EPRI Perspectives on Fusion Energy Technology

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Fusion Power Associates
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Electric Power Research Institute…Born in a Blackout

- Mission: advancing ***safe***, ***reliable***, ***affordable*** and ***environmentally responsible*** electricity for society

- Independent, nonprofit center for ***collaborative*** public interest energy and environmental research

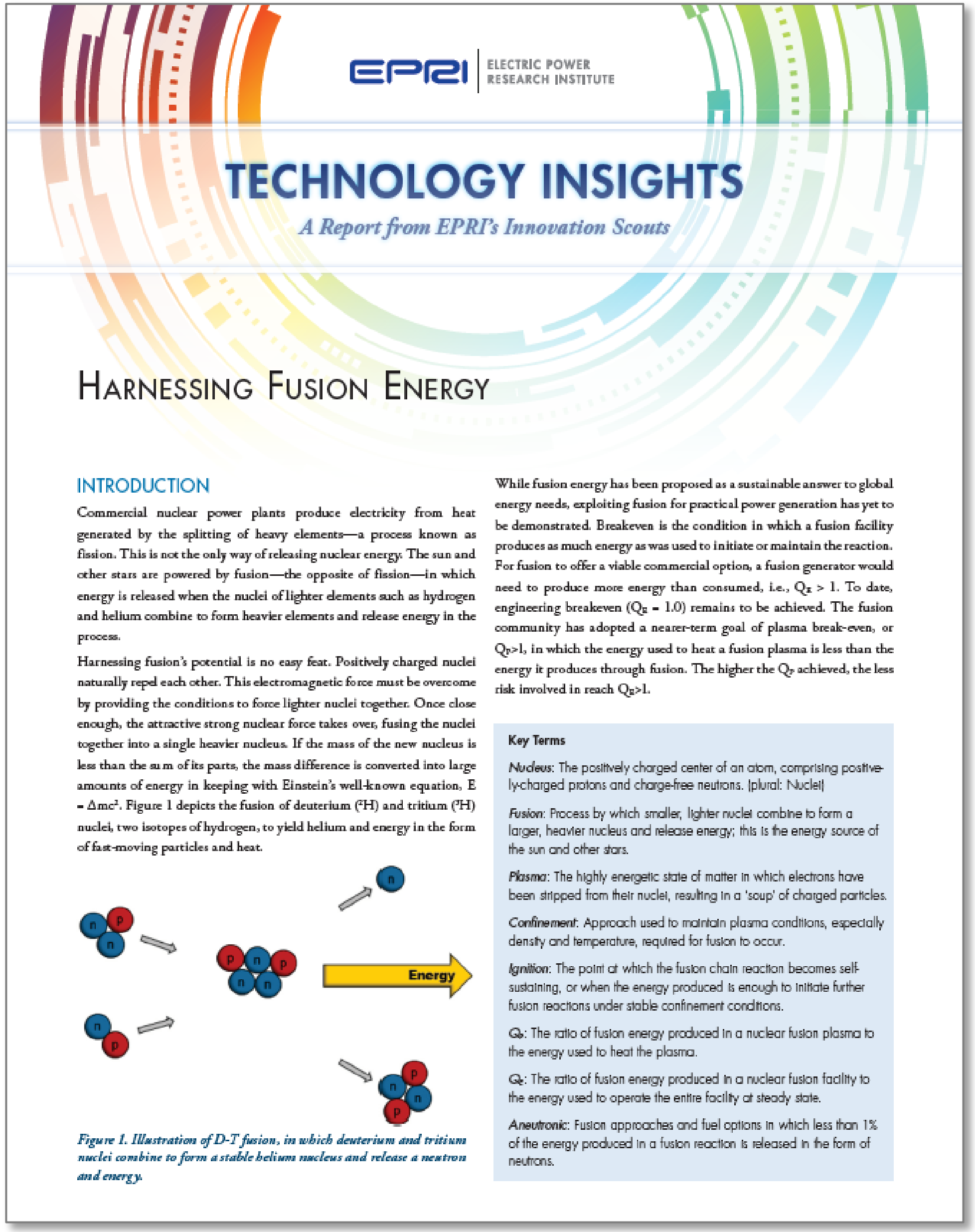
- Major offices in Palo Alto, CA, Charlotte, NC, and Knoxville, TN
  - Laboratories in Knoxville, Charlotte and Lenox, MA
  - In-country presence around the world

New York City: The Great Northeast Blackout, 1965

- International membership and reach:
  - Nearly 40 countries participate in EPRI overall research, development, and demonstration activities
  - International members > 25% of EPRI research (50% for nuclear)
  - EPRI members generate > 90% of the electricity in the United States (100% of US nuclear)

EPRI’s Return to Fusion

- Increasing engagement with U.S. DOE INFUSE and ARPA-E programs and other stakeholders
- Fusion Industry Association affiliate membership
- Internal, cross-sector Technology Innovation program support
  - Fusion technology scouting
  - Staff training
  - Fusion interest group



EPRI | ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI’s Innovation Scouts

HARNESSING FUSION ENERGY

INTRODUCTION

Commercial nuclear power plants produce electricity from heat generated by the splitting of heavy elements—a process known as fission. This is not the only way of releasing nuclear energy. The sun and other stars are powered by fusion—the opposite of fission—in which energy is released when the nuclei of lighter elements such as hydrogen and helium combine to form heavier elements and release energy in the process.

Harnessing fusion’s potential is no easy feat. Positively charged nuclei naturally repel each other. This electromagnetic force must be overcome by providing the conditions to force lighter nuclei together. Once close enough, the attractive strong nuclear force takes over, fusing the nuclei together into a single heavier nucleus. If the mass of the new nucleus is less than the sum of its parts, the mass difference is converted into large amounts of energy in keeping with Einstein’s well-known equation, $E = \Delta mc^2$. Figure 1 depicts the fusion of deuterium (^2H) and tritium (^3H) nuclei, two isotopes of hydrogen, to yield helium and energy in the form of fast-moving particles and heat.

Figure 1. Illustration of D-T fusion, in which deuterium and tritium nuclei combine to form a stable helium nucleus and release a neutron and energy.

While fusion energy has been proposed as a sustainable answer to global energy needs, exploiting fusion for practical power generation has yet to be demonstrated. Breakeven is the condition in which a fusion facility produces as much energy as was used to initiate or maintain the reaction. For fusion to offer a viable commercial option, a fusion generator would need to produce more energy than consumed, i.e., $Q_E > 1$. To date, engineering breakeven ($Q_E = 1.0$) remains to be achieved. The fusion community has adopted a nearer-term goal of plasma break-even, or $Q_P > 1$, in which the energy used to heat a fusion plasma is less than the energy it produces through fusion. The higher the Q_P achieved, the less risk involved in reach $Q_E > 1$.

Key Terms

Nucleus: The positively charged center of an atom, comprising positively-charged protons and charge-free neutrons. (plural: Nuclei)

Fusion: Process by which smaller, lighter nuclei combine to form a larger, heavier nucleus and release energy; this is the energy source of the sun and other stars.

Plasma: The highly energetic state of matter in which electrons have been stripped from their nuclei, resulting in a ‘soup’ of charged particles.

Confinement: Approach used to maintain plasma conditions, especially density and temperature, required for fusion to occur.

Ignition: The point at which the fusion chain reaction becomes self-sustaining, or when the energy produced is enough to initiate further fusion reactions under stable confinement conditions.

Q_P: The ratio of fusion energy produced in a nuclear fusion plasma to the energy used to heat the plasma.

Q_E: The ratio of fusion energy produced in a nuclear fusion facility to the energy used to operate the entire facility at steady state.

Aneutronic: Fusion approaches and fuel options in which less than 1% of the energy produced in a fusion reaction is released in the form of neutrons.

Harnessing Fusion Energy. EPRI, Palo Alto, CA: 2020. 3002020065.
https://www.epri.com/research/products/000000003002020065

EPRI

EPRI Fusion Forum

- Formal launch of new fusion technology interest group in 2021
  - An EPRI Technology Innovation thought leadership initiative

- Objectives:
  - Introduce EPRI and its members (utilities, et al.) to the fusion community
  - Introduce fusion community (and technology) to EPRI and its members

- Four sessions in 2021 spanning:
  - Owner-operator perspective from two utilities
  - Technology updates from three private sector developers
  - Relevant EPRI R&D programs, products, and activities
  - Potential opportunities for collaboration

Planning is underway for 2022

Your input is welcome and encouraged!

Let's Collaborate.
How Can EPRI Help?

Leveraging Existing EPRI Experience and Expertise
(How Much Applies?)

Engineering, Construction, and Project Management

Power Conversion

Mission, Products, Markets, Economics, and Integration

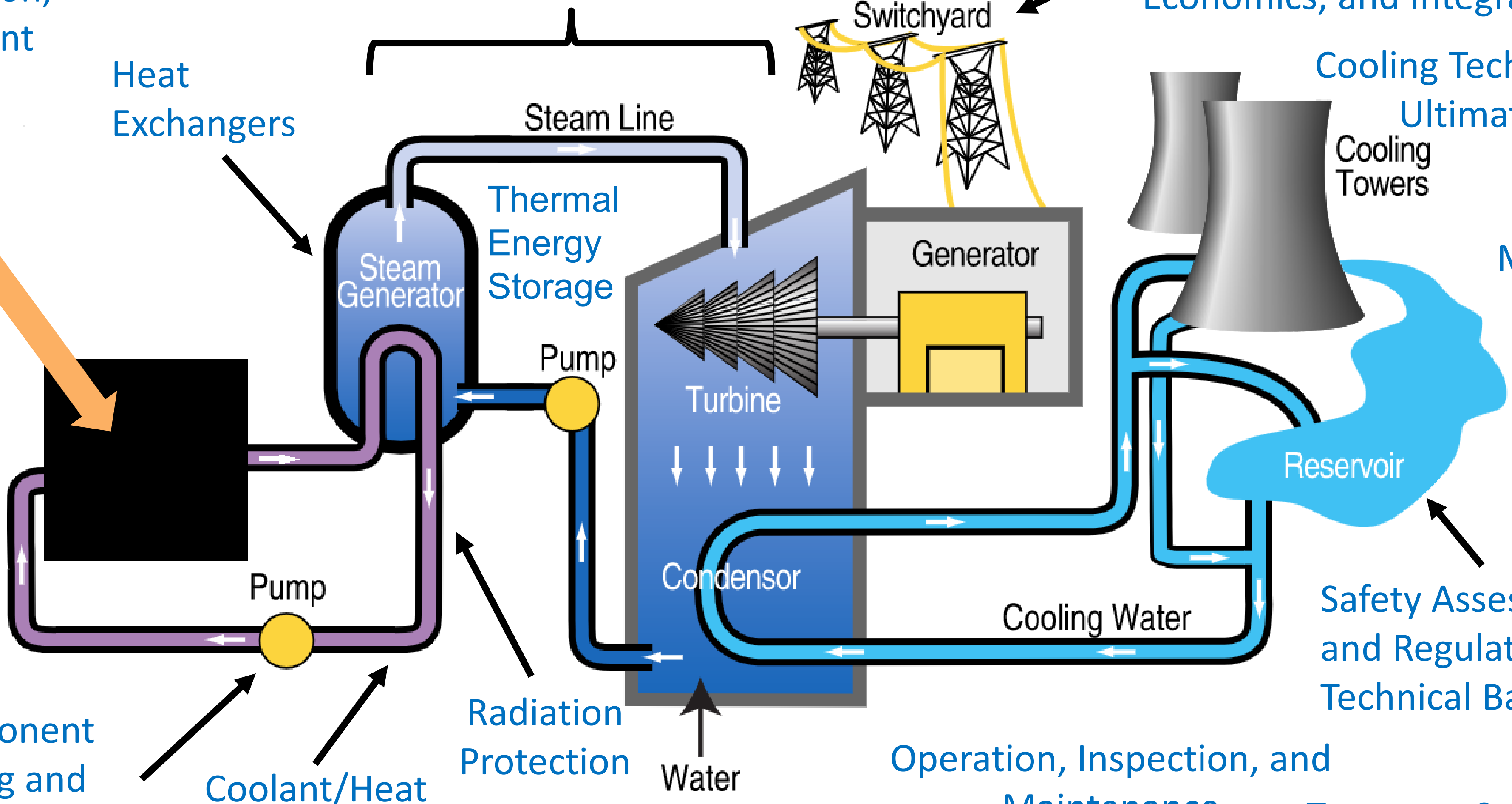
Heat Exchangers

Cooling Technology and Ultimate Heat Sink

Your Heat Source Here

Thermal Energy Storage

Waste Management



Materials, Manufacturing, and Code Qualification

Safety Assessment and Regulatory Technical Basis

Component Testing and Qualification

Coolant/Heat Transfer Chemistry

Radiation Protection

Operation, Inspection, and Maintenance

Turnover, Commissioning and Initial Operations

Balance-of-Plant (BOP)

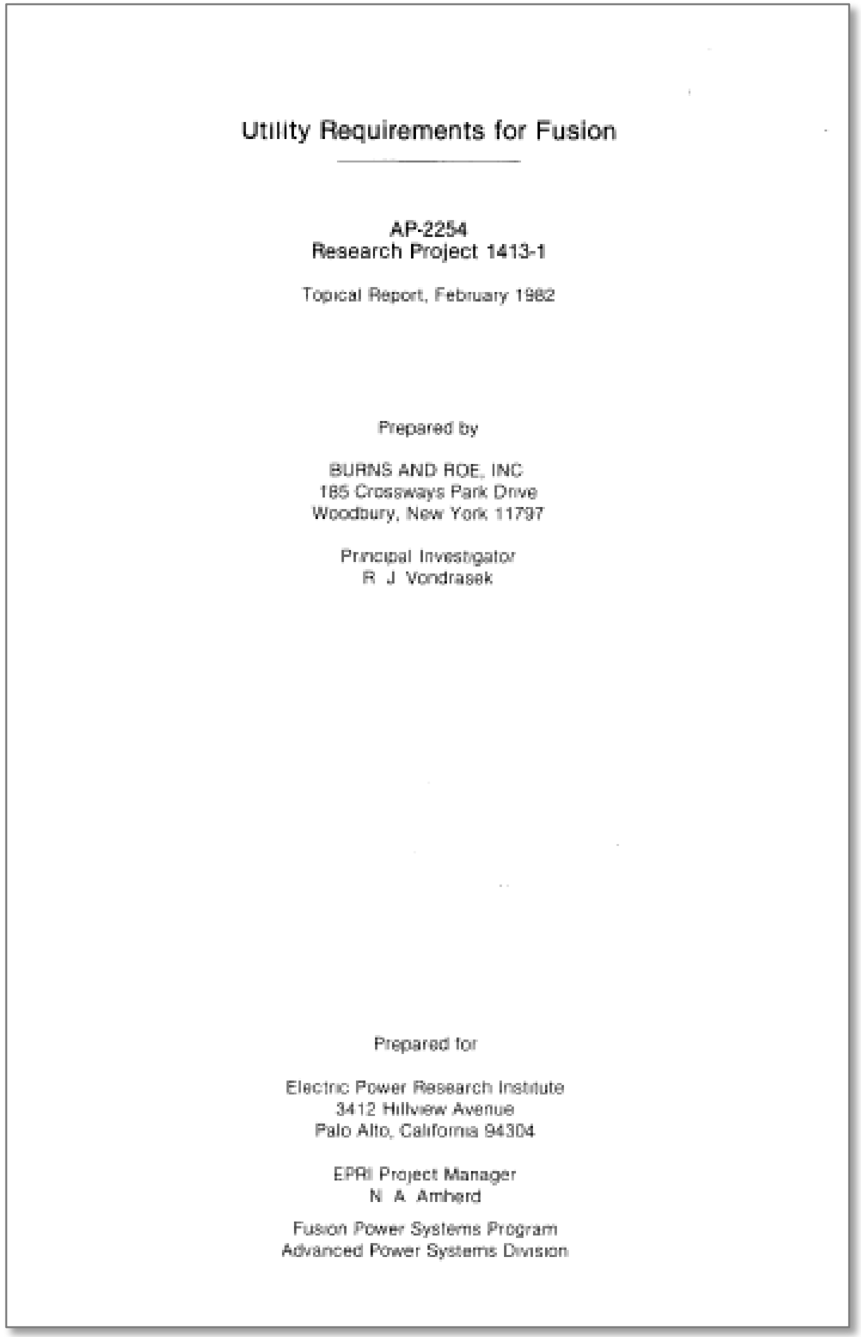
Adapted from image courtesy of TVA; Wikimedia Commons

Aligning Technologies with End-Users

- EPRI Utility Requirements Document (URD) played key role in $1 billion collaborative effort to bring a new generation of large advanced LWRs to market (1990s – 2000s)

- EPRI is now developing, maturing a high-level Owner-Operator Requirements Guide (ORG) for advanced fission

- **BUT**… EPRI supported development of utility requirements for fusion <u>first</u> beginning in 1982, emphasizing “timeless” criteria for the future:
  - Economics
  - Public Acceptance
  - Regulatory Simplicity



Utility Requirements for Fusion

AP-2254
Research Project 1413-1

Topical Report, February 1982

Prepared by

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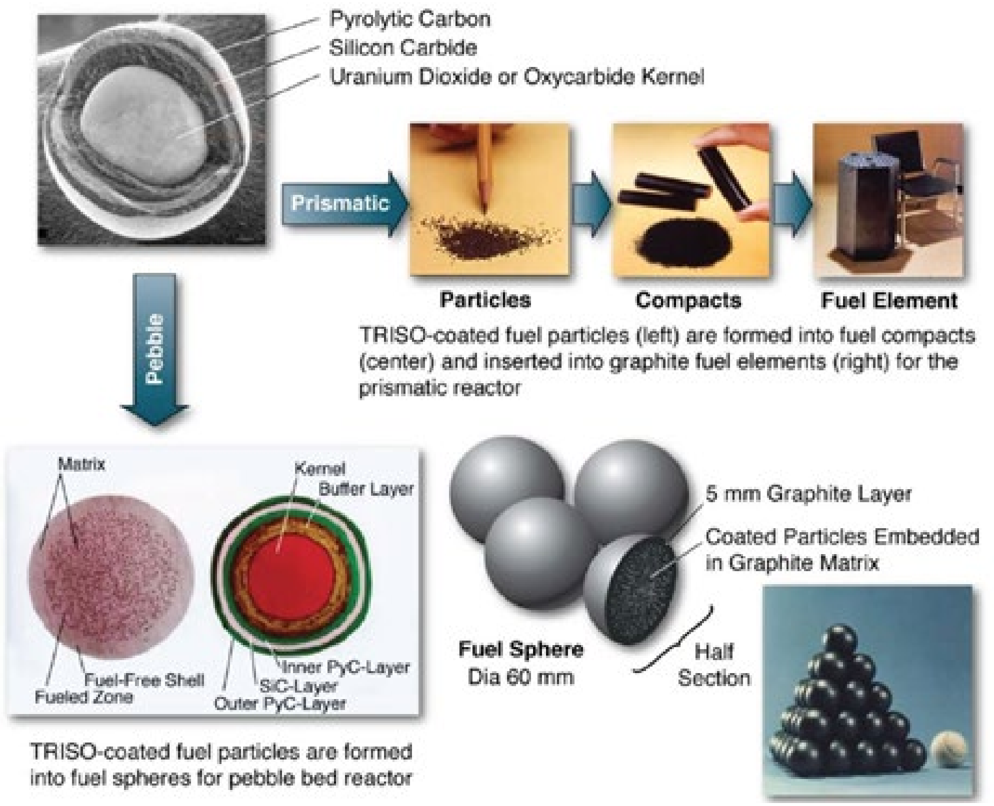
Advanced Power Systems Division

Journal of Fusion Energy, Volume 13, Nos. 2/3, 1994

Developing Technical Bases to Inform Regulation

Example: Approved 2020 EPRI TRISO Fuel Topical Report

- A collaborative EPRI-led project with EPRI and DOE co-funding, core INL technical contribution, high temperature reactor community support, and strong NRC interest (incl. fee-waiver)
- A generic topical report to lock-in large public R&D investment in U.S. Advanced Gas Reactor (AGR) program on TRISO fuel performance for qualification
- **Revised, approved topical report published November 2020**
  - *Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance: Topical Report EPRI-AR-1(NP)-A*. EPRI, Palo Alto, CA: November 2020. 3002019978.

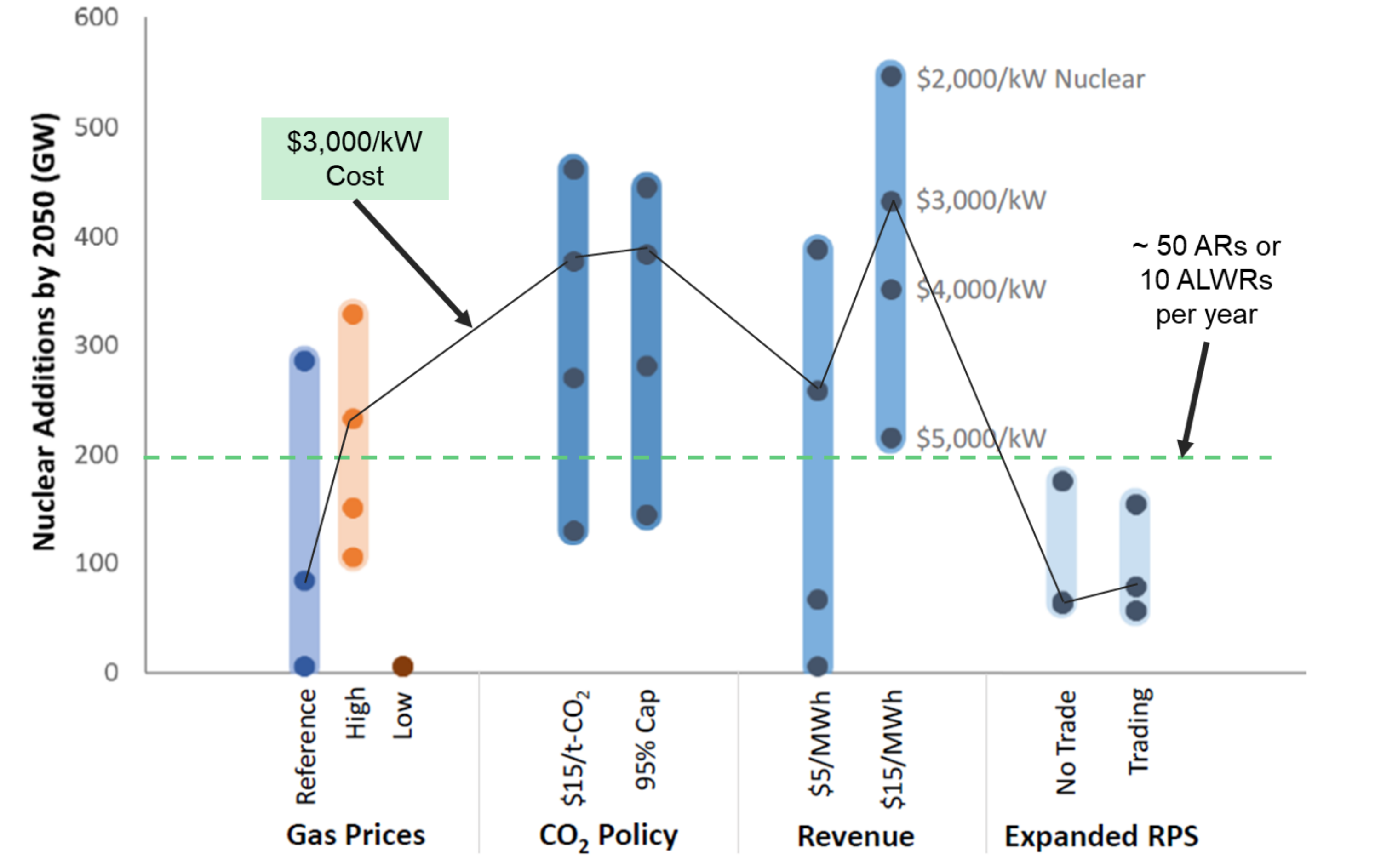


- **Submitted to NRC on May 31, 2019**
- **Briefed to ACRS in May and July 2020**
- **NRC issues SER on August 11, 2020**

What methods, data, topics would generically benefit fusion via regulatory review?

Technoeconomic Assessment of Advanced Generation

Exploring the Role of Advanced Nuclear in Future Energy Markets. March 2018, Report 3002011803



Key drivers influencing deployment:

- Competition (technology)
- Capital costs
- Revenue
- Regional factors
- Energy and environmental policies

Cumulative nuclear additions through 2050 (GW) across a range of sensitivities (horizontal axis) and nuclear capital costs (dots)

Fusion *looks* like fission in economic modeling and market analysis.

Rethinking Deployment Scenarios for Advanced Reactors

Scalable Nuclear Energy for Zero-Carbon Synthetic Fuels and Products

Technical Brief — Advanced Nuclear Technology 3002018348

#	Scenario	Product	Resource Being Substituted	Deployment Setting and Model	Compatibility with Existing Infrastructure†	Major Changes Required†
1	Ammonia production for marine shipping fuel	Carbon-free ammonia (NH_3)	Shipping fuel	Offshore (FPSO)	Medium – High	Ammonia burning engines compatible storage and distribution
2	Commercial airline fuel production	Net-zero Jet A	Fossil Jet A	Offshore (FPSO)	High	None
3	Ammonia, power, and desalinated water production for coastal cities	Carbon-free ammonia, electricity and desalinated water	Multiple	Offshore (FPSO)	Medium – High	Ammonia burning equipment compatible storage and distribution
4	Blending H_2 into existing gas network	Carbon-free hydrogen	Natural gas	Onshore (on-site fabrication, installation, and operation)	High if <20% of blend concentration	Upgrades needed for >15–20%

† Compatibility and required changes will vary for substitutes like ammonia depending on end-use, extent of adoption, location, among other factors. The characterizations provided are intended to indicate the relative ease of adoption with respect to changes required of producers and customers.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