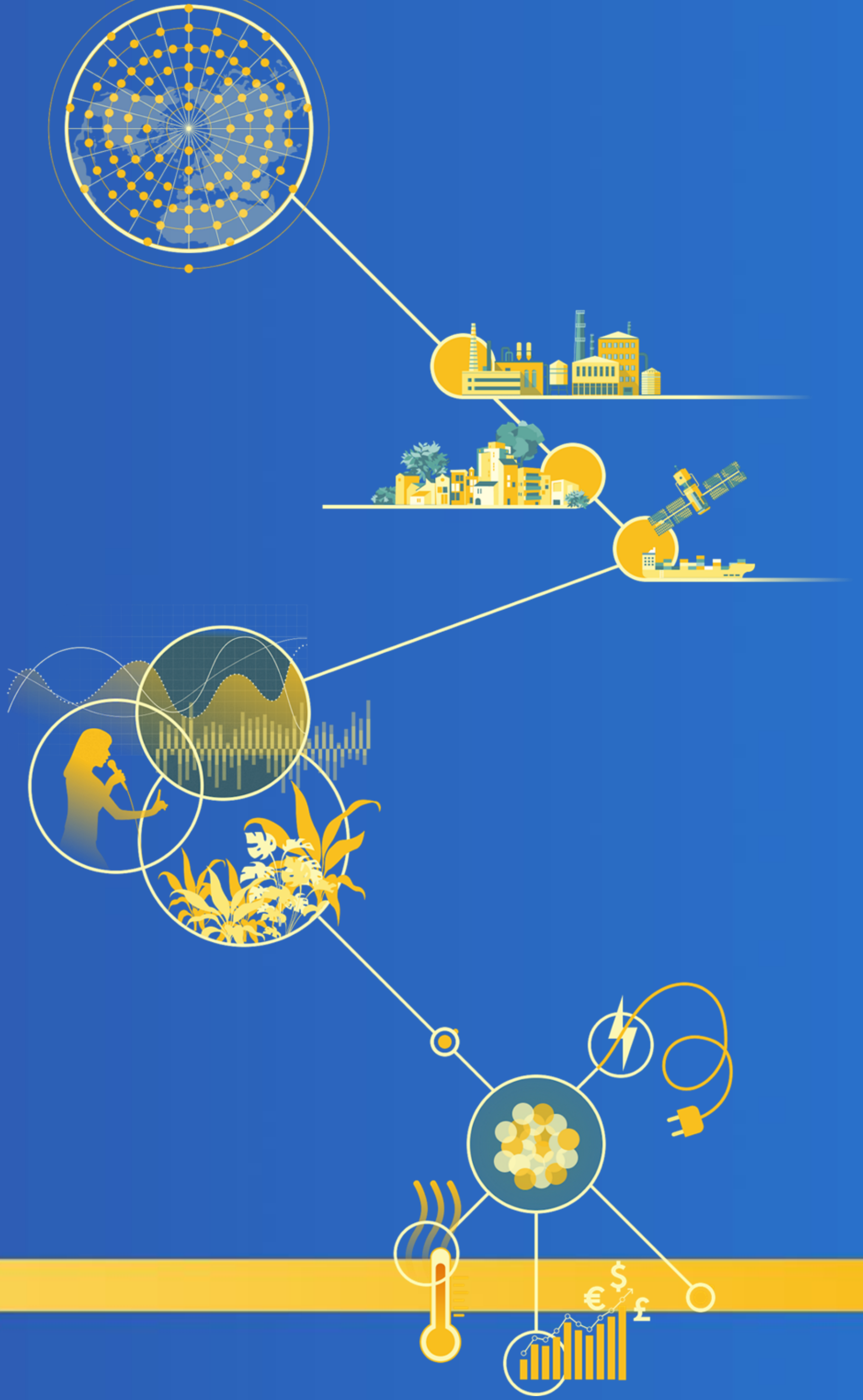
NUCLEAR INNOVATION ALLIANCE



Navigating the Advanced Reactor Landscape: An Overview of Emerging Technologies

Prepared for the NCSL's Nuclear Legislative Working Group

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June 29, 2023

Who is Nuclear Innovation Alliance (NIA)?

- NIA is a "think-and-do" tank working to ensure advanced nuclear energy can be a key part of the climate solution.

- NIA identifies barriers, performs analysis, engages with stakeholders and policy makers, and nurtures entrepreneurship through its Nuclear Innovation Bootcamp.

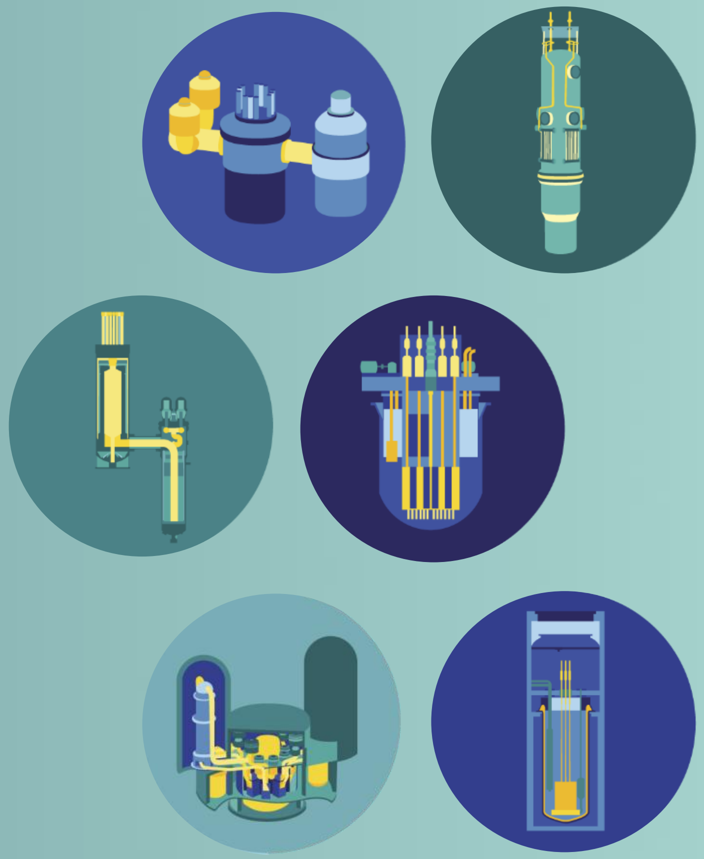
Four Fast Takeaways on Advanced Nuclear Energy

Nuclear energy can play a major role in creating a clean energy economy

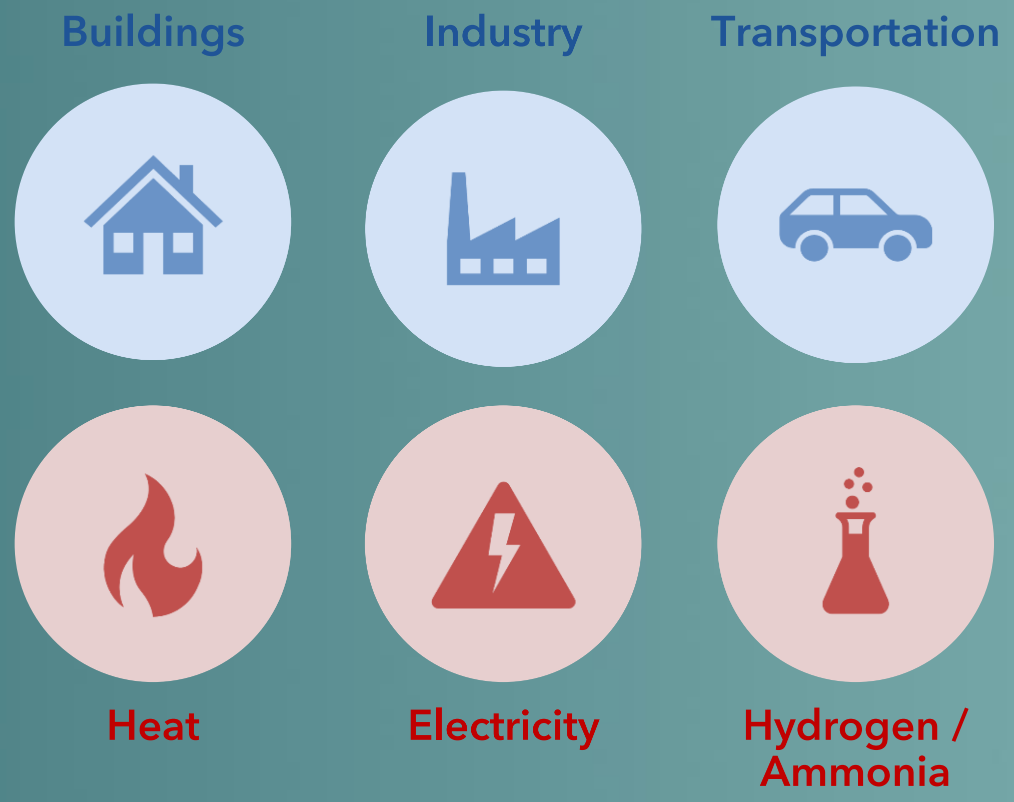
Advanced nuclear reactor types have inherent technological tradeoffs

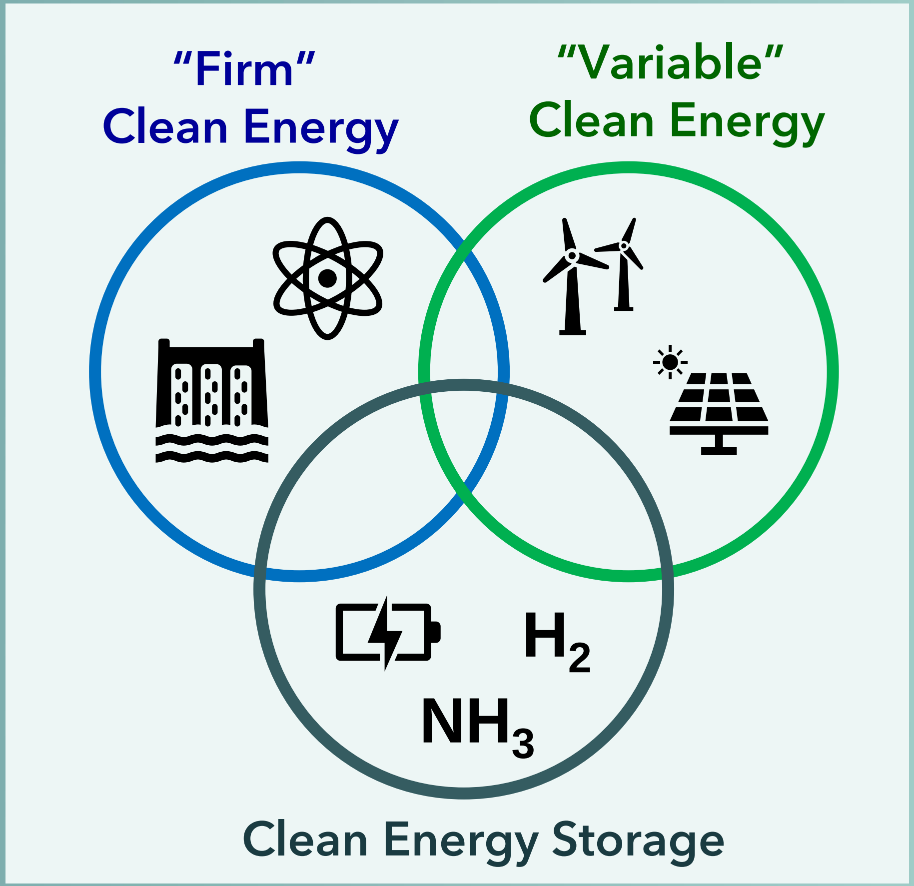
Advanced reactors have a wide array of different commercial use cases

Timing of advanced reactors deployment will vary based on specific user needs and a variety commercial and policy conditions

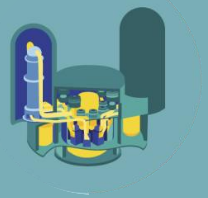


Nuclear energy is an important complementary clean energy source to help fully decarbonize global energy production





Terminology on “conventional” and “advanced nuclear” energy is inconsistent and can introduce unnecessary confusion

	“Existing Nuclear Energy”	“Conventional Nuclear Energy”	“Generation 1, 2, 3, or 3+ Nuclear Technology”
	“Small Modular Reactors (SMRs)”	“Light Water SMRs”	“Generation 3+ Technology”
	“Microreactors”	“Non-Light Water Reactors”	“Generation 4 Technology”

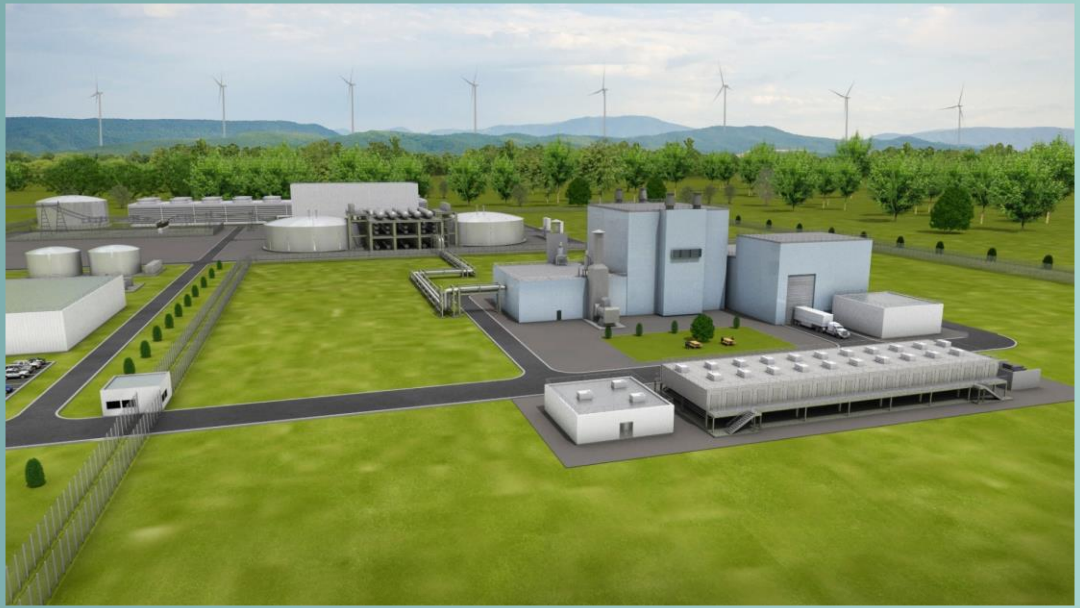
Typical U.S. definitions for “advanced nuclear reactors”

Advanced nuclear energy adds flexibility and versatility in comparison to conventional nuclear through innovative design

Conventional Nuclear Energy

Susquehanna Steam Electric Station
2 x 1350 MW_e (2700 MW_e total)
Boiling Light Water Reactor

Advanced Nuclear Energy



Example: TerraPower Natrium Reactor
345 MW_e (with 500 MW_e peak capacity)
Sodium Fast Reactor with Salt Heat Storage

Advanced nuclear energy adds flexibility and versatility in comparison to conventional nuclear through innovative design

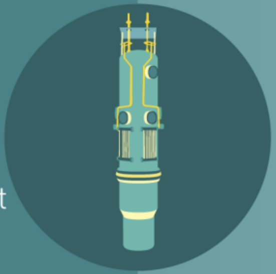
Conventional Nuclear Energy		Advanced Nuclear Energy
Predominantly Large: More than 1000 MW_e	Reactor Size	Versatile: 1.5 MW_e to 300+ MW_e
Predominantly Advanced Gas Reactors	Reactor Technology	Wide Variety of Reactor Technologies
Primarily Baseload Generation	Generation Type	Flexible and Dispatchable Generation
Designed with Active Safety Systems	Safety Approach	Designed with Inherent Safety Systems

Definition of advanced nuclear energy includes a variety of nuclear technologies with different advantages

Thermal Fission

Advanced Light-Water Reactors

Evolutionary design from existing reactors with inherent safety features



High-temperature reactors (HTRs)

High temperatures drive high efficiency, well-suited for process heat or hydrogen production. Uses TRISO fuel

Thermal or Fast Fission

Molten Salt-Fueled Reactors (MSRs)

Using molten salt for coolant and a fuel form, MSRs can bring significant safety benefits

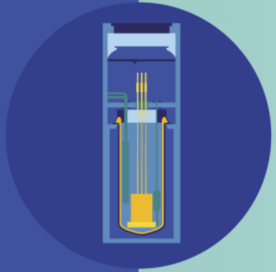
Fast Fission

Gas-cooled fast reactor (GFR)

An evolution of HTRs, GFRs operate at very high temperatures while using a more sustainable fuel cycle

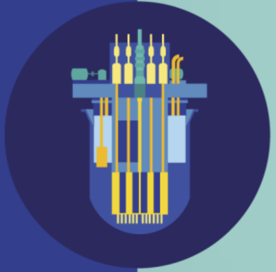
Sodium-cooled fast reactor (SFR)

With many existing experimental reactors, SFRs offer increased fuel efficiency, reduced waste, and passive safety features



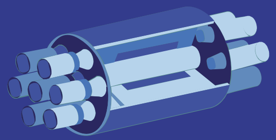
Lead-cooled Fast Reactor (LFR)

Similar in design to SFRs, LFRs are advantageous as lead is operationally safer than sodium



Variety of reactor sizes and low-carbon products enable integration of advanced nuclear into future energy systems

Electricity Production

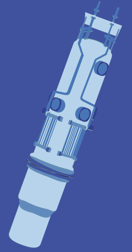


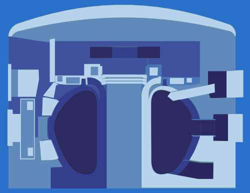
Microreactors

Can provide decentralized power and co-products to rural and off-grid locations

Small Modular Reactors

Scalable power small enough to be available to co-ops, munis, and industrial users for the first time





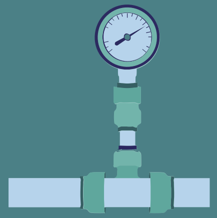
Large Reactors

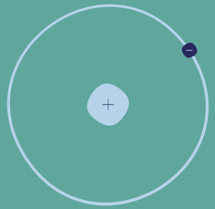
Advanced designs can play the traditional role of large, base-load nuclear power while providing improved operations, safety, and economics

Co-Products

Heat

Through cogeneration, advanced nuclear can provide district heating or process heating for industrial applications, allowing for decarbonization of non-electric sectors



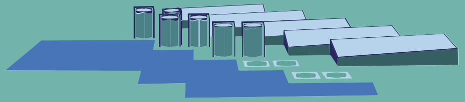


Hydrogen

Advanced nuclear power can produce hydrogen, potentially enabling a hydrogen economy to decarbonize non-electric sectors

Desalination

Some advanced designs can produce fresh water



Deployment of new advanced nuclear energy can provide climate, energy security, and economic benefits for customers

- Reliable, dispatchable, clean energy
- Cost stable energy with assured fuel supply
- Community economic advantages
- Safety improvements
- Versatile energy applications and use cases

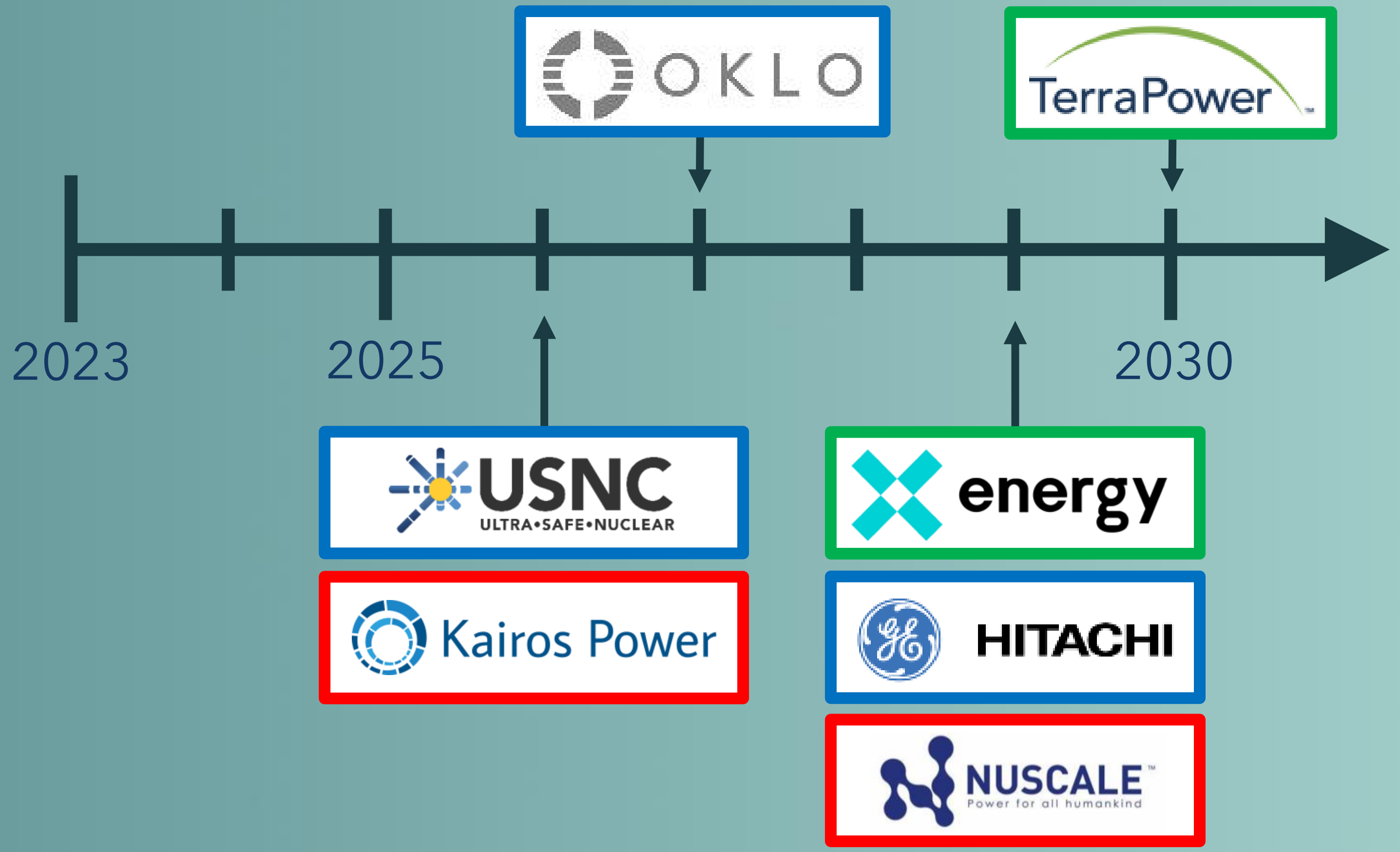
US, Canadian, and UK utility partners and industrial energy users have expressed interest in deploying advanced nuclear energy

ONTARIO POWER GENERATION
DUKE ENERGY®
Bruce Power™
UAMPS
SMARTENERGY℠
PACIFICORP
Southern Company
EDF ENERGY
Constellation℠
DOW
TVA

Public-private partnerships are accelerating the demonstration and deployment of advanced reactors in the U.S. and Canada

U.S. Partnerships with Private Companies

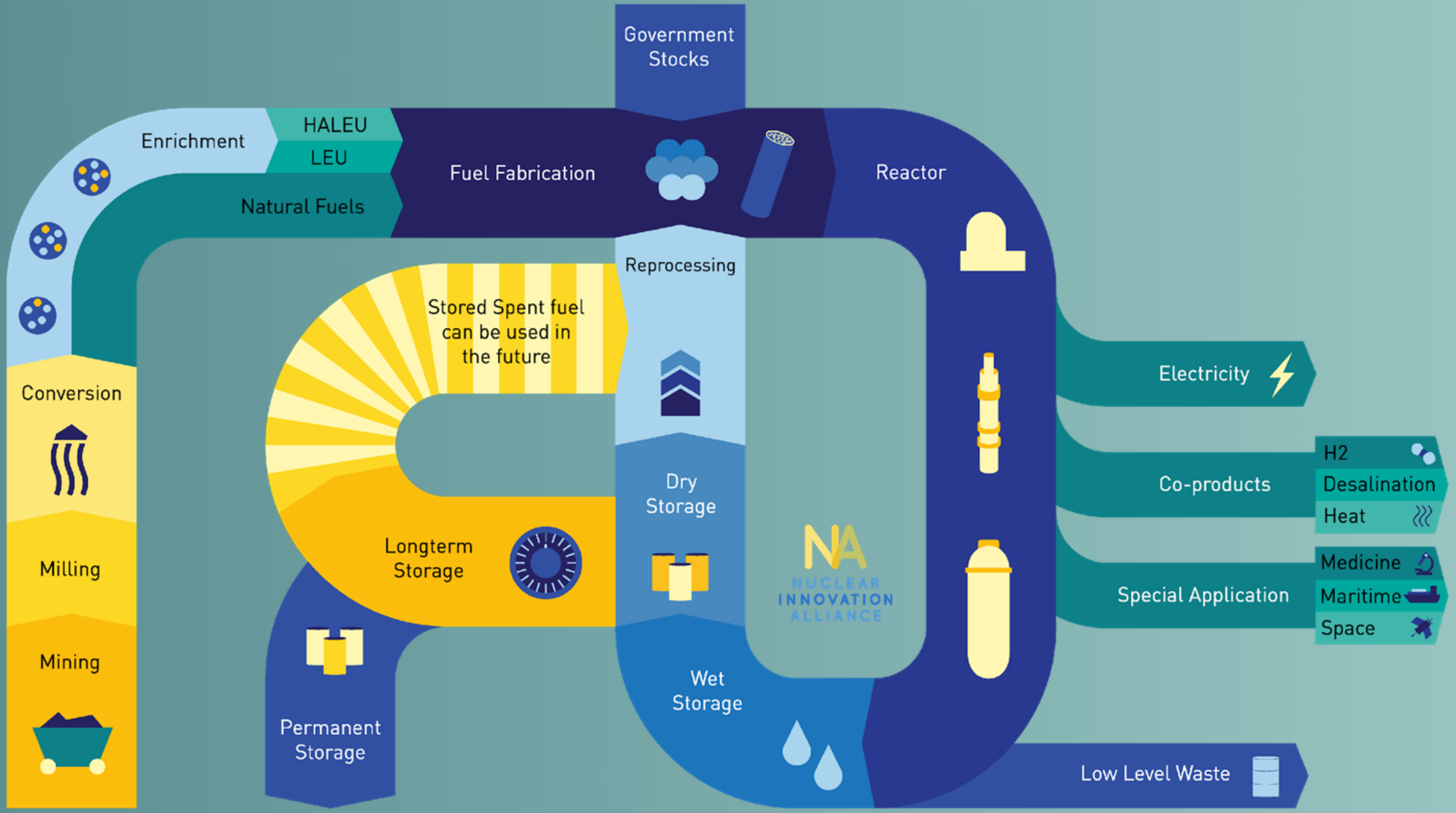
- Advanced reactor demonstration award
- Advanced reactor development award
- Enabling technology development award



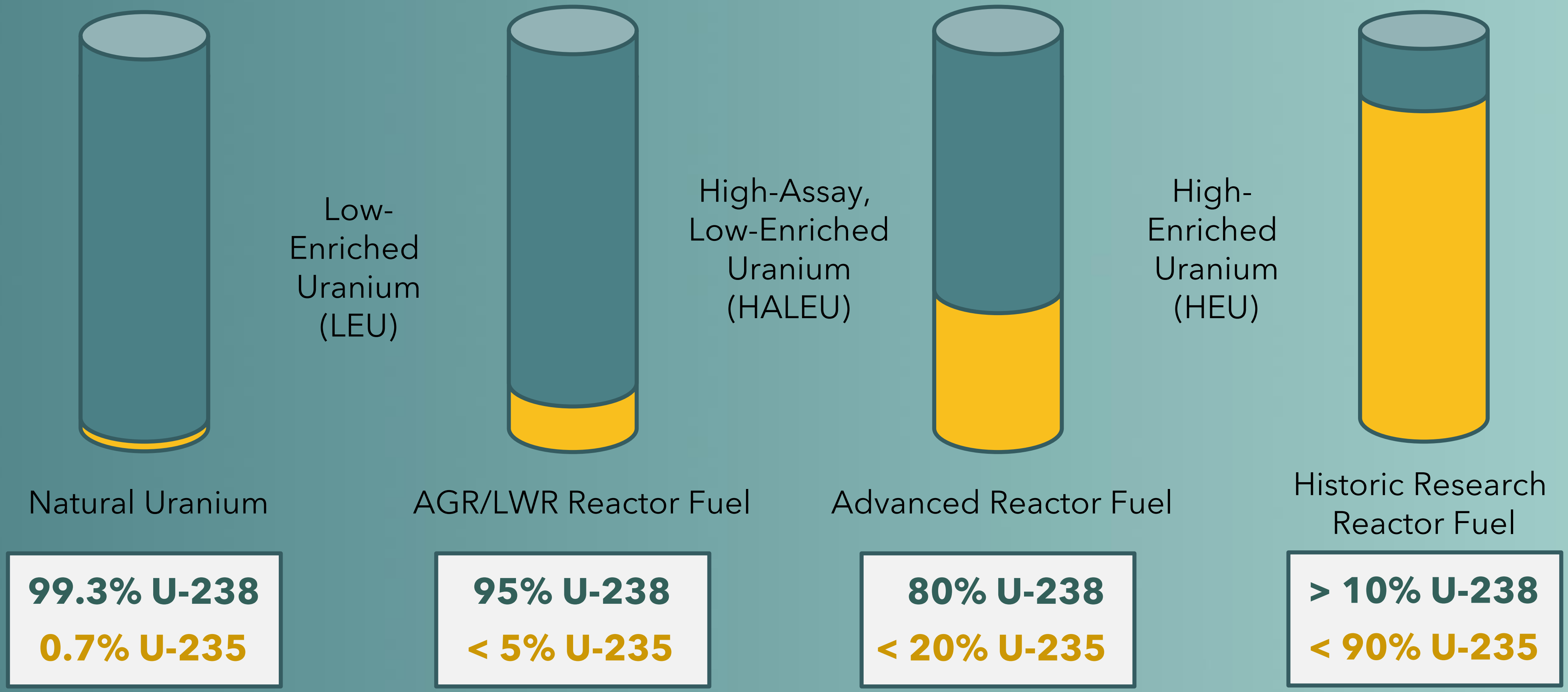
Over 60 companies around the world are in the process of developing commercial advanced reactor technologies

arc CLEAN TECHNOLOGY
GENERAL ATOMICS
NATIONAL NUCLEAR LABORATORY
TerraPower
BWXT BWX Technologies, Inc.
HOLTEC INTERNATIONAL
NUSCALE™ Power for all humankind
TERRESTRIAL ENERGY
U BATTERY® Local Modular Energy
Kairos Power
OKLO
USNC ULTRA•SAFE•NUCLEAR
framatome
LAST ENERGY
RADIANT
Westinghouse
GE HITACHI
moltex clean energy
Rolls-Royce®
X energy®

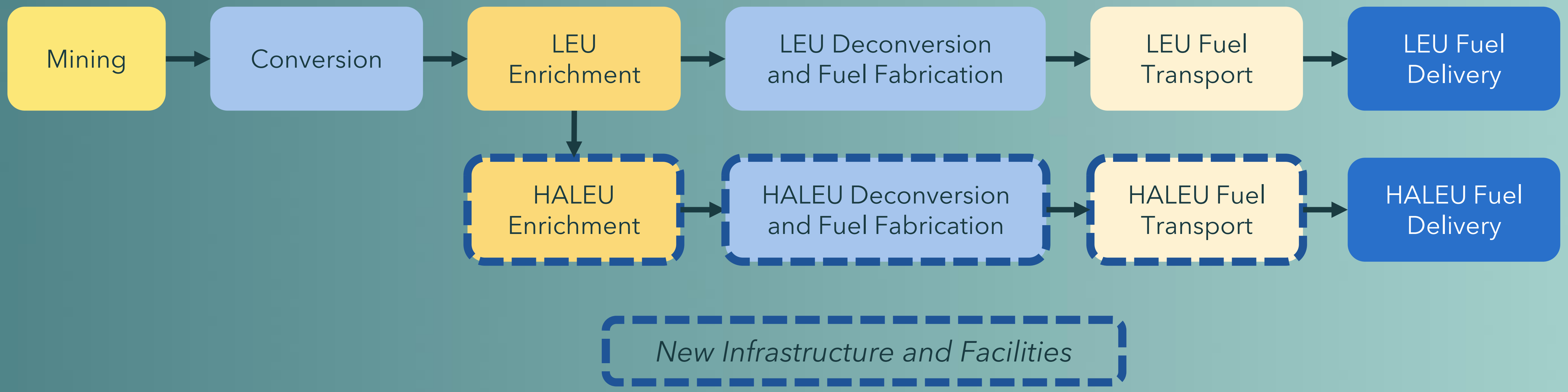
Advanced reactor commercialization requires coordination and planning across all stages of a sustainable fuel cycle



Some advanced reactor technologies will require nuclear fuel cycles with higher uranium enrichment levels



Advanced reactors that require HALEU or recycled fuels will need new fuel cycle infrastructure and facilities



Long-term solutions for used fuel disposal are still needed but advanced reactors can improve challenges of nuclear waste

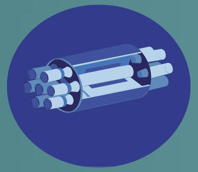
Advanced Reactor Technologies and Fuel Forms

Short term storage

TRISO Fuel

Robust fuel forms can significantly reduce fuel storage hazards

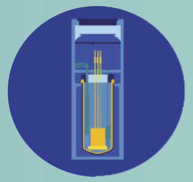
Interim storage



Microreactors

Factory fueling of transportable reactors can centralize spent fuel management

Fuel recycling



Fast reactors

Fast reactors can enable fuel recycling without isotope separation

Long term isolation

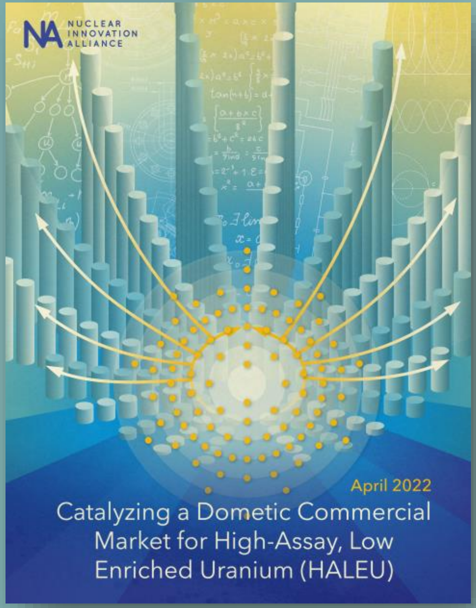
Molten salt reactors

More efficient fuel utilization can reduce long-term spent fuel volumes

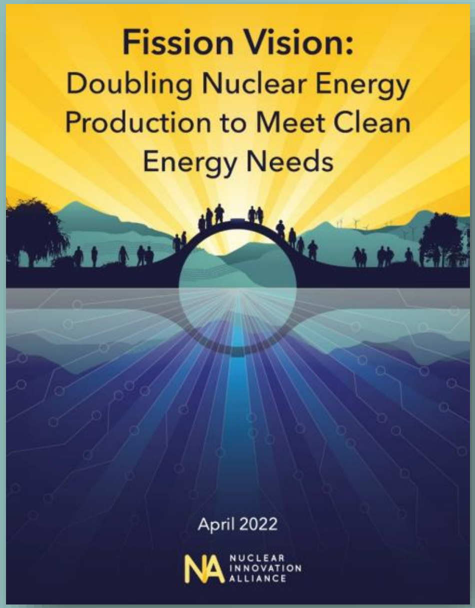
Stakeholders can get up to speed on the development and deployment of advanced nuclear energy

Advanced Nuclear Primer
March 2023 Update
Download

Advanced Nuclear Compendium
July 2022
Download



HALEU Fuel Availability
April 2022
Download



Fission Vision
April 2022
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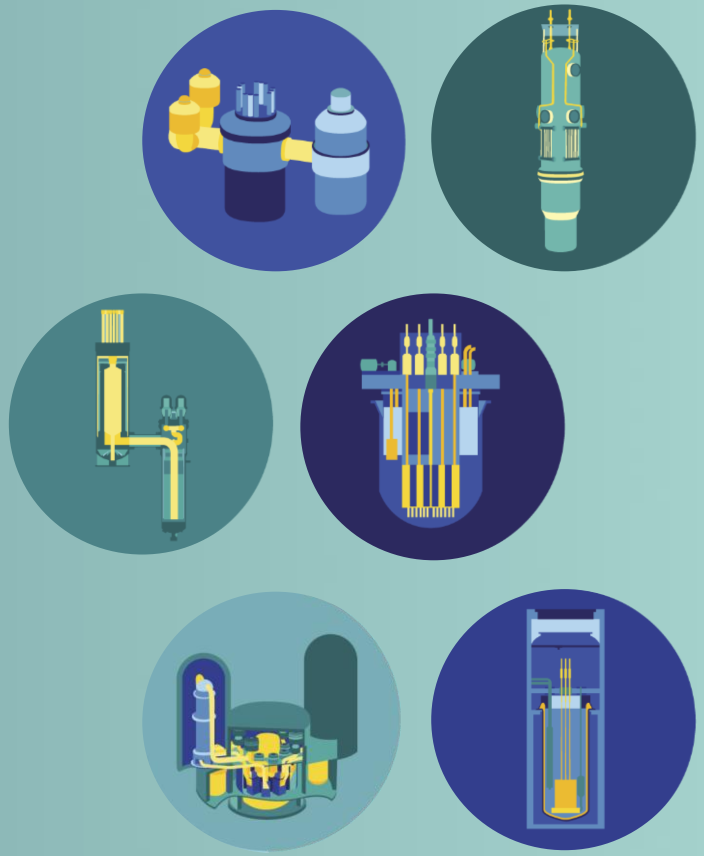
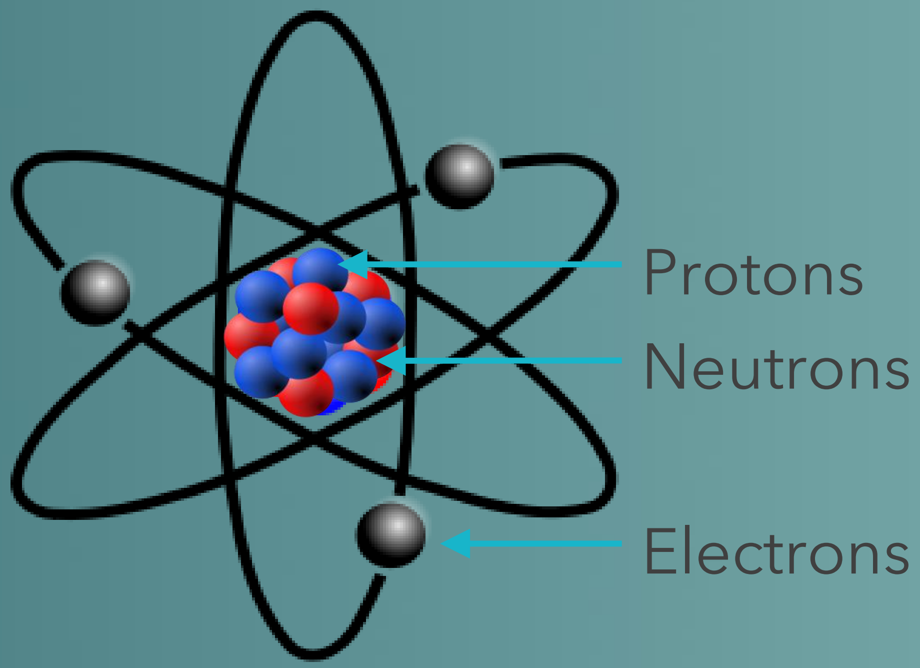
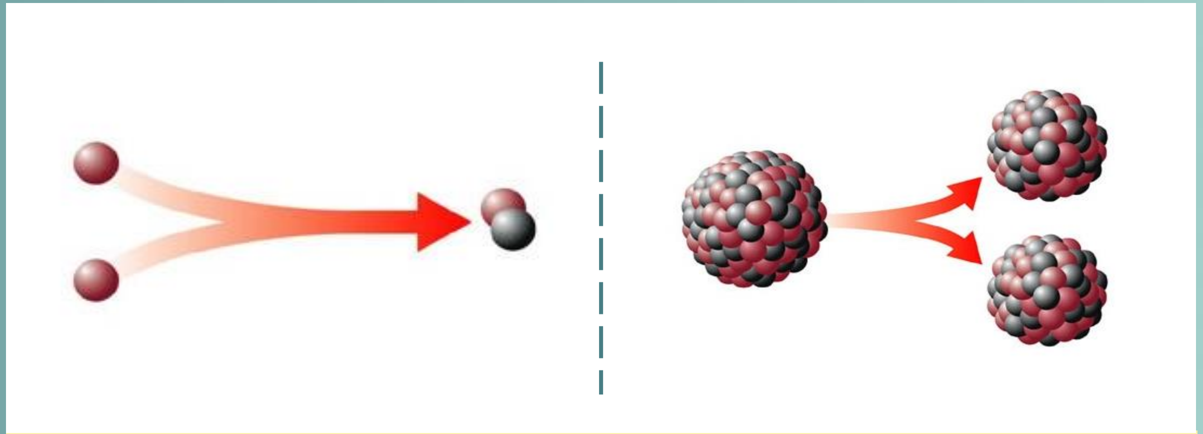


Supplemental Slides on Commercial **Fission** Energy

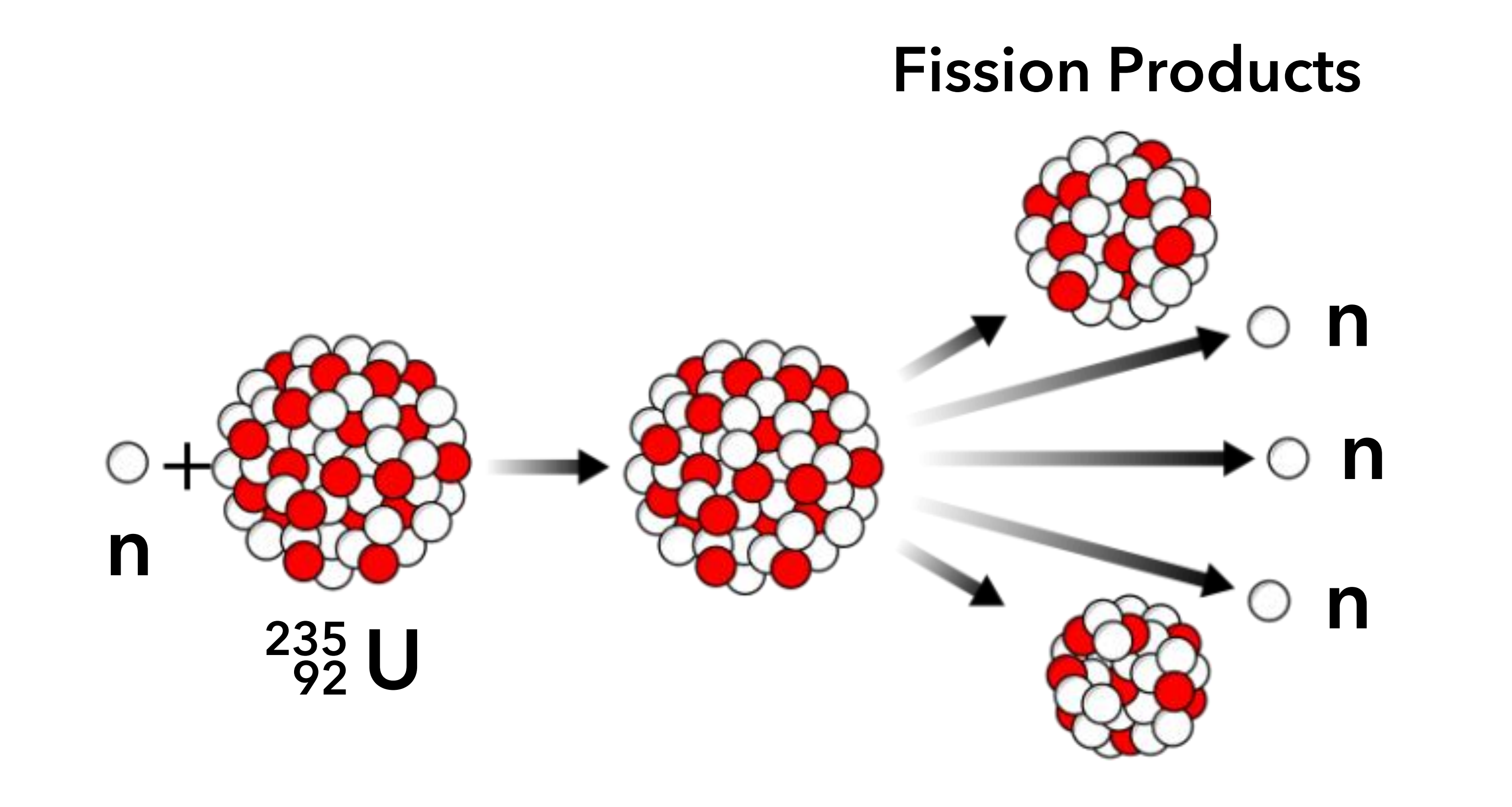
Nuclear reactions release energy stored in the bonds of the nucleus of an atom without releasing greenhouse gases





Chemical combustion reaction:	4 eV
Nuclear fusion reaction:	17,600,000 eV
Nuclear fission reaction:	200,000,000 eV

Nuclear fission is the splitting of atoms in a controlled chain reaction to release large amounts of energy and more neutrons

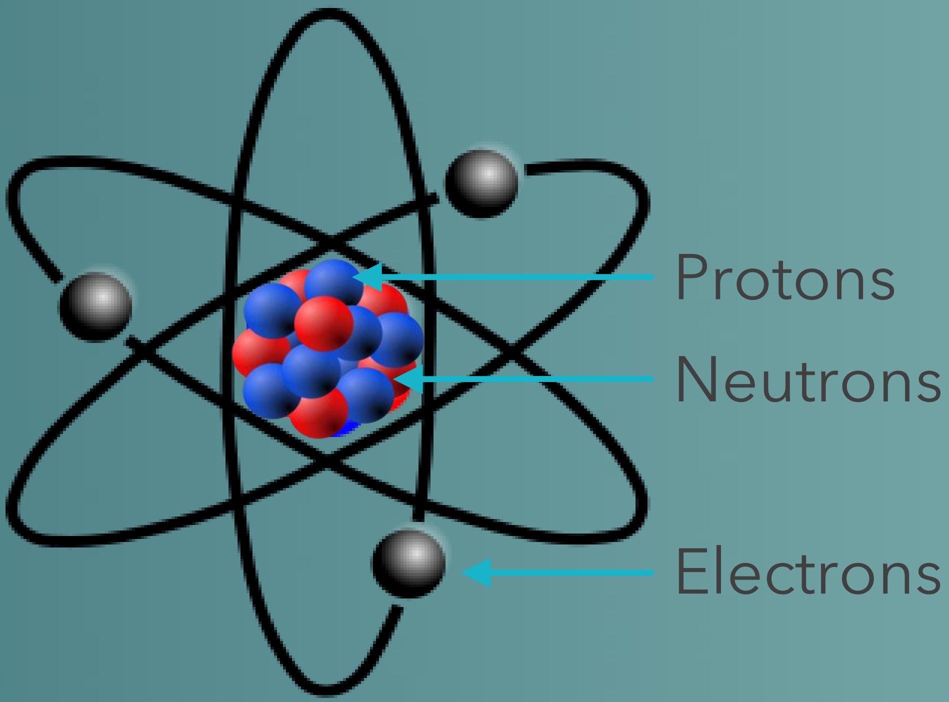


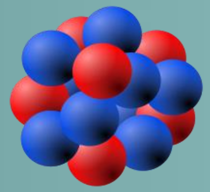
Example Fission Reaction

Sustained fission reactions requires:

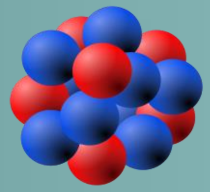
- Sufficient presence of fission fuels
- Minimal neutron absorbing materials
- Correct nuclear fuel configuration

Different uranium isotopes have very different nuclear properties based on slightly different number of neutrons



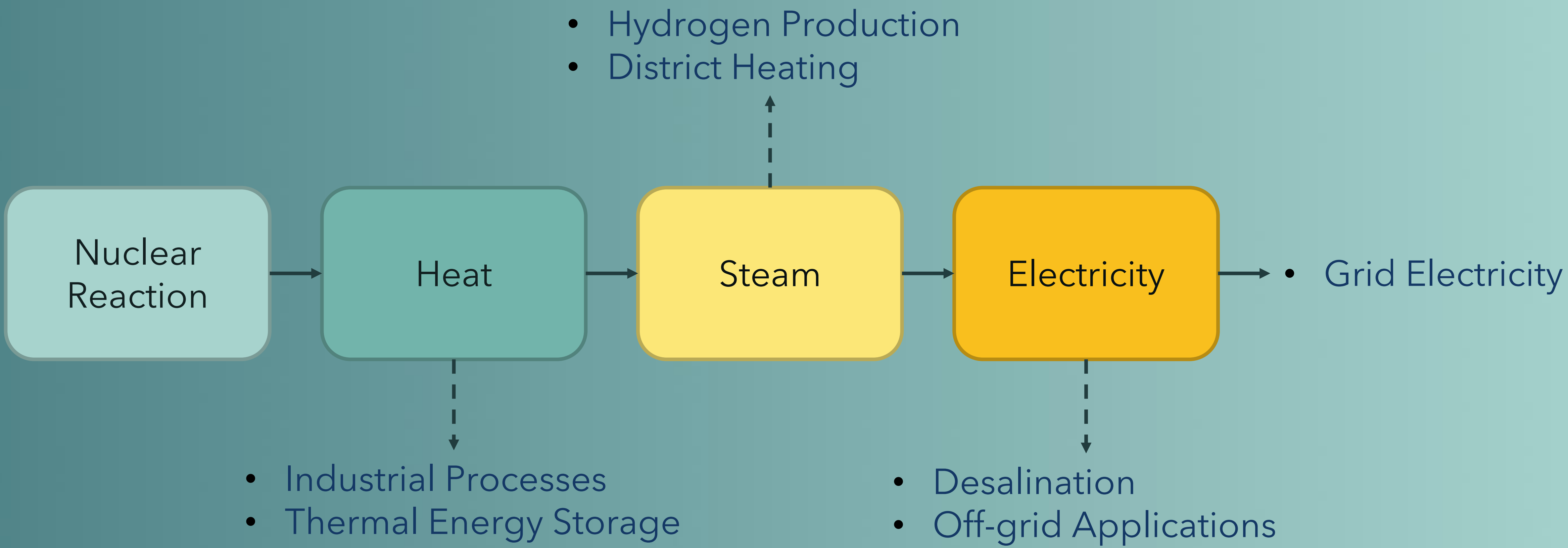


Uranium 238 –
92 Protons, 146 Neutrons
99.3% of Natural Uranium

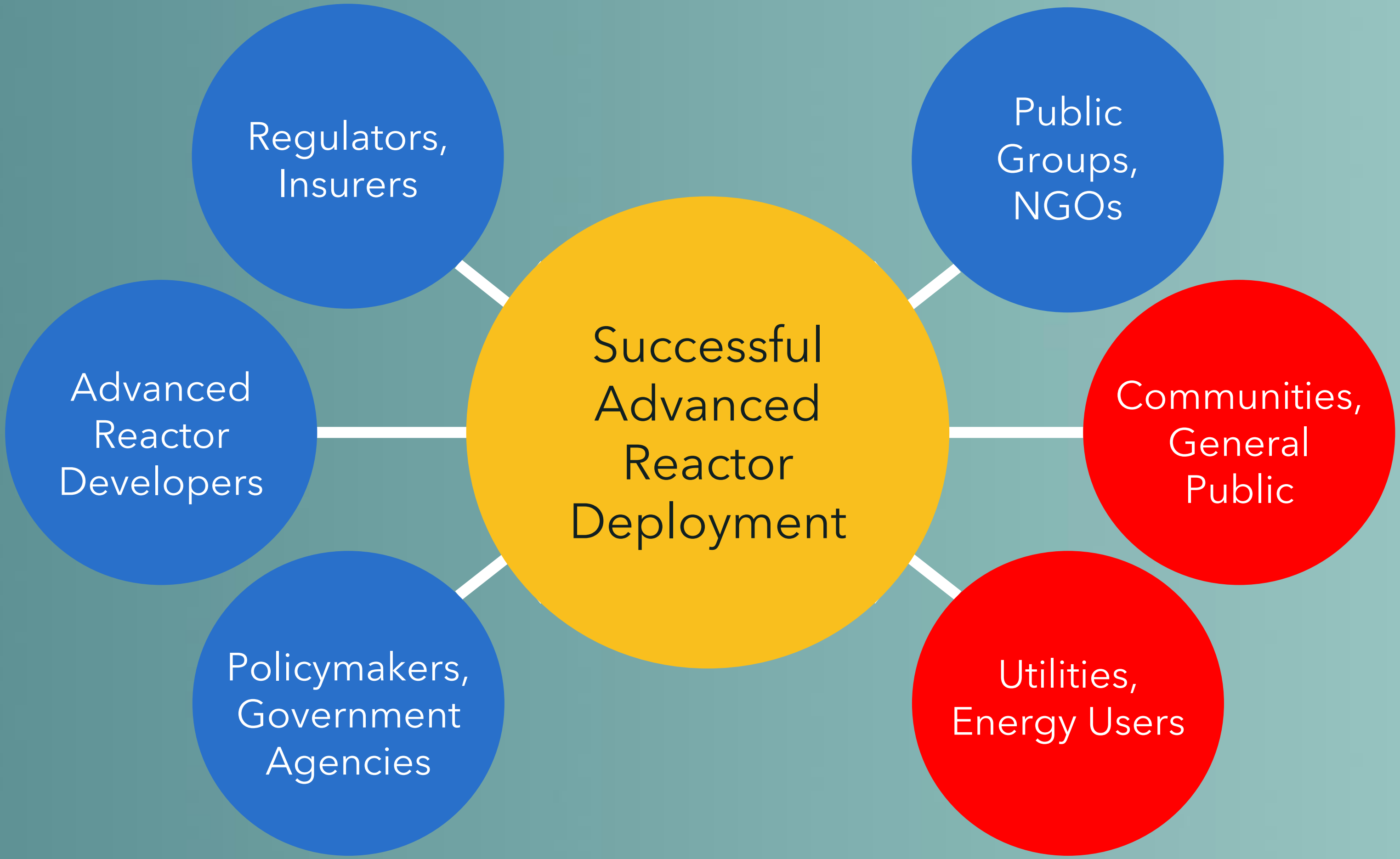


Uranium 235 –
92 Protons, 143 Neutrons
0.7% of Natural Uranium

Nuclear power plants convert energy from nuclear reactions into usable electricity, steam, and process heat



Alignment between stakeholders is critical to the development and deployment of new nuclear energy



Timeline for advanced nuclear energy deployment will vary based on reactor technology and prior project experience

	Planning & Siting	Licensing	Construction	Operation
Example First-of-a-kind Timeline	3 – 4 Years	4 – 6 Years	3 – 10 Years ($8,000/kWe)	40 + Years
Example Nth-of-a-kind Timeline	1 – 2 Years	2 – 3 Years	2 – 3 Years ($4,000/kWe)	40 + Years

Success of new advanced reactor projects will depend on project performance by companies and utilities