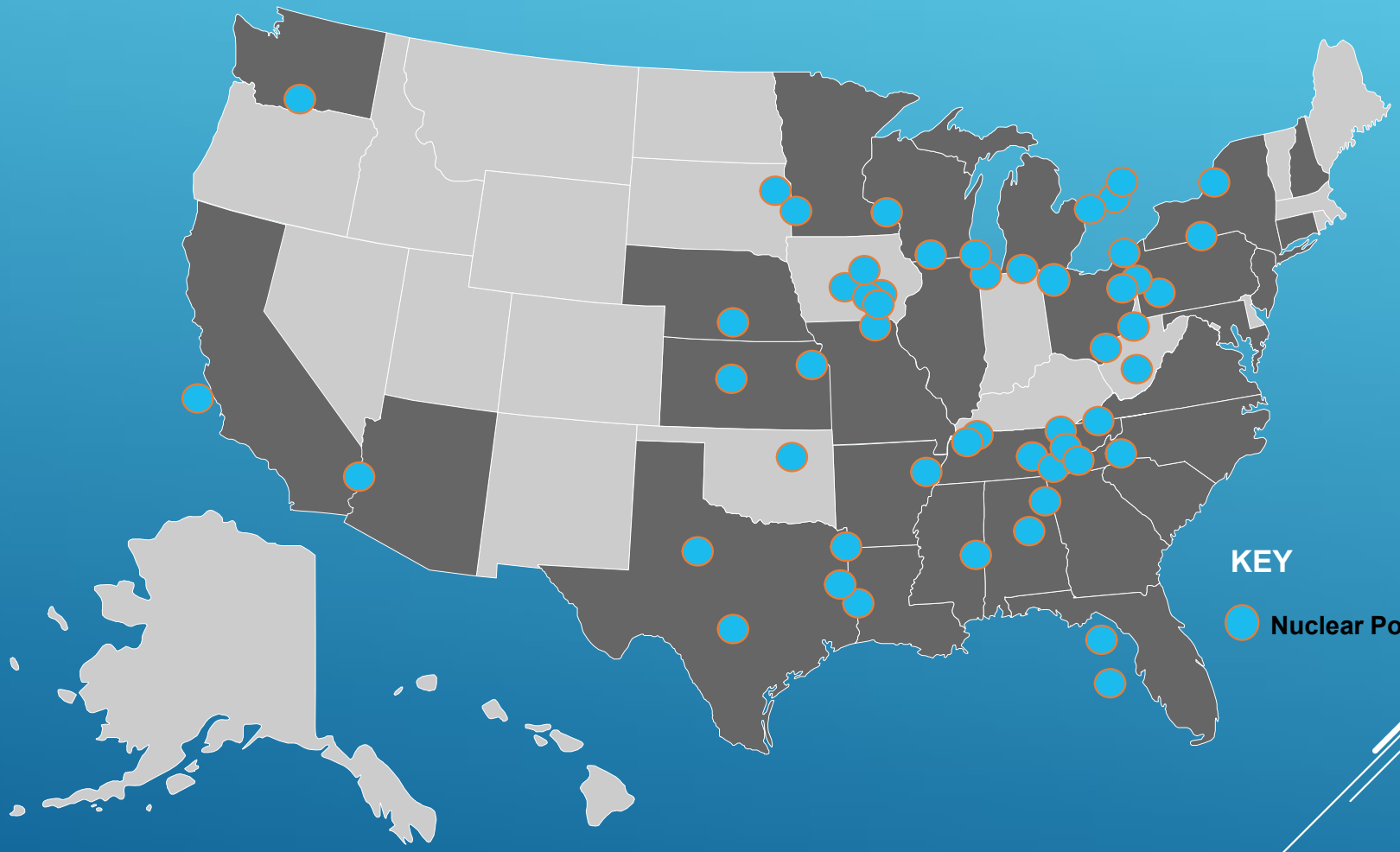
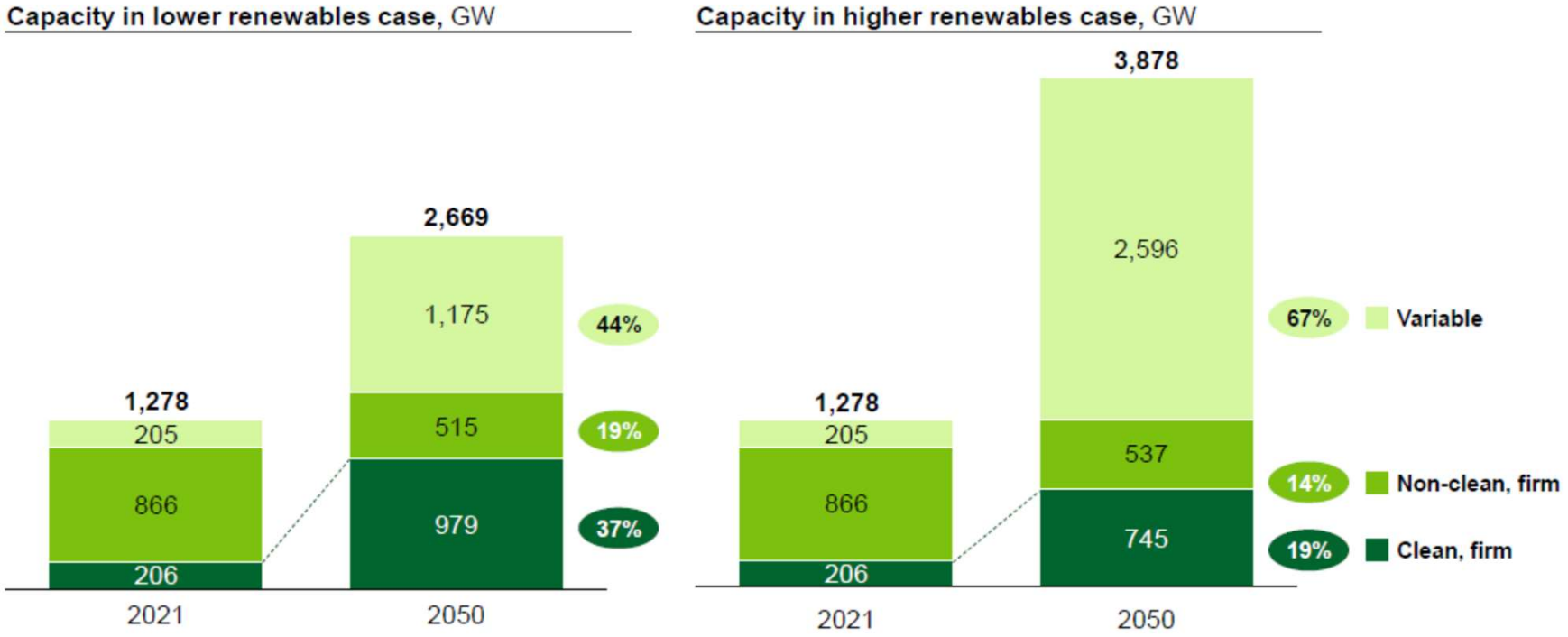
Nuclear Power Plants in the US

93 reactors at 53 plant sites across the country



Updated: May 2023

Achieving net-zero in the U.S. by 2050 would require ~550–770 GW of additional clean, firm capacity



~5x clean, firm (~770 GW)

~3.5x clean, firm (~550 GW)

U.S. DEPARTMENT OF ENERGY

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Bipartisan Leaders Embrace Nuclear Energy

Infrastructure Investment & Jobs Act:

- Operating nuclear plant credit program
- Advanced reactor demonstration funding
- Large-scale H2 demos

CHIPS and Science Act:

- Assistance for nuclear RD&D
- University nuclear engineering support

Inflation Reduction Act:

- Tax credits for existing reactors
- Tax credits for all new clean generation
- Tax credits for H2 generation
- Expanded federal loan guarantees

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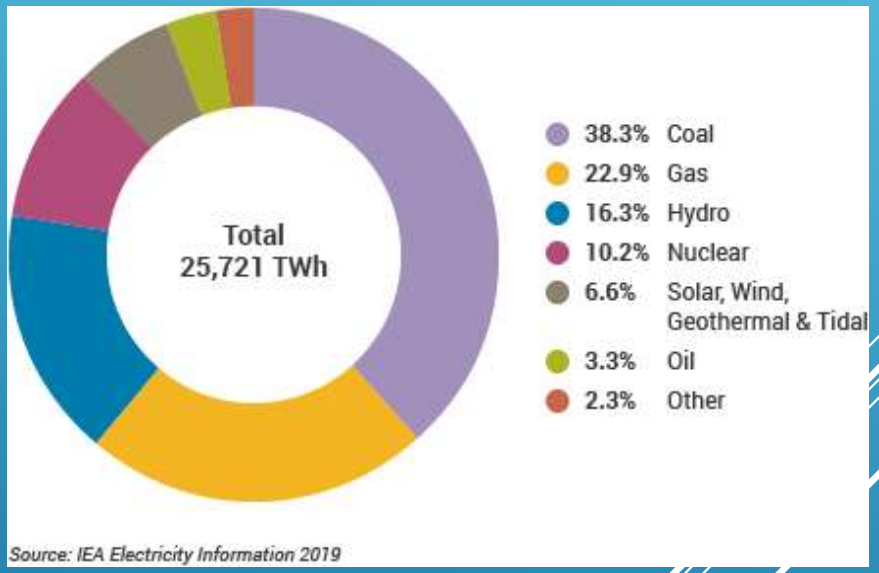
Countries that Rely on 20% or More on Electricity Generated by Nuclear Power

- France 75%
- Slovakia 52%
- Belgium 51%
- Ukraine 48%
- Hungary 42%
- Armenia 40%
- Sweden 35%
- Germany 27%
- Romania 20%
- Switzerland 38%
- Slovenia 37%
- Czech Rep. 33%
- Bulgaria 33%
- South Korea 35%
- Japan 29%
- Finland 33%
- USA 18%
- UK 19%



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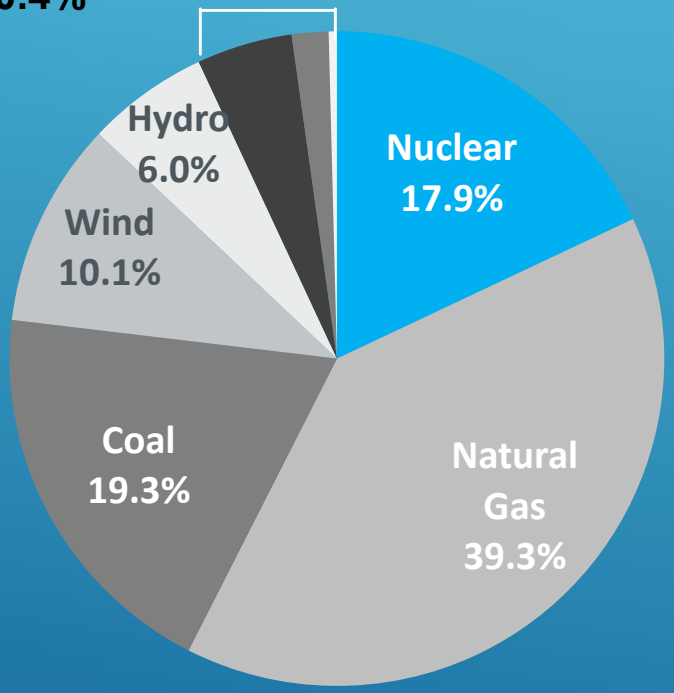
Nuclear Generated 18% of U.S. Electricity in 2022

Solar – 4.7%
Biomass & Petroleum – 1.8%
Geothermal – 0.4%



Source: U.S. Energy Information Administration
Updated: March 2023

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Electric Utilities are Planning for New Nuclear

Nuclear power's potential role in meeting their company's decarbonization goals:

- **SLR** — >90% of fleet expects to operate to at least 80 years
- **GW** — ~100, some estimate 200 GW of new nuclear opportunity by 2050s
- **SMRs** — Translates to > 300 SMR-scale plants

* - NEI utility member companies produce nearly half of all US electricity

Advanced Nuclear Deployment Plans

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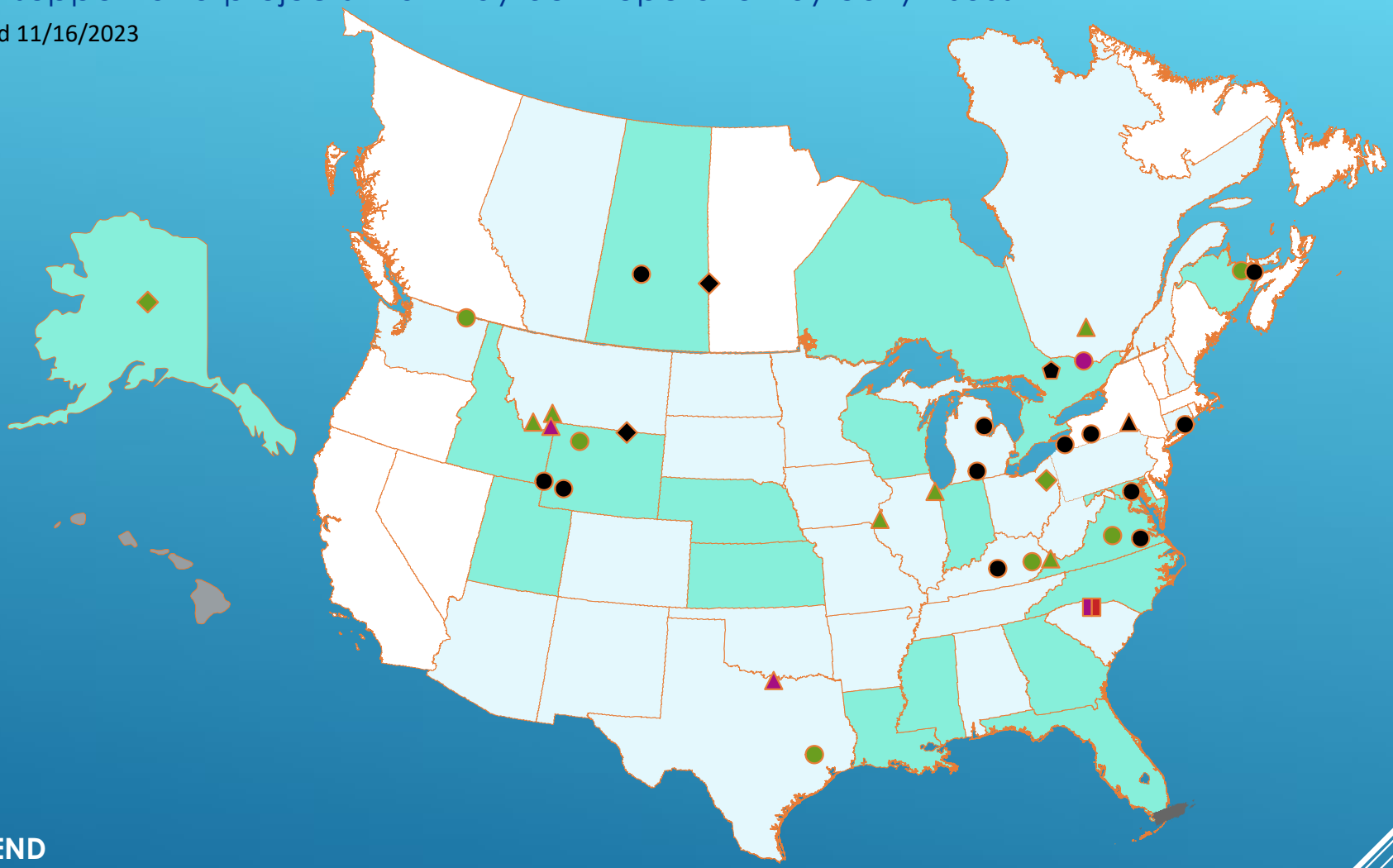
State support and projects that may be in operation by early 2030s

Updated 11/16/2023



LEGEND

- State Actions – Substantive Incentives
- State Actions – Supportive and Exploring
- Considered project
- Planned project
- Under construction
- Operating
- Large (1,000 MWe)
- Small (<300 MWe)
- Micro-reactor (<50 MWe)
- University / Research / Test

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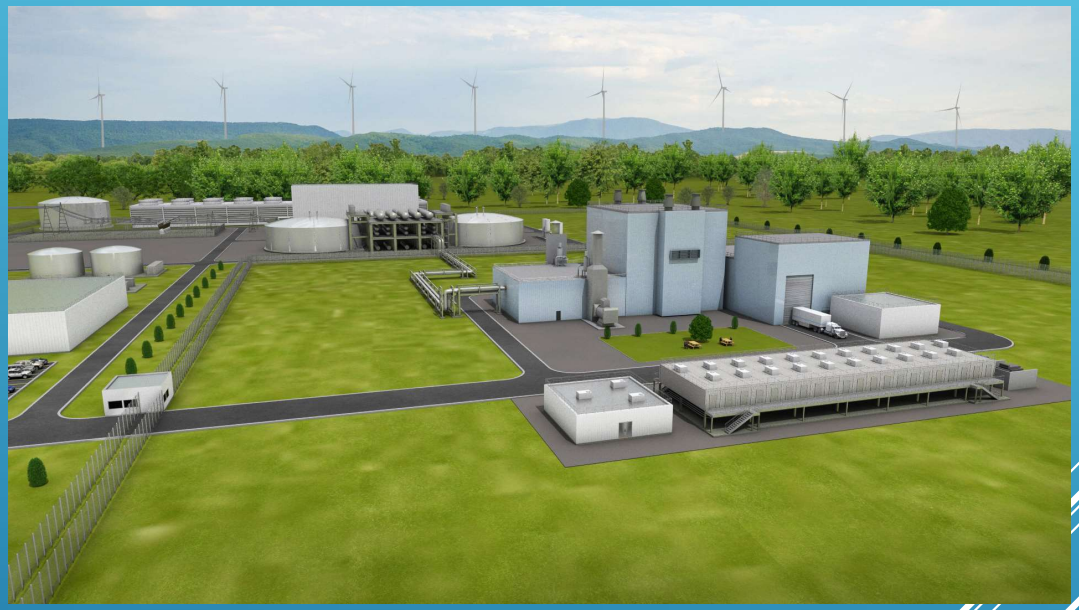
New Applications for Small and Advanced Reactors

DOE ARDP Demonstration Awards

TerraPower

Natrium Reactor

- Liquid sodium fast reactor - 345 MWe
- Metallic fuel
- Molten salt thermal storage for peaking to 500 Mwe
- Selected construction site in Kemmerer, WY



DOE ARDP Demonstration Awards

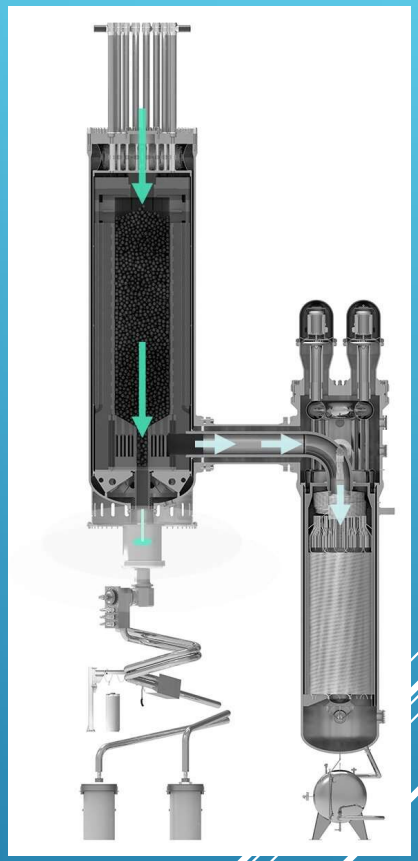
X energy®

Xe-100

- Pebble bed, helium cooled gas reactor – 80 MWe
- Four reactors
- TRISO fuel
- Planned construction at Dow/Union Carbide Seadrift, TX plant

DOW®

TRISO Fuel Pebble Cutaway



Advanced Nuclear Affordability

Small +

Inherently Safer

= Simpler

- ✓ Readily available equipment
- ✓ Factory- Built
- ✓ Faster Construction
- ✓ Improved Performance

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Advanced Nuclear Versatility

Spectrum of Sizes and Options

Micro (Few MW)

Mini (10s of MW)

Small (100s of MW)

Large (1,000+ MW)

Variety of Outputs

Electricity

H_2 Hydrogen

Process Heat

Multitude of Uses

Homes

Vehicles

Businesses

Aviation

Rail

Shipping

Concrete

Steel

Factories

Water

Space

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Global Shift to Nuclear and Geopolitical Implications

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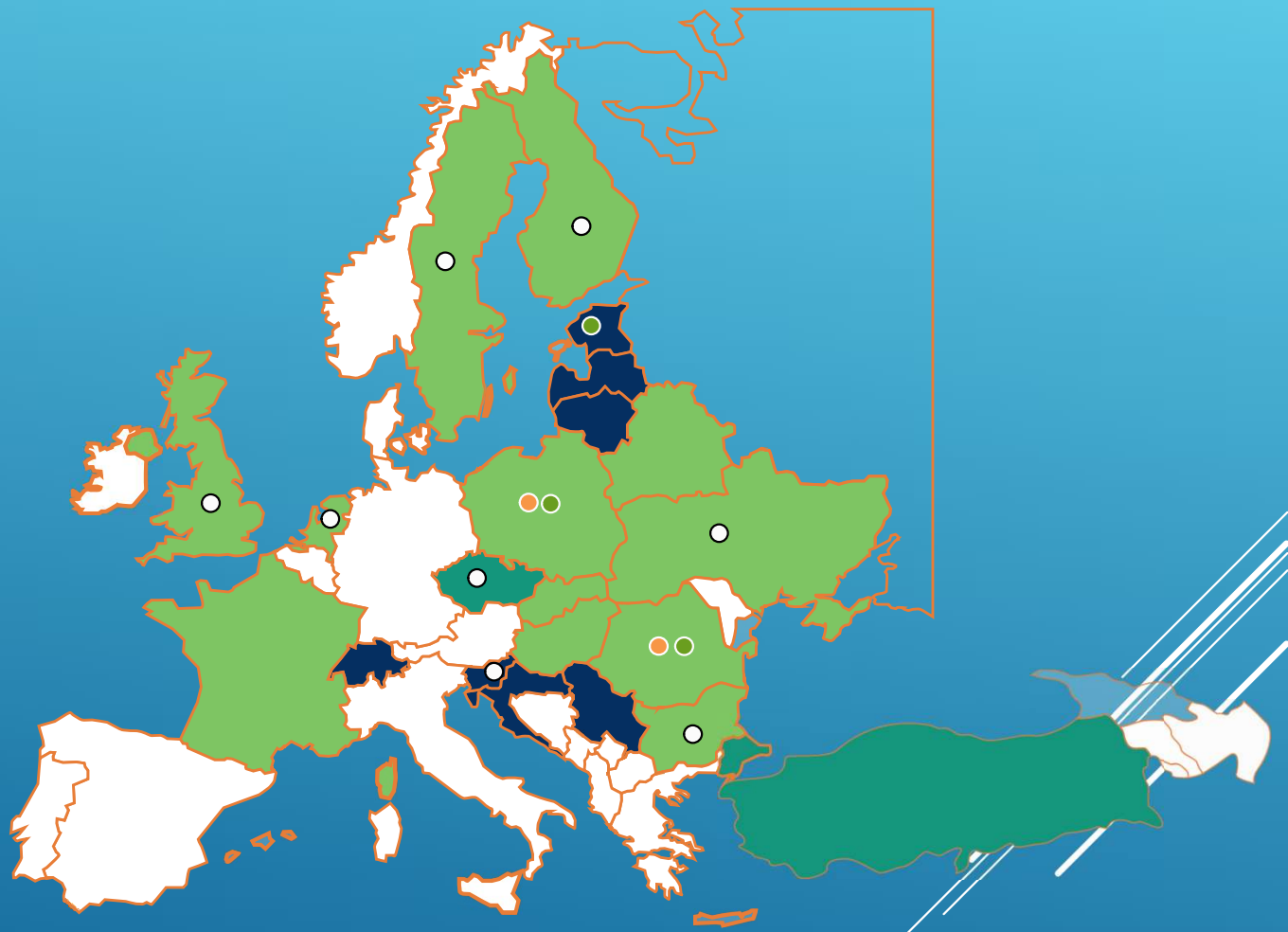
U.S. Advanced Nuclear Deployment – Europe

KEY

- National policies to support new nuclear in place
- National policies to support new nuclear under consideration
- U.S. supplier selected for one or more SMR projects
- U.S. supplier selected for one or more large reactor projects
- Near-term commercial opportunity for large and/or SMR projects



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A Nuclear Energy Program is a Century-long Relationship

Licensing & Construction

Cooperation on:

- Reactor system procurement
- Operator training
- Regulatory capacity
- Construction quality & safety
- Environmental protection

5-10 YEARS

Operations

Cooperation on:

- Physical security
- Cyber security
- Nuclear material protection & accountability
- Nuclear nonproliferation
- Supply of fuel & services
- Research & development
- Workforce development
- Nuclear materials transportation
- Operational safety & performance
- Safety regulation

60-80+ YEARS

Decommissioning

Cooperation on:

- Decommissioning services
- Decontamination technologies
- Nuclear waste management
- Environmental protection

5-10 YEARS

Challenges Ahead of the US industry

- Strong Opposition to nuclear power by many local and state governments until very recent
- Premature plant shutdowns started a decade ago
- Several units (about 10 closed in the past 10 years)
- One plant, Diablo Canyon in CA saved
- Another one, Palisades in Michigan is in the process of restarting the unit
- Lack of experienced workforce
- Lack of substantial recent construction experience
- Long process Licensing of New Design
- Cost escalation

Can we meet our goal

- In the 70s US was building a dozens reactors at the same time, most of our current fleet was built and commissioned by mid-1975, a dozen units later, in mid 1980s, and only a few later on
- Building 300 reactors in 25 years, especially now days will be a monumental task
- We have built only two new reactors in the recent years, Vogtle 3&4
- It took close to 15 years to complete, unit 4 was just completed
- Project was 150% over budget and several years behind schedule
- The other similar units, VC Summer 2&3 was cancelled halfway through the construction
- Building so many new reactors will require close coordination, and collaboration in the industry
- Many industry groups, like NEI, ANS are actively preparing the industry for the uptick in new demand for nuclear power

- **References and Resources**
  - Material presented here are from various sources
  - Some of the slides presented here are exact copies of slides from a recent NEI presentation (Nuclear Energy Status Outlook, December 2023
  - The following websites can provide additional information about this topic
  - www.nei.org
  - https://www.nrc.gov/
  - www.ans.org
  - https://www.energy.gov/ne/office-nuclear-energy
  - https://local.ans.org/ne/

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