U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

Nuclear Energy Overview

August 1, 2018

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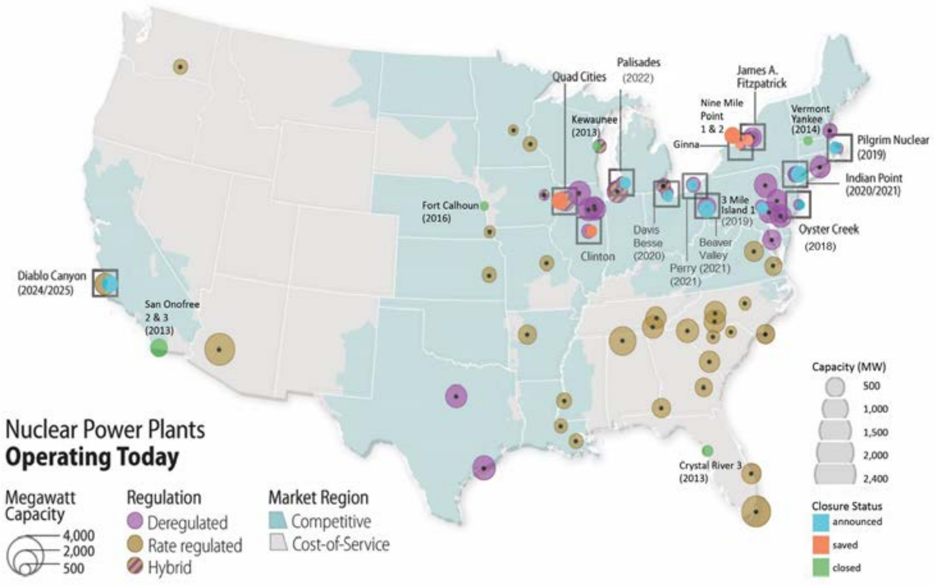
Senior Advisor to the Assistant Secretary for Nuclear Energy

Office of Nuclear Energy

U.S. Department of Energy

Nuclear Energy: A National Strategic Asset

- Recognition of the importance of nuclear – today and in the future
  - Energy Security
  - Economic Prosperity
  - Global Security
  - Environmental Sustainability
- Concern about the financial viability of some currently operating plants, yet benefits from keeping them running
- Increased interest in nuclear in some domestic and international markets
- Innovators and utilities looking at advanced nuclear as a way to move beyond electricity
- Secretary Perry: Make Nuclear Energy Cool Again!

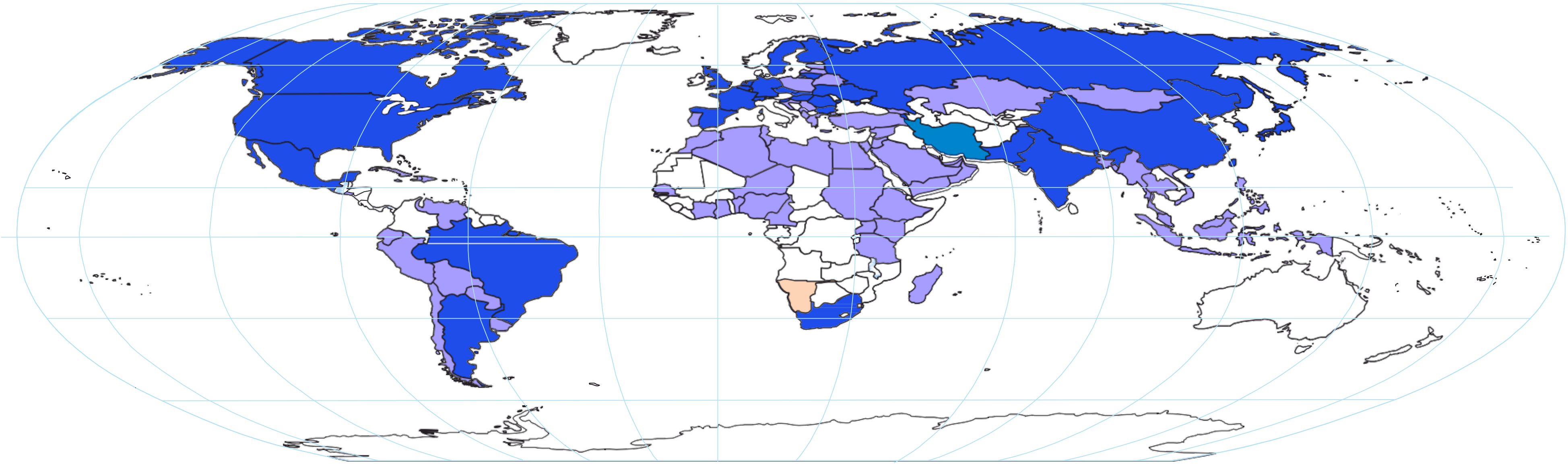


- **20% of electricity (56% of non-emitting)**
- **92% capacity factor**
- **Supports 475,000 jobs**
- **$10B in federal & $2.2B in state taxes annually**

"If you really care about this environment that we live in… then you need to be a supporter of this [nuclear energy] amazingly clean, resilient, safe, reliable source of energy."

Secretary Rick Perry at Press conference, May 10th

Global Growth and Market Opportunity



Potential Nuclear Power Expansion

- **35 countries taking steps to develop nuclear power**
- **30 countries with operating reactors developing expansion plans**

~450 reactors operating

11% of electricity / 40% of clean electricity

Source: IAEA/PRIS & WNA

- ~60 reactors under construction in 15 countries (20 in China)
- ~170 reactors planned in over 25 countries, worth as much as $700 billion over the next 5-10 years
- ~370 reactors proposed in 36 countries, worth as much as $1.6 trillion over the next 10-25 years

Office of Nuclear Energy Mission Pillars

Existing Fleet

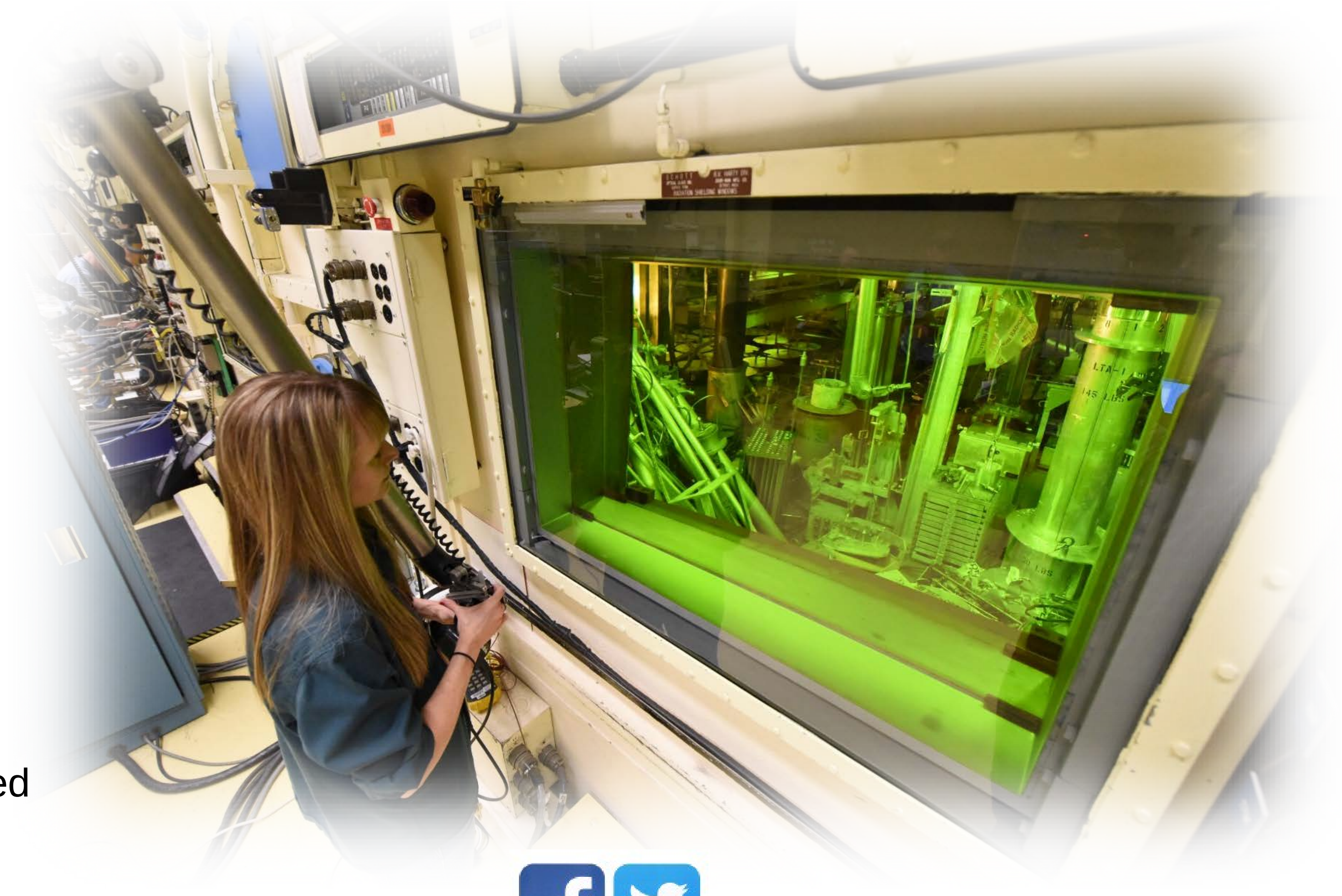
Advanced Reactor Pipeline

Fuel Cycle Infrastructure

Gateway for Accelerated Innovation in Nuclear (GAIN)

GAIN Gateway for Accelerated Innovation in Nuclear

A private-public partnership framework aimed at rapid and cost-effective development of innovative nuclear energy technologies towards market readiness



Mission

Provide the nuclear energy industry with access to **technical, regulatory and financial support** necessary to move innovative nuclear energy technologies toward *commercialization* in an accelerated and cost-effective fashion

@GAINnuclear https://gain.inl.gov

Small Modular Reactors

Greater affordability

- Easier financing for public power entities
- Lower capital investment
- Factory fabrication, shorter construction times

New standard of passive nuclear safety

Energy and environmental benefits

- Greenhouse gas and air pollution avoided
- Grid benefits: stability, security, quality, availability, reliability
- Siting flexibility
- Hybrid energy systems and flexible integration with renewables

Importance to National Security

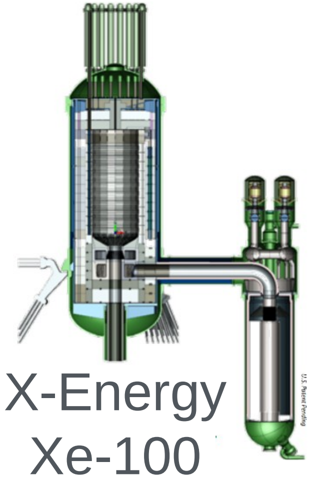
Economic development and job growth

- Manufacturing jobs and supply chain opportunities in the United States

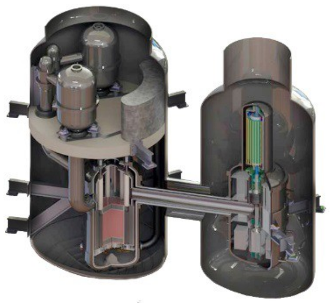
NUSCALE™
Power for all humankind

Non-Water Advanced Reactor Designs Being Developed By Industry

Gas Reactors



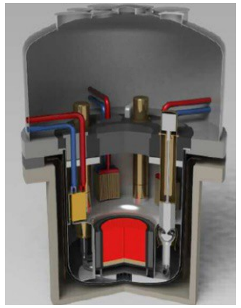
X-Energy
Xe-100



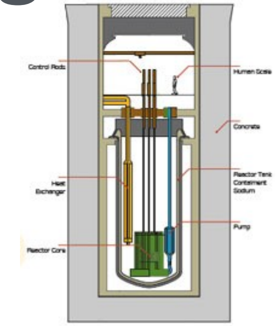
General Atomics
Energy Multiplier Module, EM2

Fast Reactors

GE Hitachi
PRISM

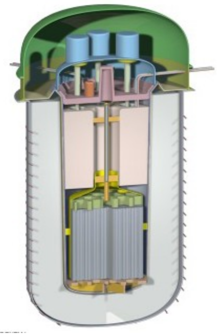


TerraPower
TWR

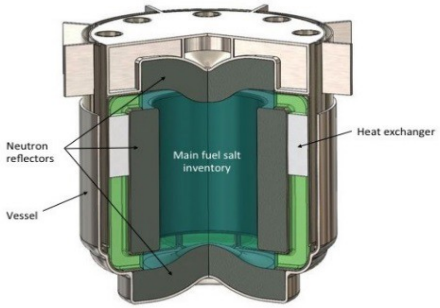


Advanced Reactor
Concepts LLC
ARC-100

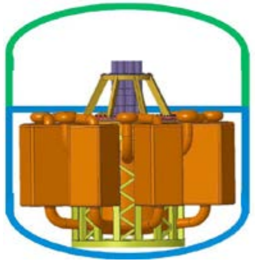
Molten Salt Reactors



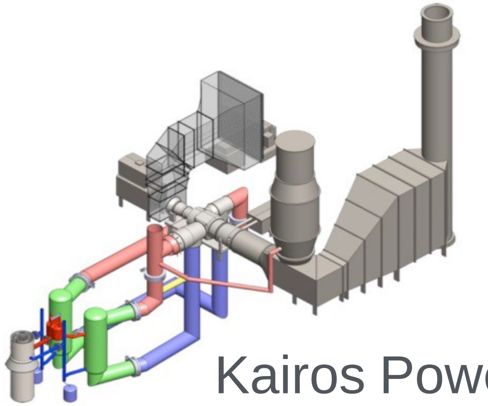
Terrestrial Energy
USA IMSR



TerraPower
MCFR



Elysium USA
MCSFR



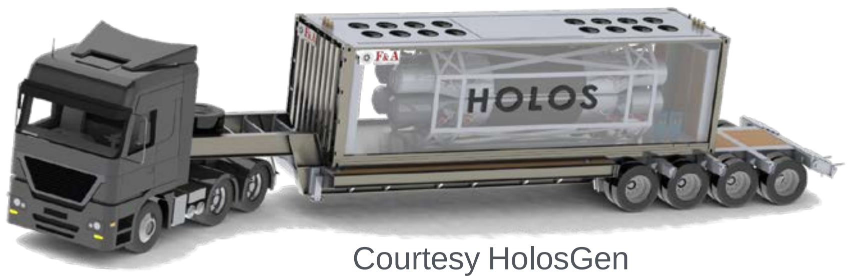
Kairos Power
UCB PB-FHR

Micro Reactors

Designed for Specialized Applications

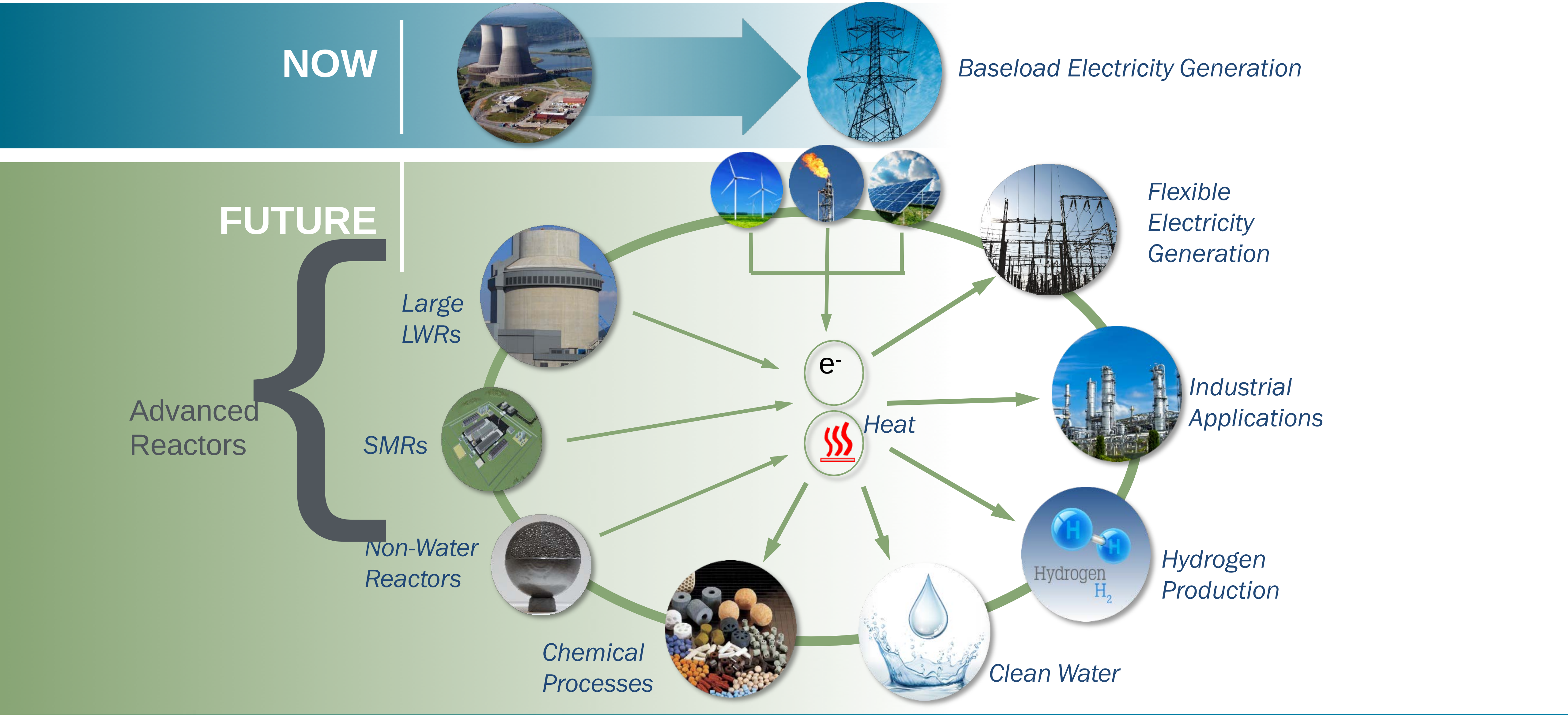
- Siting flexibility including near population centers
- Micro-grids
- Remote Operating Bases
- Data Centers
- Disaster Relief (FEMA)
- Specialized Non-electric Applications

eVinci™ Micro Reactor



Courtesy HolosGen

Nuclear Beyond Electricity – Advanced Reactors



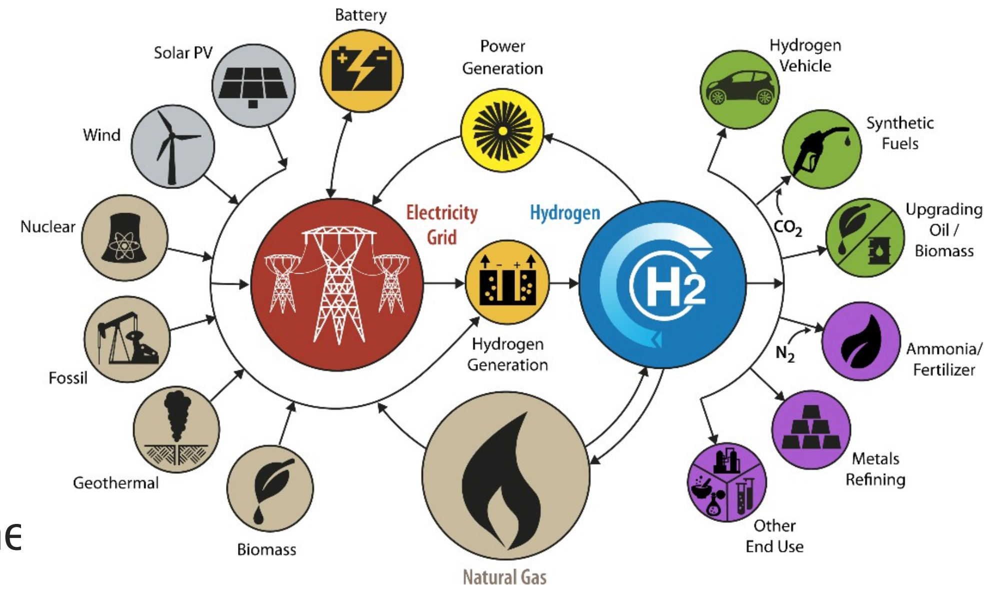
Nuclear-Renewable Hybrid Energy Systems: Program Overview

- Modeling and Simulation

  Tool development and associated analysis to assess technical and economic viability and to determine optimal system design and energy dispatch
  FY-18 Focus: Pilot case studies for specific plants and regions with utility partners

- Demonstration / Experimental Systems
  Electrically heated system testing to demonstrate hardware interfaces, control systems, dynamic operation
  FY-18 Focus: Design review with key stakeholders for PWR-emulation loop
  Design/build thermal energy distribution system (TEDS) to connect PWR loop to hydrogen electrolysis.

- Stakeholder engagement
  - Federal: DOE-EERE collaboration, complementary work in -OE, -FE, DOD
  - Industry: Utilities (incl. Utility Advisory Committee), developers, end users
  - International: Clean Energy Ministerial, various othe



***H2@Scale is a complementary, collaborating program supported by the DOE EERE Fuel Cell Technologies Office.*

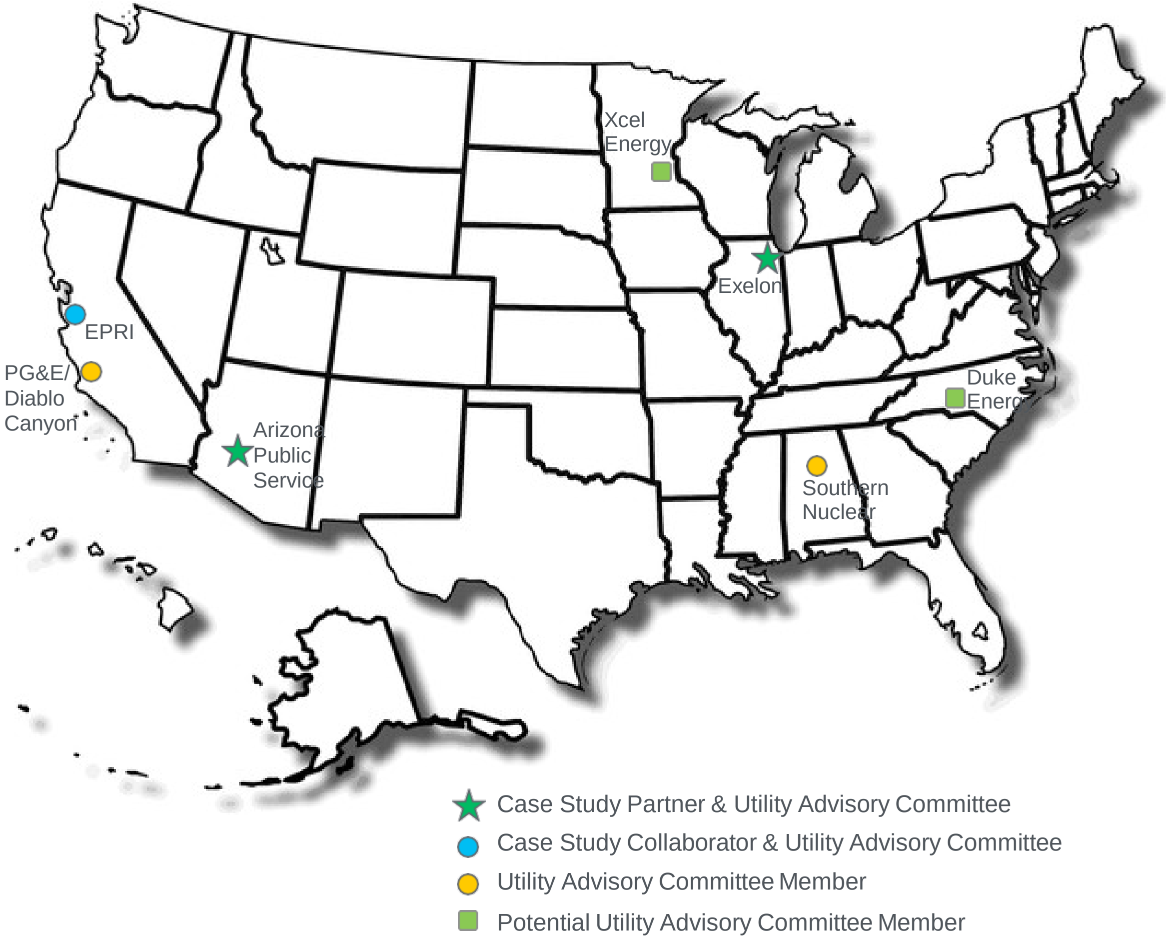
Evaluating Technical and Economic Feasibility with Utility Partners

Case I: Nuclear-Renewable-Water Integration in Arizona

- *Electrical integration of existing nuclear generation and desalination in a region with significant solar generation*
- *Collaboration with Arizona Public Service (APS), operating owner of Palo Verde Generating Station, with consultation from Electric Power Research Institute (EPRI)*

Case II: Nuclear-Industrial Process Variable Hybrid in the Midwest

- *Retrofit of an existing LWR to support an industrial application and electricity production in a region with significant wind generation*
- *Focus on H2 generation and associated off-take industries (e.g., steel making or ammonia production)*
- *Collaboration with multiple industrial partners, led by Exelon, with consultation from EPRI*



Nuclear Innovation: Clean Energy Future (NICE Future)

CLEAN ENERGY MINISTERIAL
Accelerating the Global Clean Energy Transition

Lead Participants:

USA | CANADA | JAPAN

Participants

ARGENTINA | POLAND | ROMANIA
RUSSIA | UAE | UK

Official Launch:
At the 9th Clean Energy Ministerial (May 2018, Denmark) NICE Future was launched by the United States, Canada and Japan to spotlight nuclear energy in the internaIonal clean energy community.

Overview:
NICE Future focuses on nuclear power as a clean energy opIon for reliable and resilient baseload electricity, and non-electric applicaIons especially when deployed as hybrid nuclear-renewable systems.

Areas of Work:

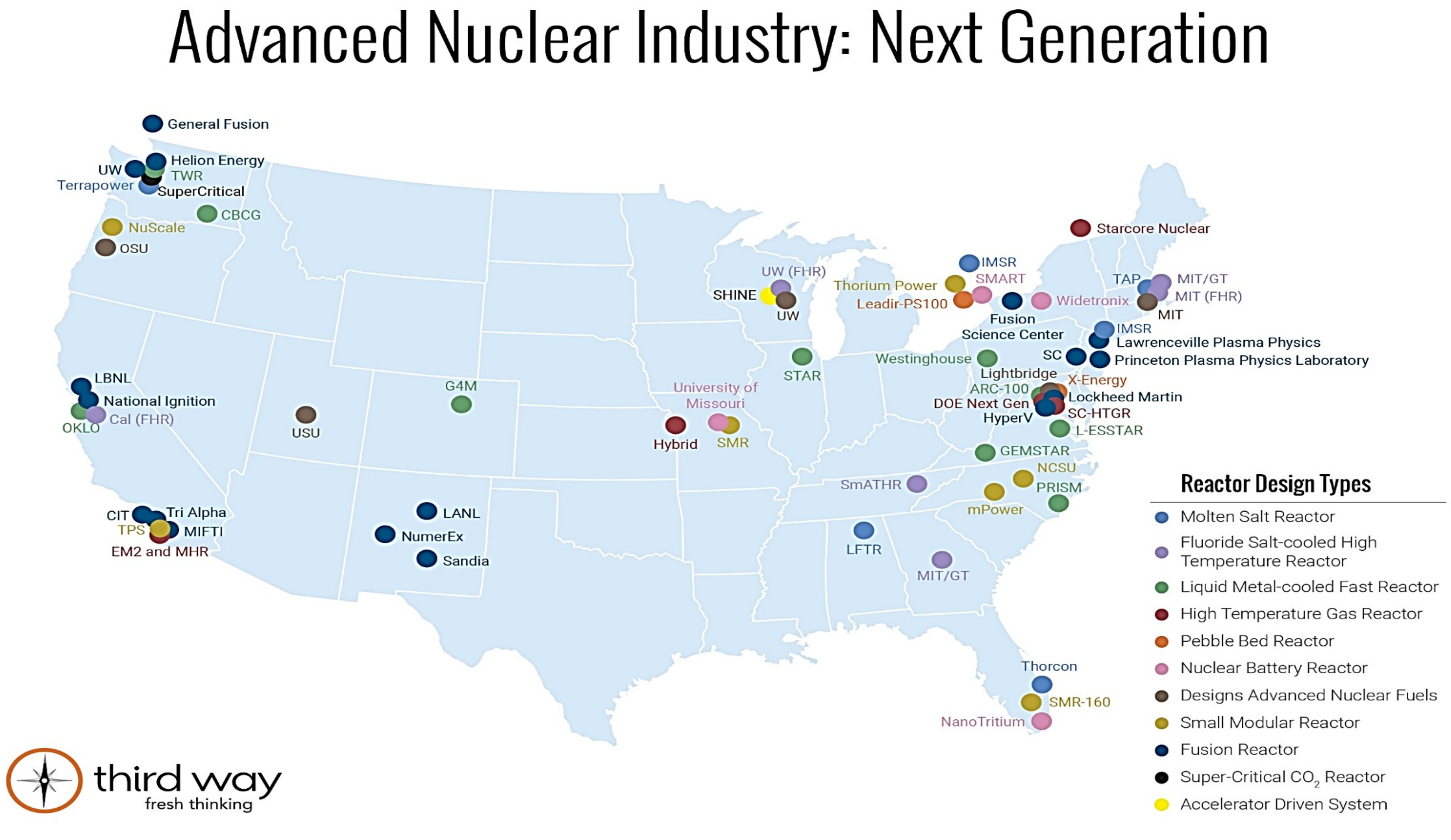
1) EvaluaIons of innovaIve systems, technology, storage, uses
2) Policy-maker and Stakeholder Engagement
3) Economics
4) CommunicaIng nuclear energy's role in clean energy systems

Questions?

Clean. **Reliable. Nuclear.**

BACK-UP

American Innovation Can Capture the Global Market

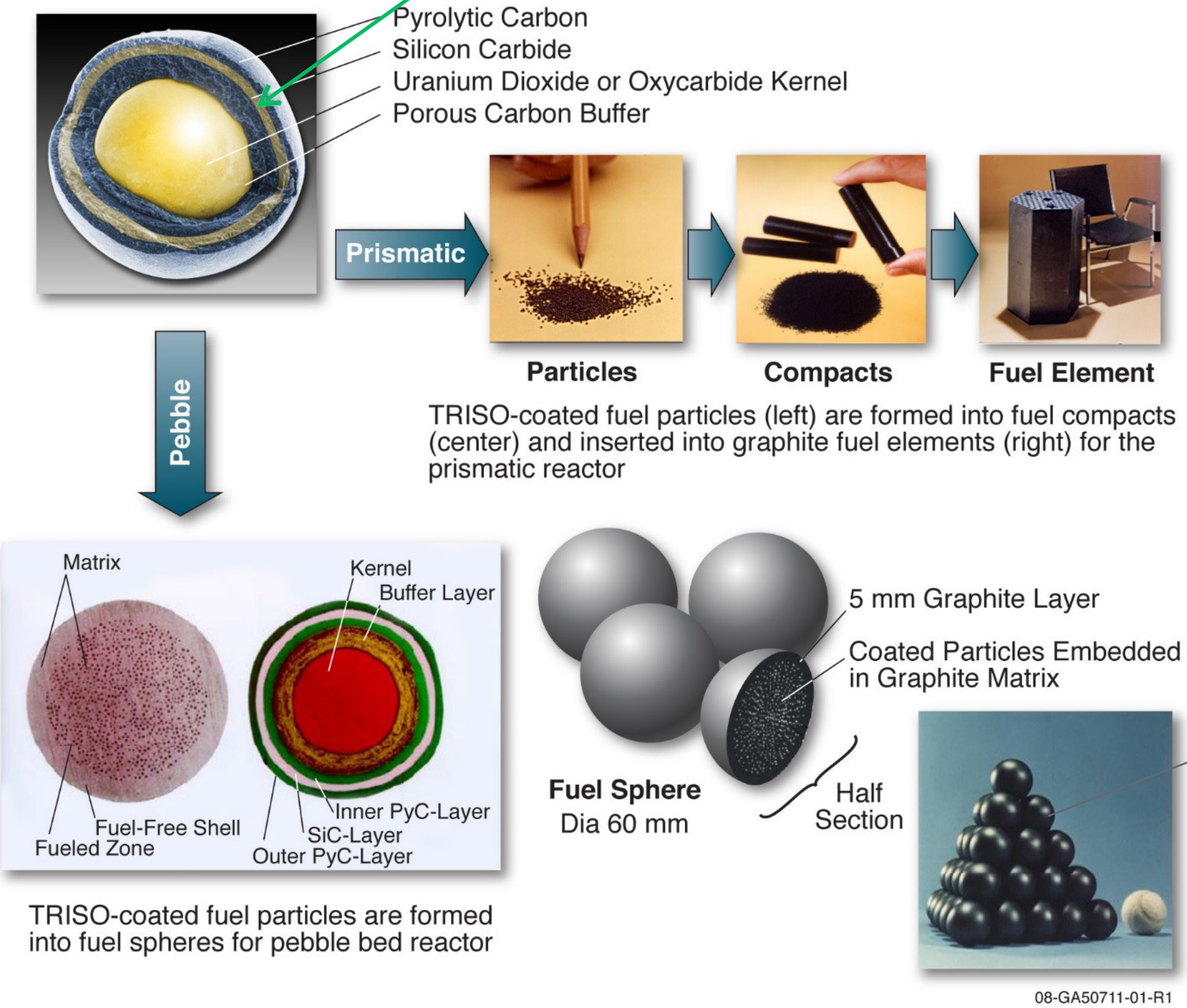


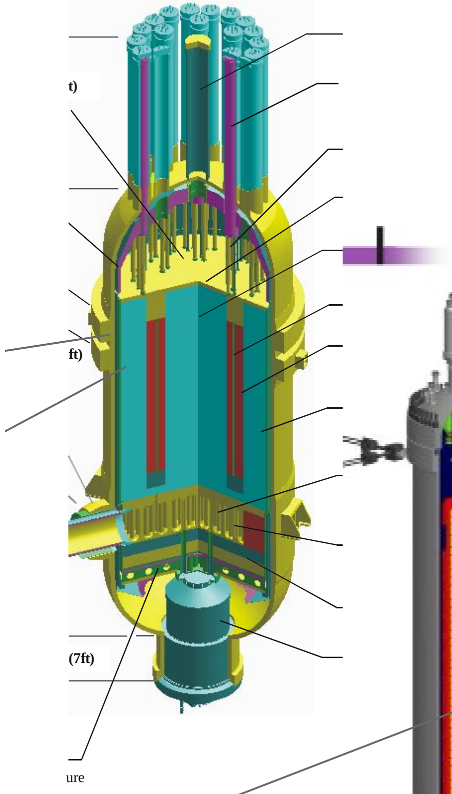
Quick Comparison

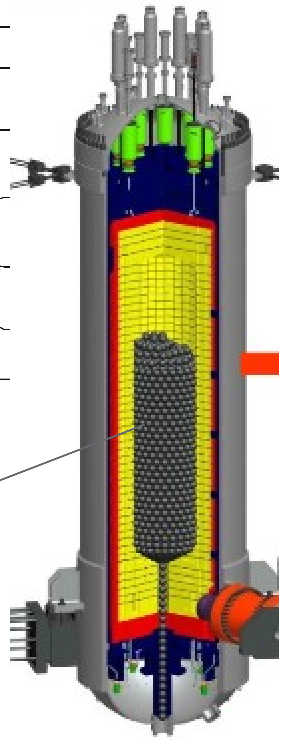
	Light Water Reactors	High-Temp Gas Reactors	Sodium Fast Reactors	Gas-Cooled Fast Reactor	Lead-Cooled Fast Reactor	Molten Salt Reactors
Electrical Power (MWe)	600-1000	100-300	50-2000	1000	20-1200	1000
Coolant	water	helium	sodium	helium	Lead or lead-bismuth eutectic	Fluoride or other salt
Moderator	water	graphite	--	--	--	--
System Pressure (MPa)	8-16	4-7	0.3	7-9	0.3	0.6
Coolant Temperature at Outlet (˚C)	325	700-1000	500-550	750-850	480-570	700-800
Average Core Power Density (W/cm3)	100	4-8	>200	60-100	70-120	330

High Temperature Gas Reactors

This is the pressure boundary





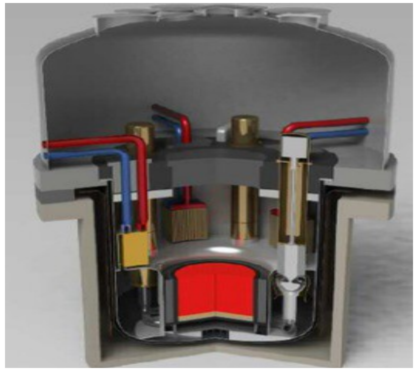


Prismatic or
Pebble Bed Core

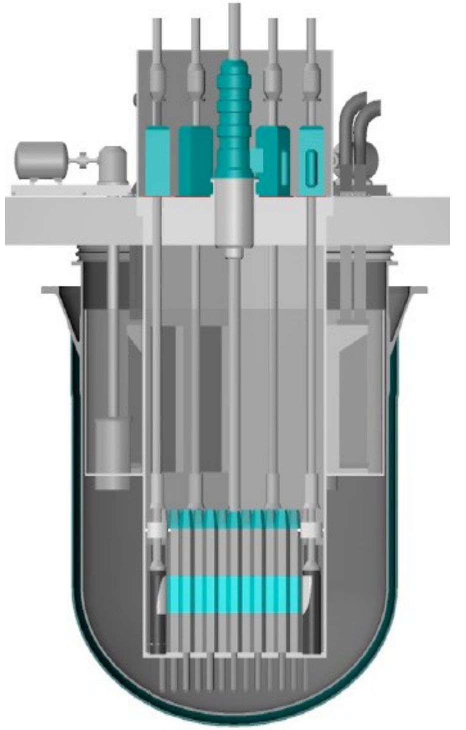
Fast Reactors

- Sodium-Cooled Fast Reactors
  - Fast neutron spectrum
  - Low pressure for simplified compact operation
  - Liquid metal coolant – high conductivity
  - Enhanced passive safety
  - High fuel utilization
  - Flexible fuel cycle applications that can be self-sustaining

- Lead-Cooled Fast Reactors
  - Liquid metal coolant that is not reactive with air or water
  - Lead or lead-bismuth eutectic options
  - Fast neutron spectrum
  - Low operating pressure
  - High fuel utilization
  - Flexible fuel cycle applications that can be self-sustaining



TerraPower – TWR
Sodium Fast Reactor



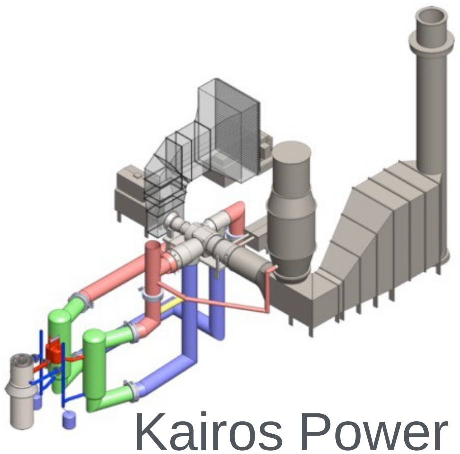
Westinghouse
Lead Fast Reactor

Molten Salt Reactors

- Two major types – salt cooled and salt fueled
  - High temperatures for non-electric applications
  - Low operating pressures

- Fluoride salt-cooled high temp reactor (FHR)
  - Molten fluoride salt as coolant; typically FLiBe
  - Solid fuel; typically TRISO in pins, pebbles

- Liquid Fueled Molten Salt Reactor
  - Molten salt used as both coolant and fuel
  - Salts typically fluoride or chloride
  - Thermal or fast spectrum
  - No fuel fabrication – online refueling
  - On-line waste Management



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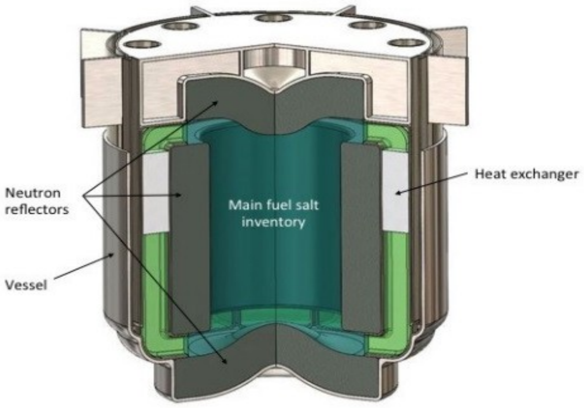

TerraPower MCFR