Clean Nuclear Energy for Industry Part II: Advanced Nuclear Technologies

May 29, 2020

12:30 p.m. – 2:00 p.m. MDT

GAIN
Gateway for Accelerated Innovation in Nuclear

EPRI ELECTRIC POWER RESEARCH INSTITUTE

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Webinar Details

- Thank you for joining!
- If you have technical issues, please submit them through the *“Chat”* option on the GoToWebinar control panel
- Please enter all questions for speakers using the *“Questions”* option on the GoToWebinar control panel; questions can be entered throughout the webinar
- We will address questions after each set of speakers, followed by a general discussion session at the end of the webinar
- The webinar is expected to run approximately 90 minutes

Webinar Goals

- Highlight innovations in nuclear energy and associated integrated-energy options that may be beneficial to a wide range of industrial energy applications
- Introduce unique capabilities of advanced nuclear technology concepts, highlighting key operational features, options to support industrial users, and potential deployment timelines
- Initiate a discussion on requirements, considerations and concerns for energy system planning at “end use” facilities

Webinar Introduction
Integrated Energy Systems

Dr. Shannon Bragg-Sitton

Lead, Integrated Energy Systems
Nuclear Science & Technology
Idaho National Laboratory

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DESIGNING OUR FUTURE ENERGY SYSTEMS

What goals are we trying to achieve?

How will energy be used?

What role(s) can each energy source fill?

IES
Integrated Energy Systems

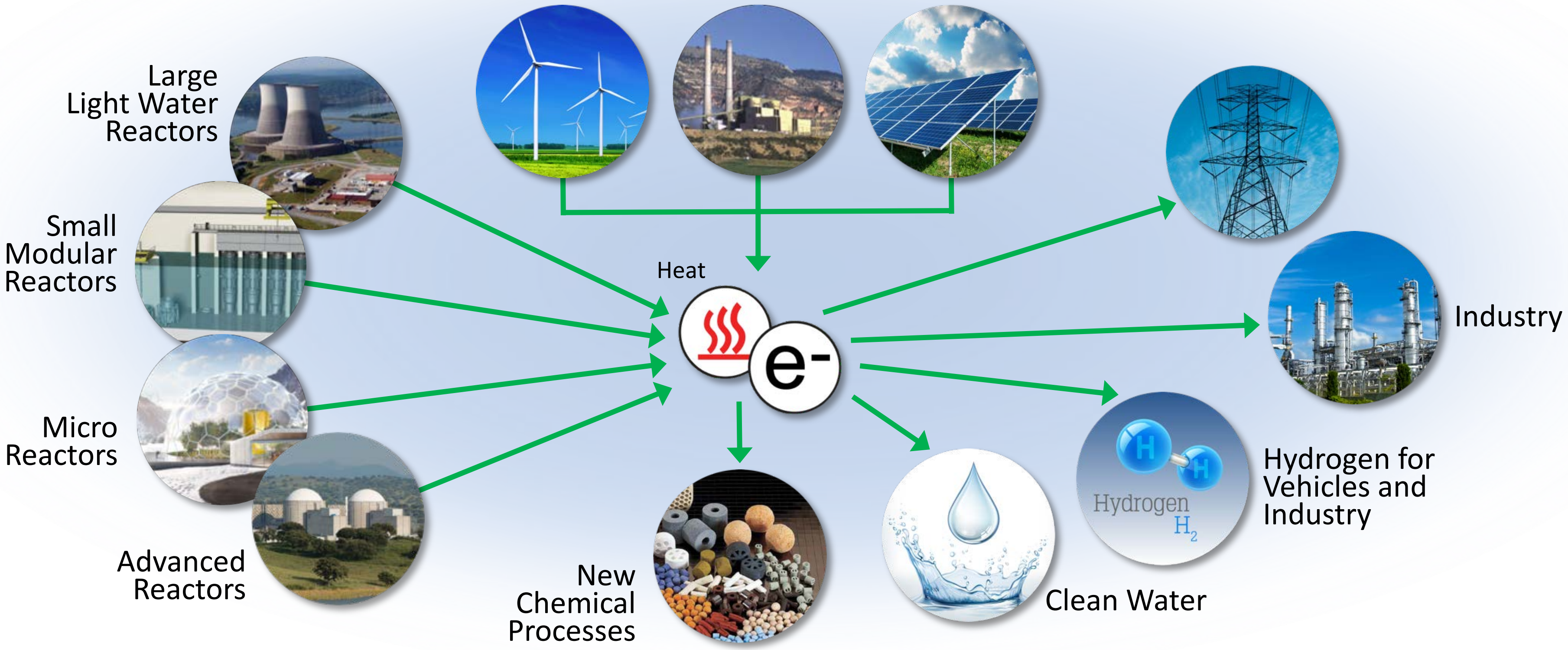
Integrated Energy Systems: A Key Opportunity

Today

Electricity-only focus

Potential Future Energy System

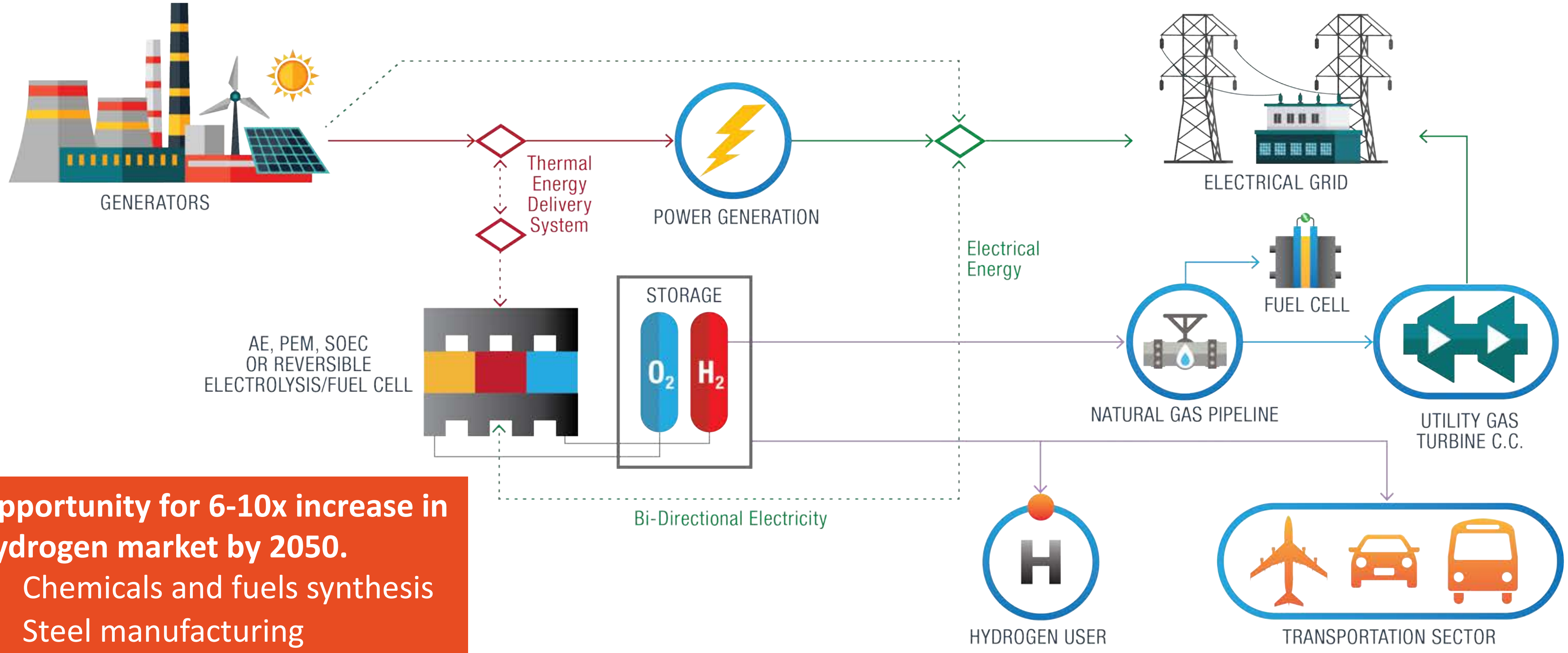
Integrated grid system that maximizes contributions from carbon-free energy generation for electricity, industry, and transportation



Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design

IES Integrated Energy Systems

Example: Hydrogen Production via Electrolysis



For details on upcoming LWR-H_2 demonstrations, see Part I of the Clean Nuclear Energy for Industry webinar series at https://gain.inl.gov/SitePages/GAINWebinarSeries.aspx

Opportunity for 6-10x increase in hydrogen market by 2050.

- Chemicals and fuels synthesis
- Steel manufacturing
- Ammonia-based fertilizers

1) Provides second source of revenue
2) Provides energy storage, for electricity production or hydrogen user
3) Provides opportunity for grid services, including reserves and grid regulation

IES Integrated Energy Systems

Meeting future **CLEAN** energy needs

Image courtesy of GAIN and ThirdWay, inspired by *Nuclear Energy Reimagined* concept led by INL.

Download this and other energy park concept images at:
https://www.flickr.com/photos/thirdwaythinktank/sets/72157665372889289/

Molten Salt Reactor Technologies

Lauren Lathem

Chair, MSR Technology Working Group

Senior Research Engineer
Advanced Energy Systems
Southern Company

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MOLTEN SALT REACTOR TECHNOLOGY WORKING GROUP

LAUREN LATHEM

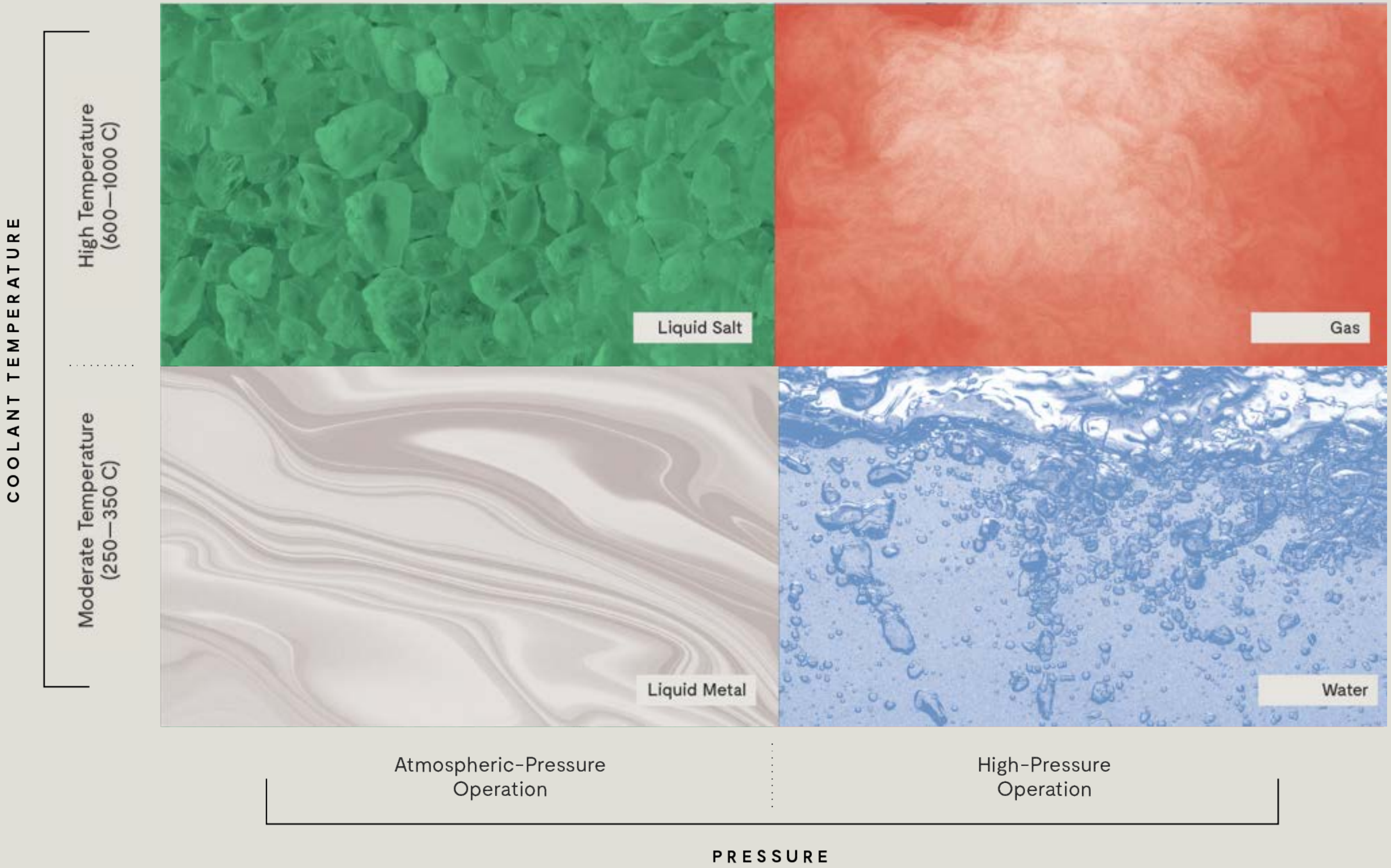
Southern Company

Fast	vs	Thermal
Breeder		Burner
Liquid Fuel		Solid Fuel
Thorium		Uranium

COOLANT CHOICE

Salt, Water, Gas, Metal

Coolant Choices for Nuclear Reactors →



MSR Design Space →

Molten Salt Reactor TWG →

ONE

Terra Power

Fast
Breeder
Liquid Fuel
Salt Cooled
Uranium
(Could use Th)

TWO

Thorcon

Thermal
Burner
Liquid Fuel
Salt Cooled
Thorium

THREE

Terrestrial Energy

Thermal
Burner
Liquid Fuel
Salt Cooled
Uranium
(Could use Th)

FOUR

Flibe Energy

Thermal
Breeder
Liquid Fuel
Salt Cooled
Thorium

FIVE

Muons Inc.

Thermal
Burner
Liquid Fuel
Salt Cooled
Uranium

SIX

Elysium Industries

Fast
Breeder
Liquid Fuel
Salt Cooled
Uranium

SEVEN

Alpha Technology Corporation

Thermal
Breeder
Liquid Fuel
Salt Cooled
Thorium

Exelon. NEI NUCLEAR ENERGY INSTITUTE DUKE ENERGY. EPRI

MSR TWG

COLLABORATE ON TECHNOLOGY NEUTRAL TOPICS

- SALT PROPERTY MEASUREMENT
- FUEL QUALIFICATION
- MODELING AND SIMULATION TOOL DEVELOPMENT

EDUCATE AND BUILD RELATIONSHIPS

- MEET QUARTERLY
- PARTICIPATION NOT EXCLUSIVE TO MEMBERS

High Temperature Reactor Technologies

Peter Hastings

Chair, HTR Technology Working Group

Vice President
Regulatory Affairs & Quality
Kairos Power LLC

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HTR TWG

- HTR = High Temperature Reactor
  - Evolution of previous high-temperature gas reactor team
  - Common theme for technology is TRISO fuel
- TWG = Technology Working Group
  - Industry collaboration with other stakeholders
  - Coordinated under NEI and INL/GAIN

HTR TWG Membership

HTR - Simple Safe Secure

Kairos Power

X-energy

BWXT
BWX Technologies, Inc.

framatome

NuGen

STARCORE NUCLEAR

Southern Company

HolosGen™

USNC
ULTRA•SAFE•NUCLEAR

DUKE ENERGY®

NEI
NUCLEAR ENERGY INSTITUTE

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

INL
Idaho National Laboratory

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What is TRISO Fuel?

TRISO = TRi-structural ISOtropic particle fuel

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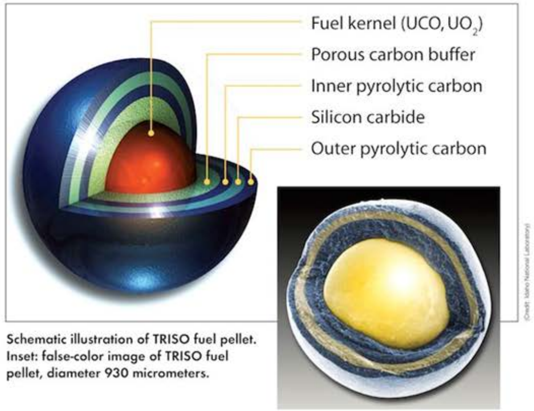
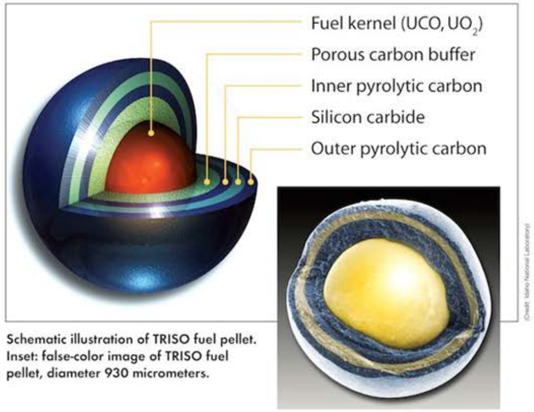


Schematic illustration of TRISO fuel pellet. Inset: false-color image of TRISO fuel pellet, diameter 930 micrometers.

What is TRISO Fuel?

HTR - Simple Safe Secure

TRISO = TRi-structural ISOtropic particle fuel



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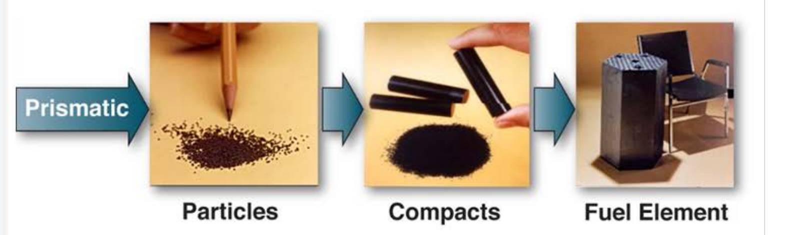

TRISO-coated fuel particles are formed into fuel compacts and inserted into graphite fuel elements for prismatic reactor

TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor

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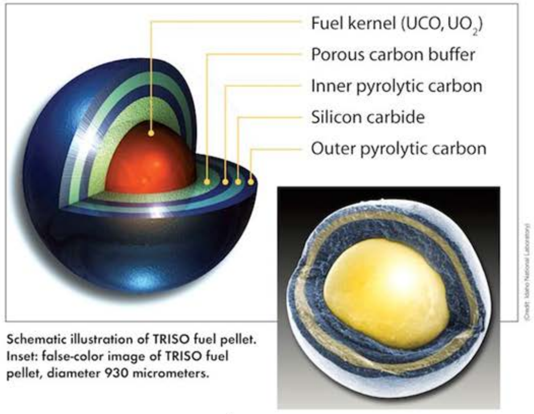

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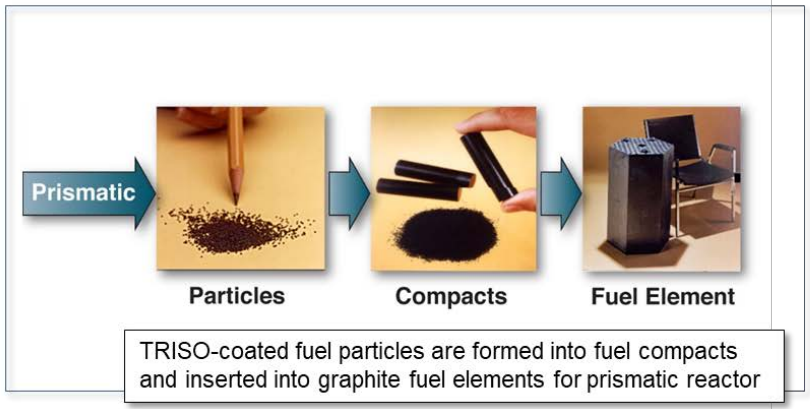
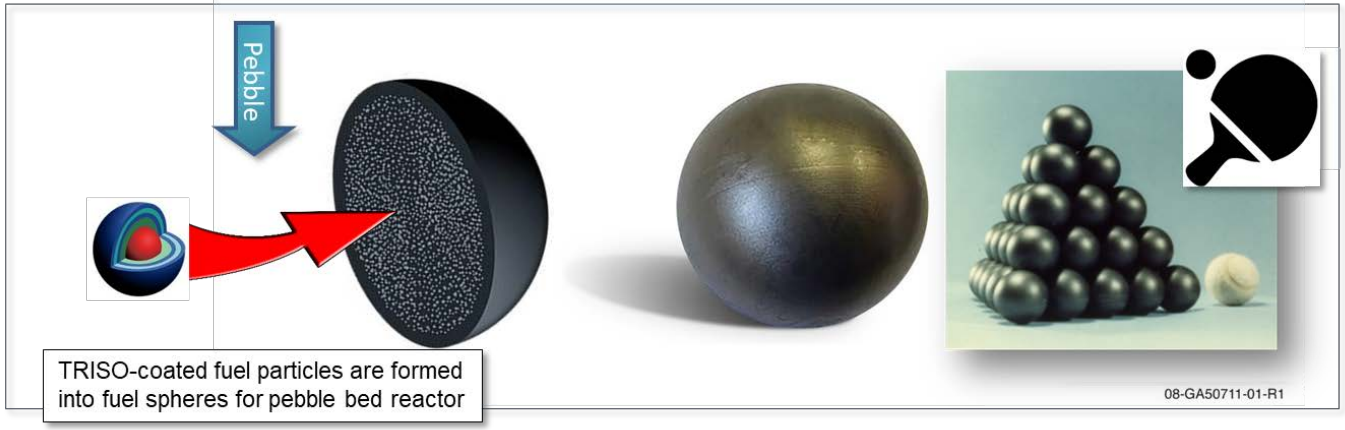




*“Simply put, **TRISO particles cannot melt in a reactor** and can withstand extreme temperatures that are well beyond the threshold of current nuclear fuels”* *- US Dept of Energy*

HTR TWG

HTR - Simple Safe Secure

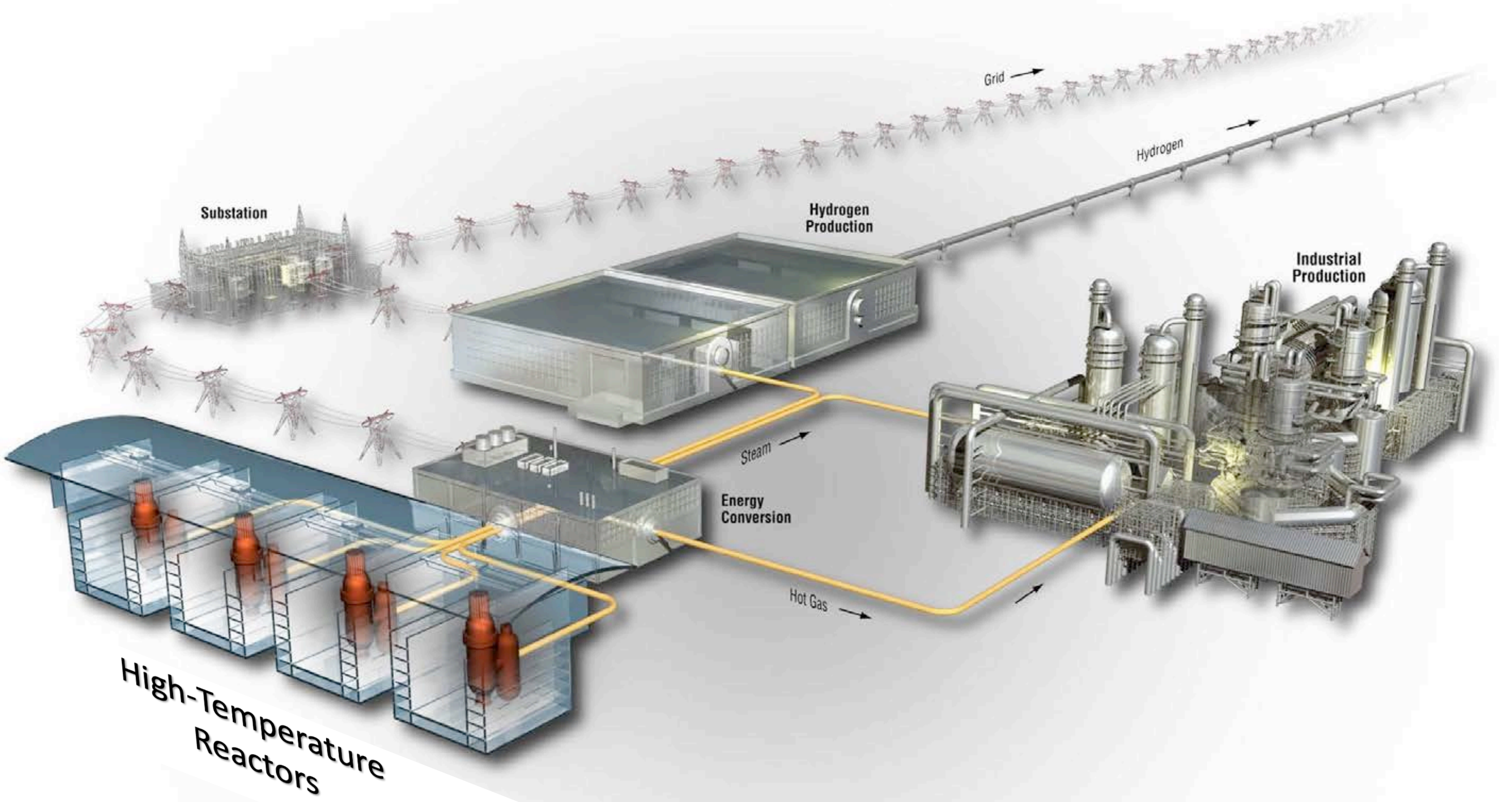
- Mission
  - Ensure that RD&D infrastructure is created, maintained, and available to support the timely development, demonstration and deployment of high temperature reactor technology.
- Objectives
  - Coordinate R&D needs with DOE and National Laboratories to ensure relevant work is aligned with technology goals
  - Support advancement, development, and deployment of high temperature reactor technology
  - Establish domestic US fuel supply chain including identification and resolution of issues related to front-end of HTR fuel supply, TRISO manufacturing, and back-end storage, transportation, and/or recycling
  - Support and coordinate efforts with other organizations and technology working groups to achieve shared objectives

Non-Electricity Applications

HTR - Simple Safe Secure

- Nuclear energy excellent source of process heat for
  - desalination
  - synthetic and unconventional oil production
  - oil refining
  - biomass-based ethanol production
  - hydrogen production
- Nuclear energy only credible non-carbon option for most major industrial heat applications
- Light water reactors produce relatively low temperatures relative to many industrial needs; technology focus is on high-temperature reactors (HTR) and more recently on molten salt reactors (MSR)
- 79 nuclear reactors used for desalination, district heating, or process heat in 2019, with 750 reactor-years of experience

Source: WORLD NUCLEAR ASSOCIATION


Grid
Hydrogen
Substation
Hydrogen Production
Industrial Production
Steam
Energy Conversion
Hot Gas
High-Temperature Reactors

Fast Reactor Technologies

Jake DeWitte, Ph.D.

Chair, FR Technology Working Group

CEO and co-Founder
Oklo, Inc.

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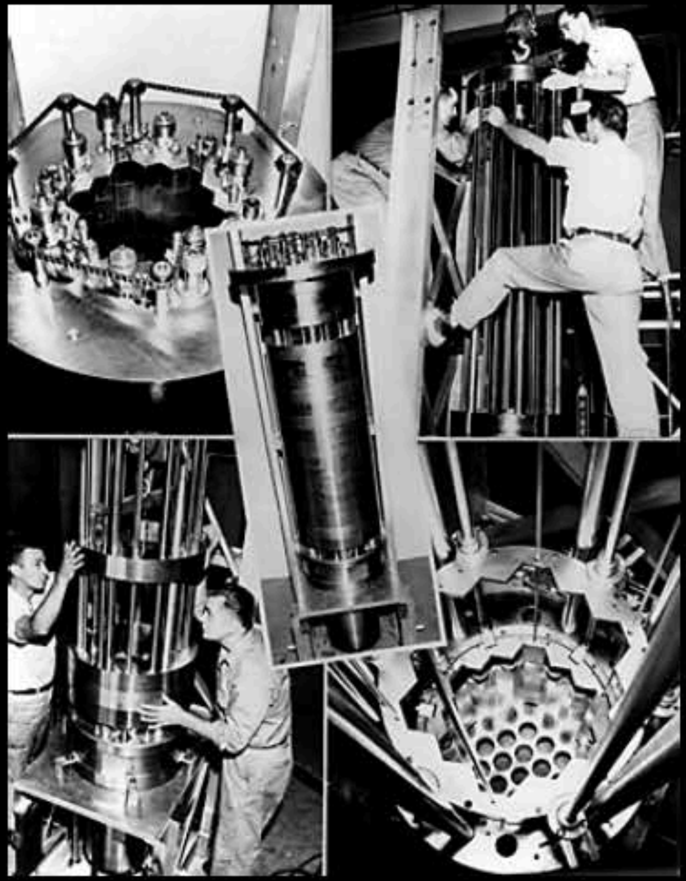
Why fast neutrons?

- Fast reactors refer to a class of reactors that use high energy neutrons to sustain the fission reaction
  - High energy fissions lead to a better neutron balance
- High fuel use efficiency
  - Allows fast reactors to extract more energy from fuel, to produce more fuel than used, and to consume used fuel from other reactors
- Diversity of designs
  - Support a variety of missions – long-lived cores, fuel recycling, process heat generation, among others
- Use cheaper, more readily available materials



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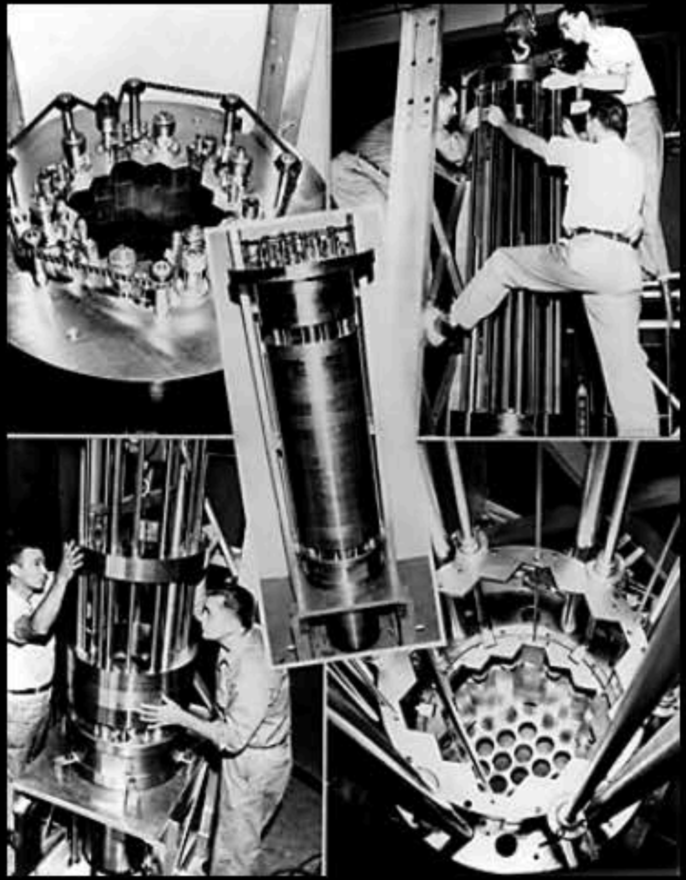


Fast Reactor Working Group

- Multiple developers working on multiple technologies
- Spans variety of fast reactor technologies in development

ARC	Columbia Basin	Elysium Industries	Flibe Energy
GA	GE	Hydromine	Oklo
TerraPower	Westinghouse	Duke	Exelon
Southern	Studsvik Scandpower	EPRI	NEI

Design diversity

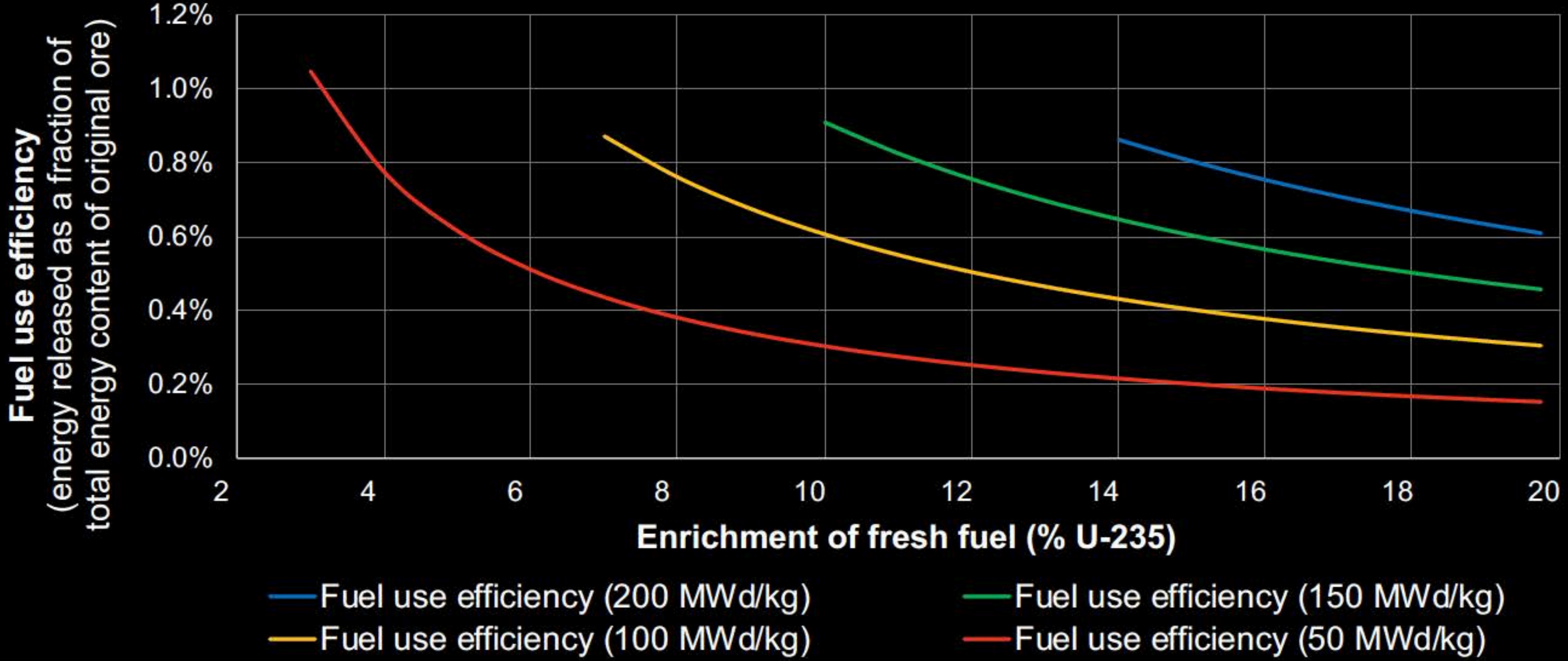
- Liquid metal cooled
- Gas cooled
- Molten salt cooled and fueled

Capabilities

- High fuel use efficiency
- All types can provide low to medium temperature process heat ~500°C (932°F)
- Some working to provide heat above 800°C (1472°F)
- Long fuel lifetimes – single core load can operate for 20 years or longer
- Fast reactors can recycle used fuel from today's reactors and future advanced reactors

Fuel use efficiency

Fast recycling allows for >90% fuel use efficiency!

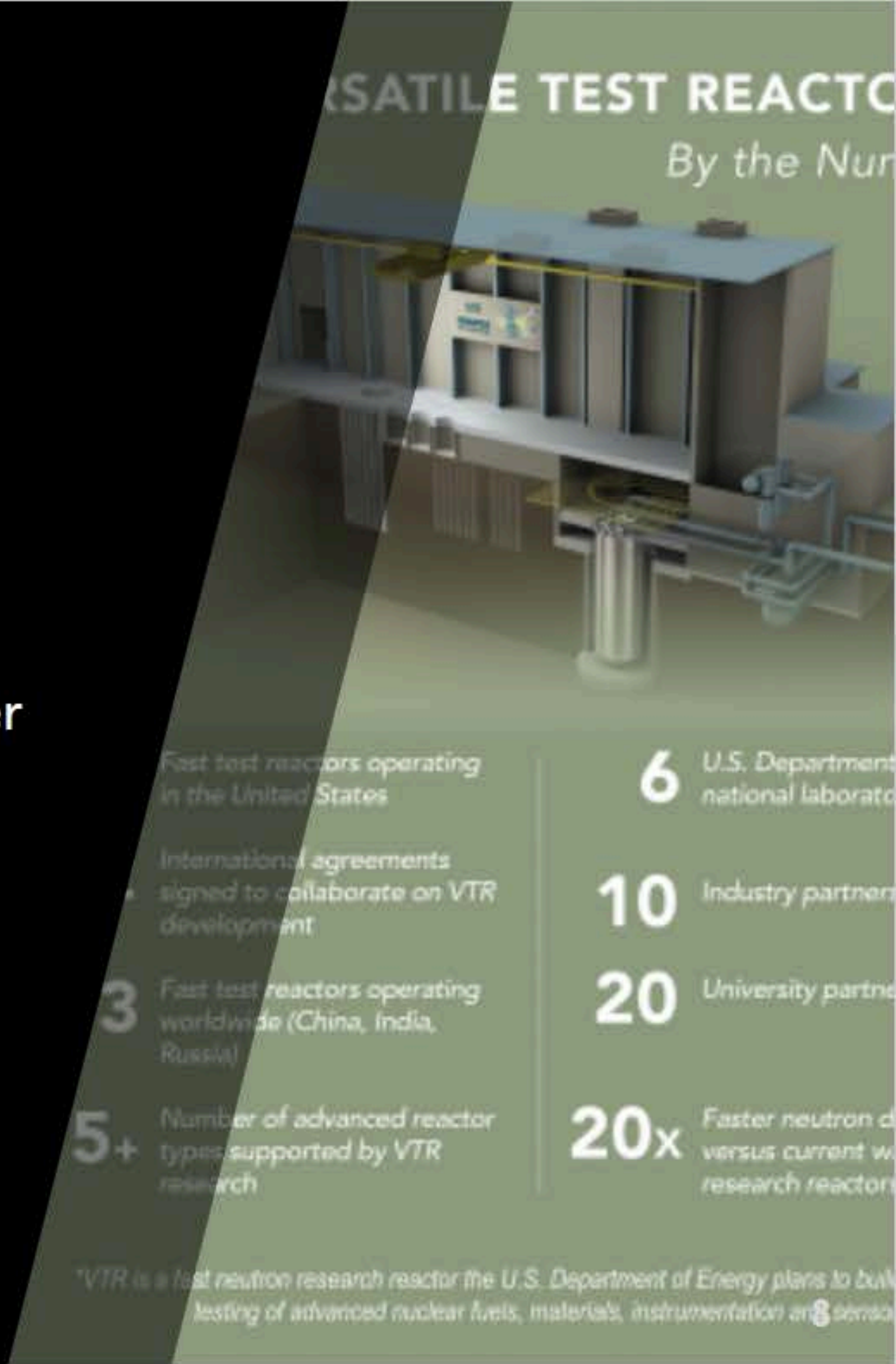


Early experience

- First usable nuclear electricity was generated by a fast reactor – EBR-I in 1951
- EBR-II (20 MWe) operated in Idaho from 1963 to 1994
  - Metal and oxide fuels demonstrated
  - Inherent safety testing in 1986
- FERMI-1 fast commercial power reactor (61 MWe) in 1965

Global perspective

- About 20 fast reactors with 400 operating-years
- Test and/or demonstration reactors built and operated in US, France, UK, Russia, Japan, India, Germany, and China
- Recent startup of CEFR
- Russian BN-600 continues reliable operations for over 30 years at >75% capacity factor with no sodium leaks for last two decades
- New power reactors: BN-800 (880 MWe), Oklo Aurora (1.5 MWe) submitted NRC license application
- Versatile Test Reactor (VTR) being developed by U.S. Department of Energy (DOE) to be a fast test reactor



Technology roadmap

- Developers pursuing near-term to mid-term deployment of fast reactors domestically and abroad
  - Some fast reactor technologies are already demonstrated, working towards deployment
  - Others are being researched and developed
- First advanced reactor combined license application to build and operate an advanced reactor was submitted to the Nuclear Regulatory Commission by Oklo in March 2020 for a fast reactor

Fast reactor summary

- Fast reactors have the potential to deliver a diverse array of usable products spanning temperature ranges and power levels
- Fast reactors can achieve high fuel utilization and recycle waste from other reactors
- Near-term to long-term technology readiness

Questions and Discussion

- Please enter all questions or comments using the *"Questions"* option on the GoToWebinar control panel
- We will address as many questions as possible during the webinar, and will follow-up later to address additional questions
- At the end of the webinar, please submit ideas for the next webinars in this series, so they can be tailored to fit your interests

Clean Nuclear Energy for Industry: The Case for SMRs and Microreactors in Puerto Rico

Thursday, June 18 | 1:00 - 2:30 pm EDT

Register at https://gain.inl.gov/SitePages/GAINWebinarSeries.aspx

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