There's Much More to Nuclear than Electricity

By

Zabrina Johal

Director of Business Development

Presented to

North American Young Generation in Nuclear

Washington, DC

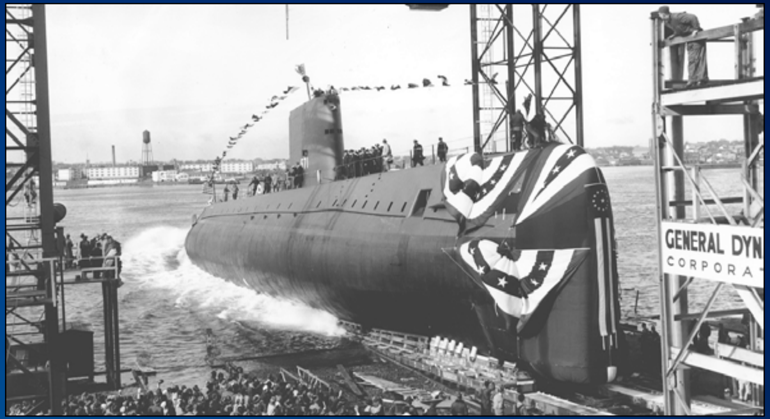
June 3, 2019

Out of Montana . . .

. . . to California and Beyond

Admiral Hyman G. Rickover

ADM Hyman G. Rickover
"Father of the Nuclear Navy"



USS Nautilus (SSN-571)

Shippingport Atomic Power Station

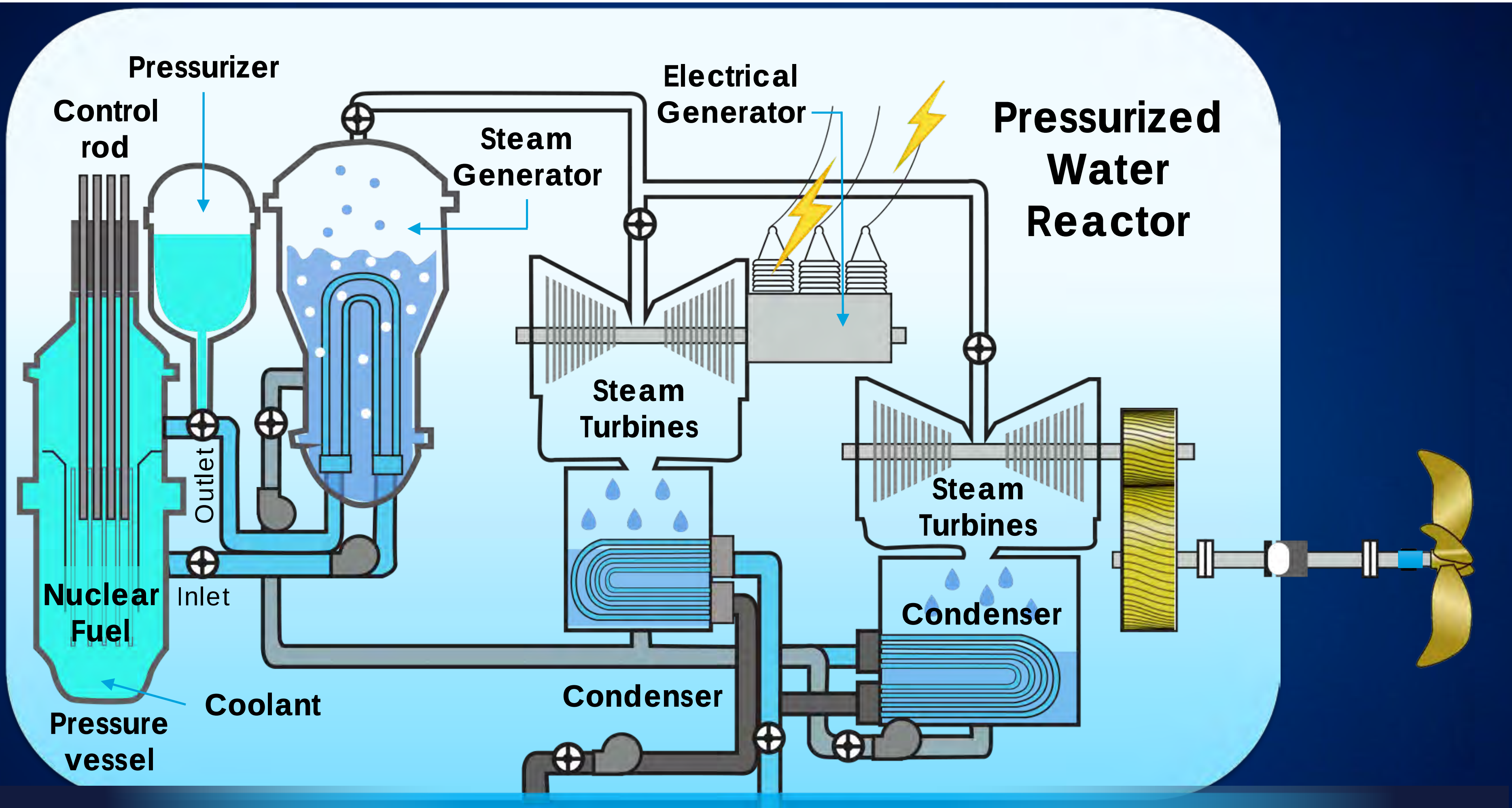
How I Got Here

LT Zabrina Johal, aboard USS Carl Vinson *(CVN-70), in the Persian Gulf*

Navy Nuclear Plants Power a Floating City

- Launch aircraft
- Provide electricity
- Motive force for turning propellers
- Seawater → drinking water

How Navy Nuclear Plants Work



Not shown: Steam off-takes for catapults, evaporators, auxiliary systems, etc.

General Atomics

TORREY PINES
GENERAL ATOMICS

LOCATION: San Diego

FOUNDED: 1955 by General Dynamics

STATUS: Privately held corporation

BUSINESS: High-technology research, design, manufacturing and production for industry and government worldwide

General Atomic Division of General Dynamics	Gulf General Atomic	Gulf/Royal Dutch Shell GA	GA Technologies Inc, Chevron USA	General Atomics

1955 - 1967 → PRESENT

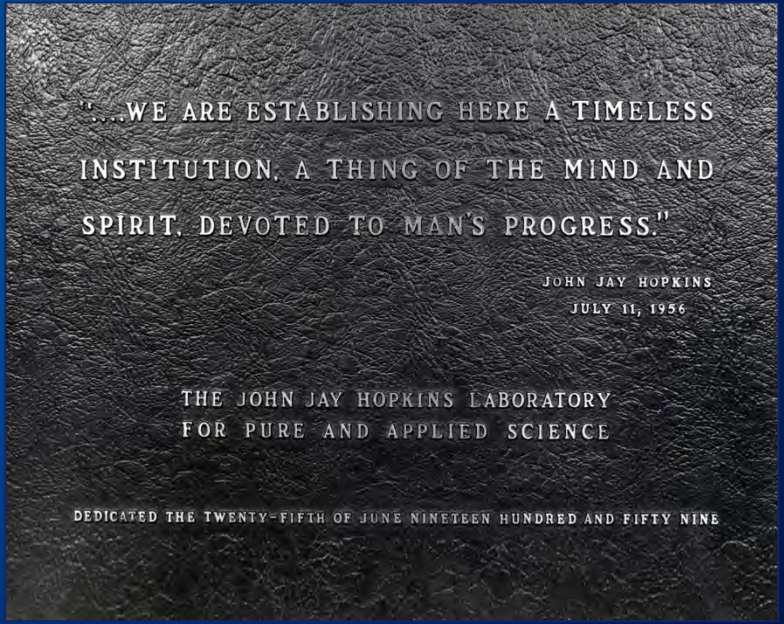
"Atoms for Peace"

Eisenhower delivering his "Atoms for Peace" speech to the UN General Assembly in December 1953

1955 UN Conference on the Peaceful Uses of Atomic Energy in Geneva

Out of an Old Schoolhouse

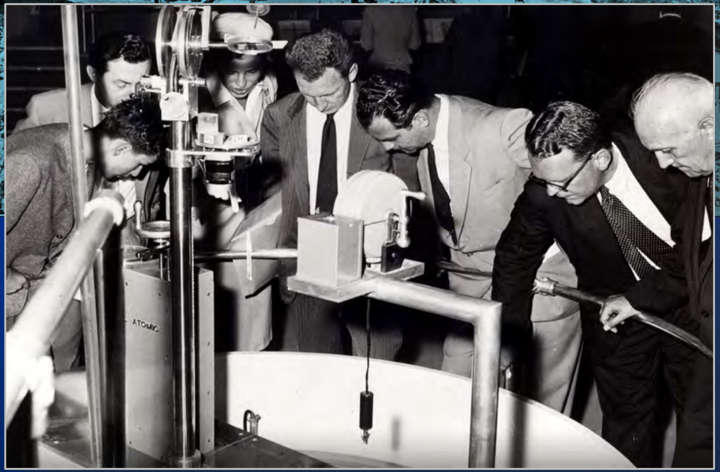
The schoolhouse that served as GA's first home



John Jay Hopkins, San Diego Mayor Charles Dail, and Fred de Hoffman dedicating the facility in July 1956

“What the world needs is a safe reactor.”

– Edward Teller, San Diego, 1956



One of the first TRIGAs on display at the second UN Conference in 1958

- Developed at General Atomics in San Diego
- First reactor started up in 1958 – three years after GA was founded
- 66 TRIGAs built in 23 countries
- Inherently safe $UZrH_x$ fuel

Training Research Isotopes General Atomics

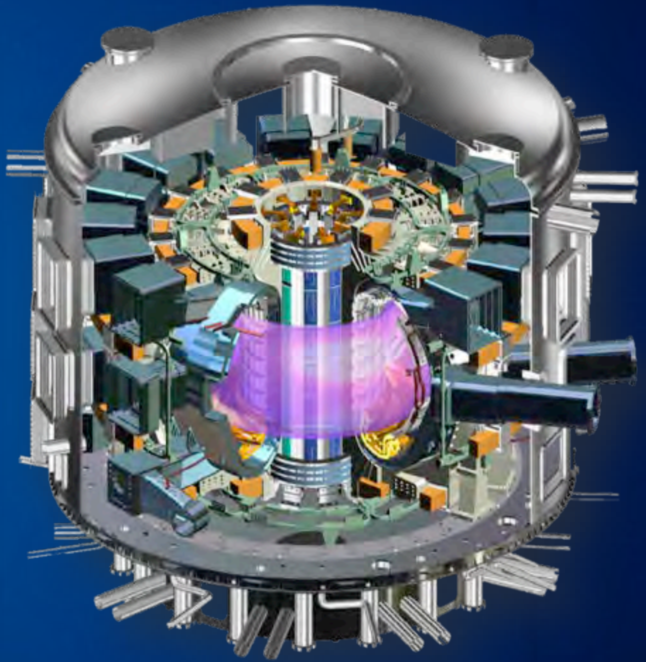
GENERAL ATOMICS

Providing Solutions at the Nexus of National Security + Nuclear Interests

Magnetic Fusion Energy

GA hosts the DIII-D National Fusion Facility and is a major contributor to the success of ITER

DIII-D:
Nation's premier fusion energy facility

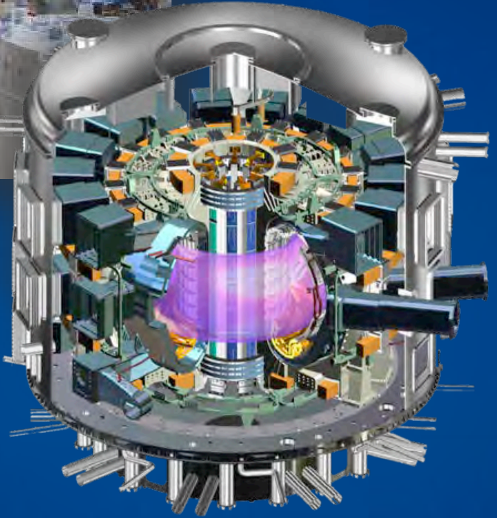


ITER:
Rapid progression to burning plasma

Providing the Heart of ITER

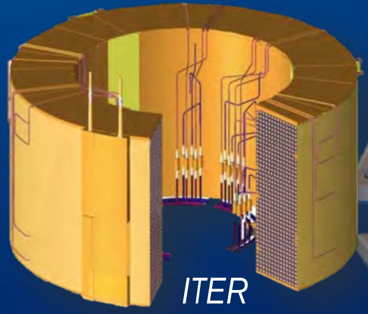
GA ITER Central Solenoid Facility

GA is building ITER's Central Solenoid – the world's most powerful pulsed electromagnet

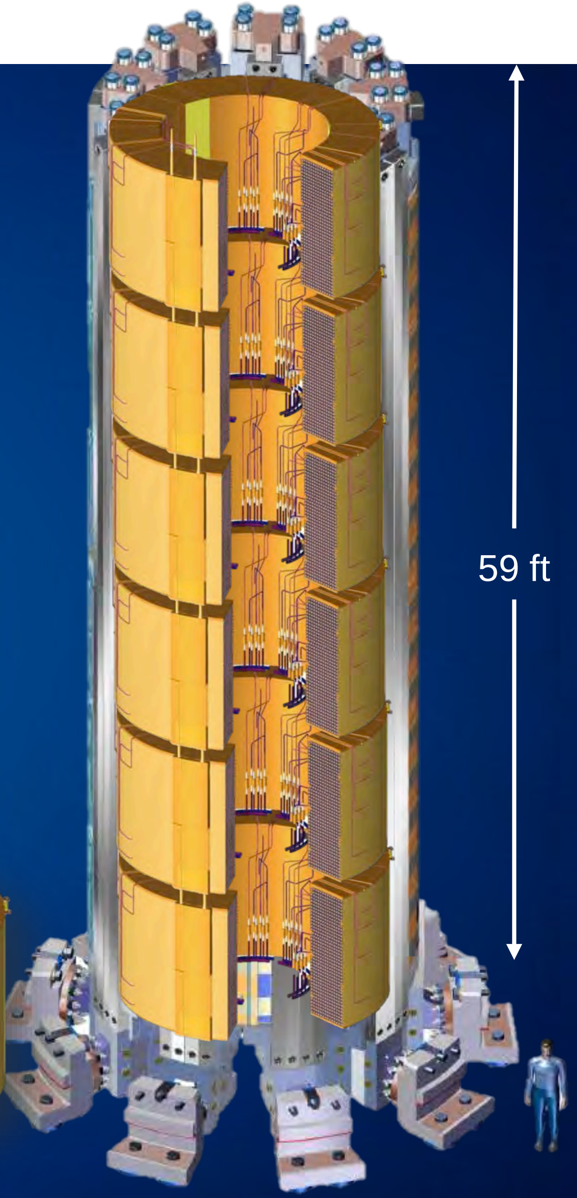


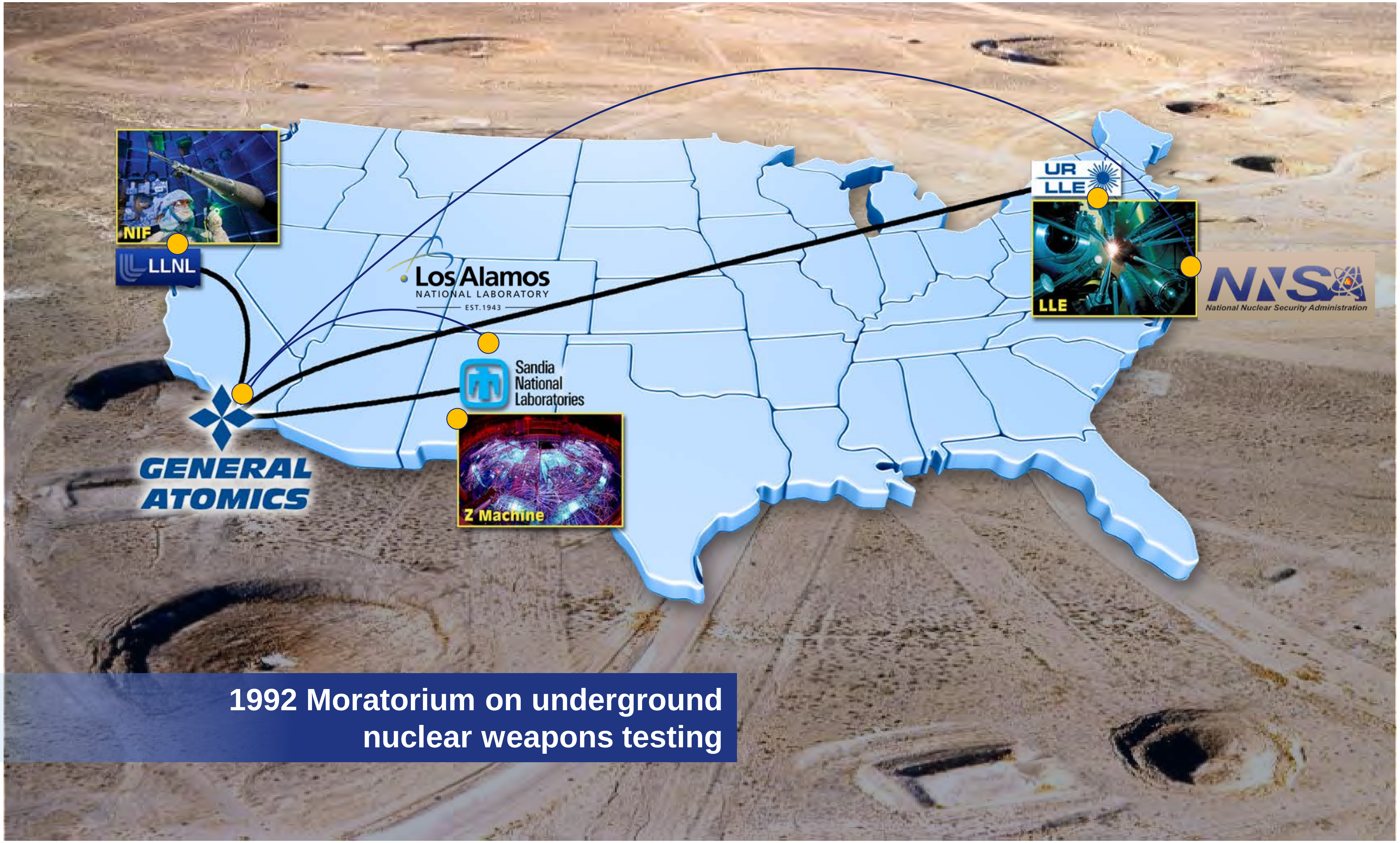
ITER

Magnet winding process

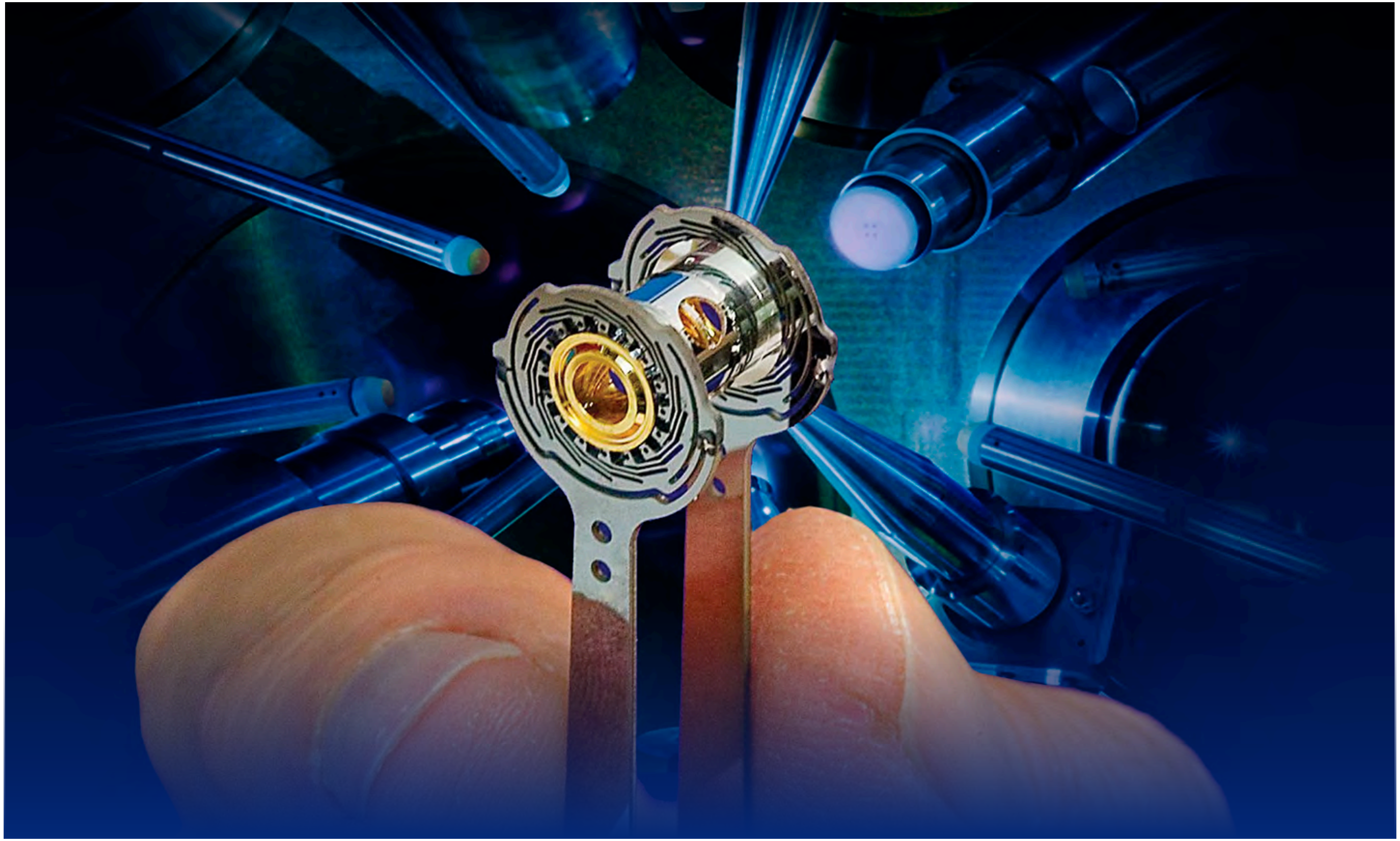


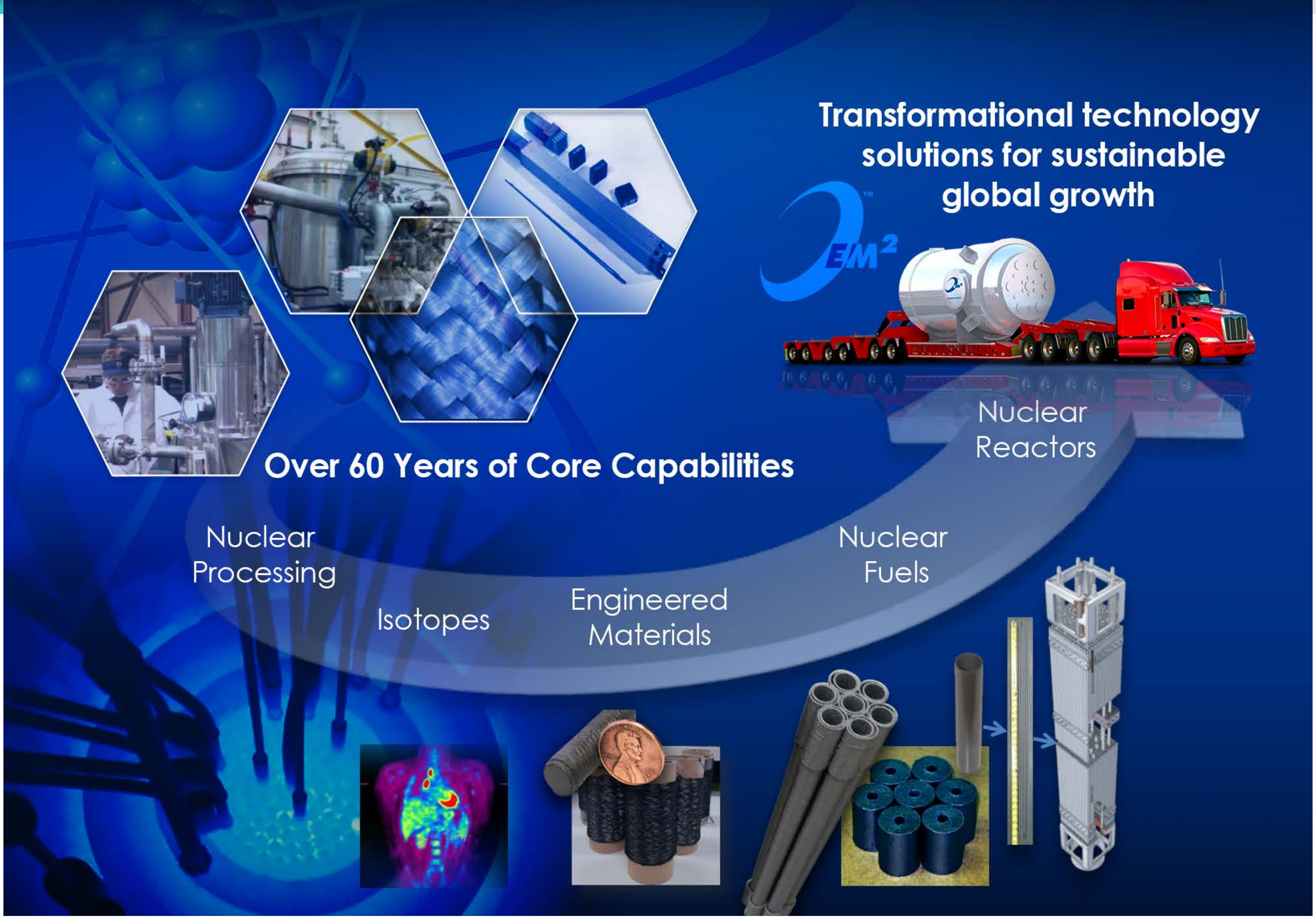
ITER Magnet

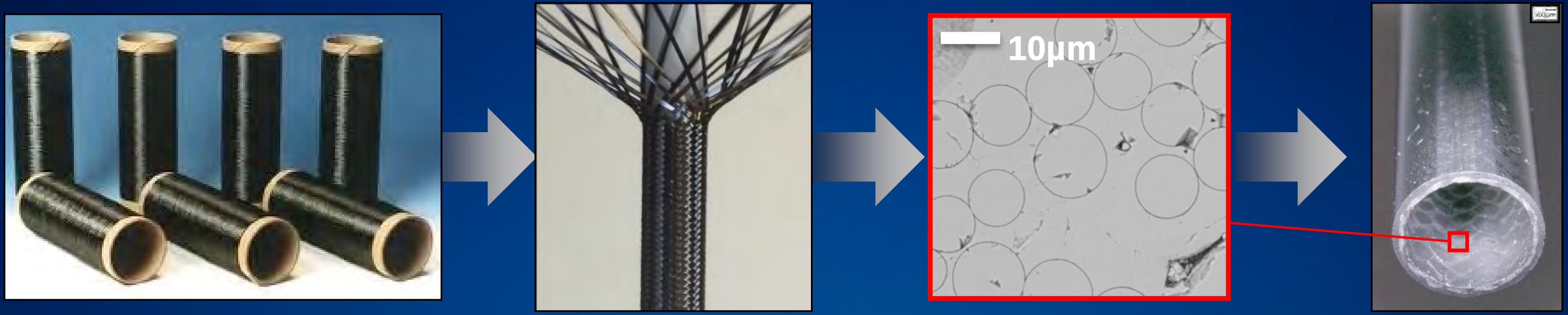



NIF
LLNL
Los Alamos
NATIONAL LABORATORY
EST. 1943
Sandia
National
Laboratories
Z Machine
GENERAL
ATOMICS
UR
LLE
LLE
NNSA
National Nuclear Security Administration
1992 Moratorium on underground
nuclear weapons testing

Precision Fabrication Enables HED Experiments




Transformational technology solutions for sustainable global growth
EM²
Over 60 Years of Core Capabilities
Nuclear Processing
Isotopes
Engineered Materials
Nuclear Fuels
Nuclear Reactors



Crystalline SiC fiber | **Fiber braided to precise tolerances** | **Fiber infiltrated with SiC matrix** | **SiGA™ composite**

- Silicon-carbide fiber reinforces silicon-carbide composite to create innovative matrix material (SiGA™)
  - SiC fibers reinforce the composite like rebar in concrete
  - Exceptional strength retention to 1800ºC (3x higher than Zircaloy)
  - Extremely stable in harsh environments

Addressing Nuclear Safety Needs Post-Fukushima

SiGA^{TM} composite is a revolutionary ATF cladding material

- Highest safety, performance and economic reward
- Steady DOE support required to meet schedule
- Strong industry demand for deployment

Development from 2011 to 2030

2011 – 2016	2017 – 2022	2023 – 2030
Feasibility Demonstration	Development	Scale-Up & Commercialization

- **Modular design**
  265 MWe increments as needed
- **Site flexibility**
  no need for water source
- **Provides grid stability**
  supports solar and wind renewable energy
- **Passively safe**
  no need for emergency power or operator actions
- **Cost competitive**
  >50% efficient

Questions?

Contact:
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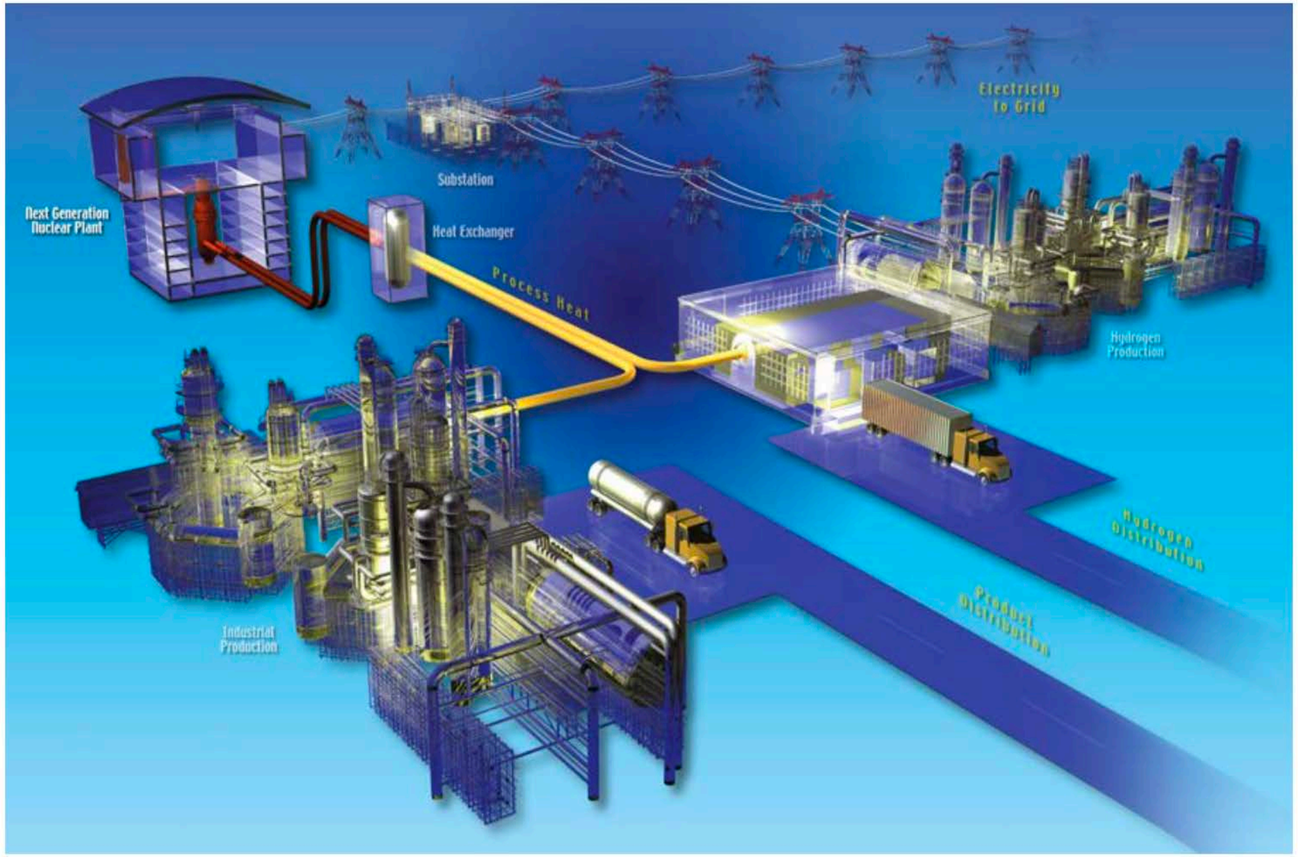
858-455-4004

Prospects for A Nuclear/Hydrogen Future

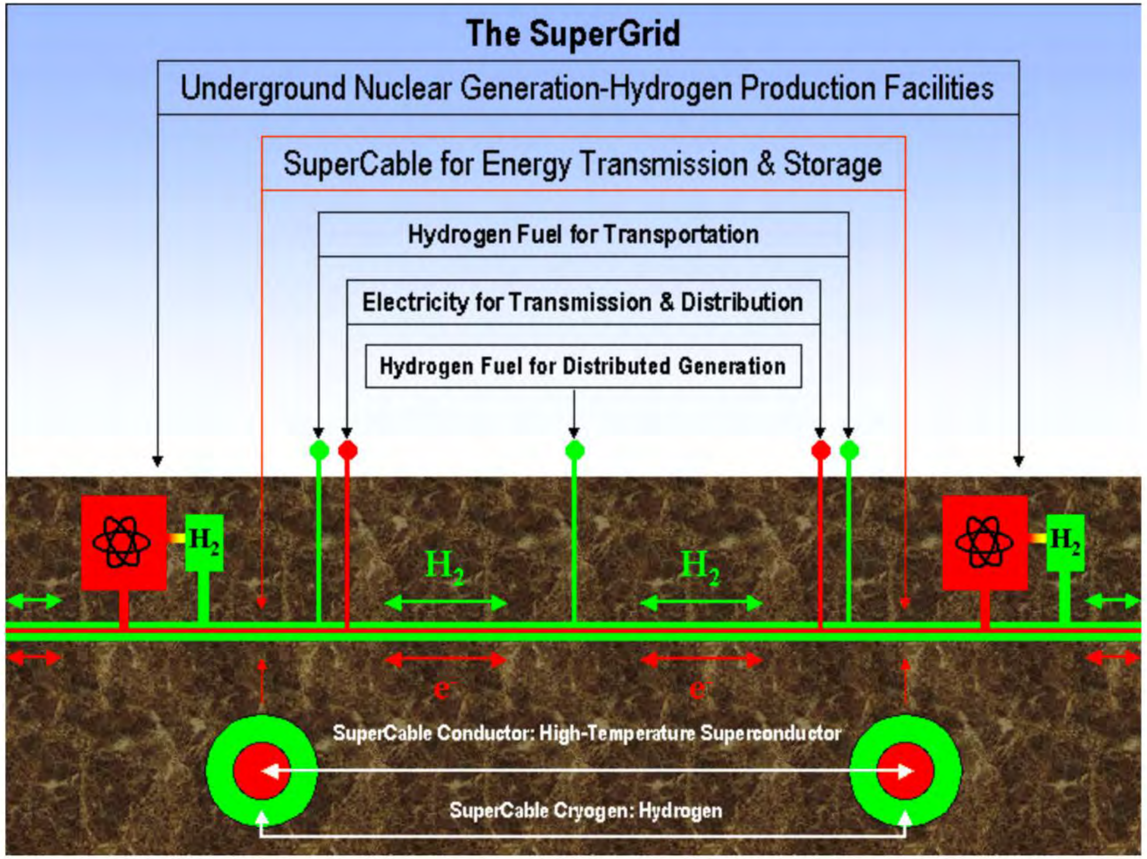
Tina Taylor
Deputy Chief Nuclear Officer and Senior Director R&D

www.epri.com

Back to the Future?

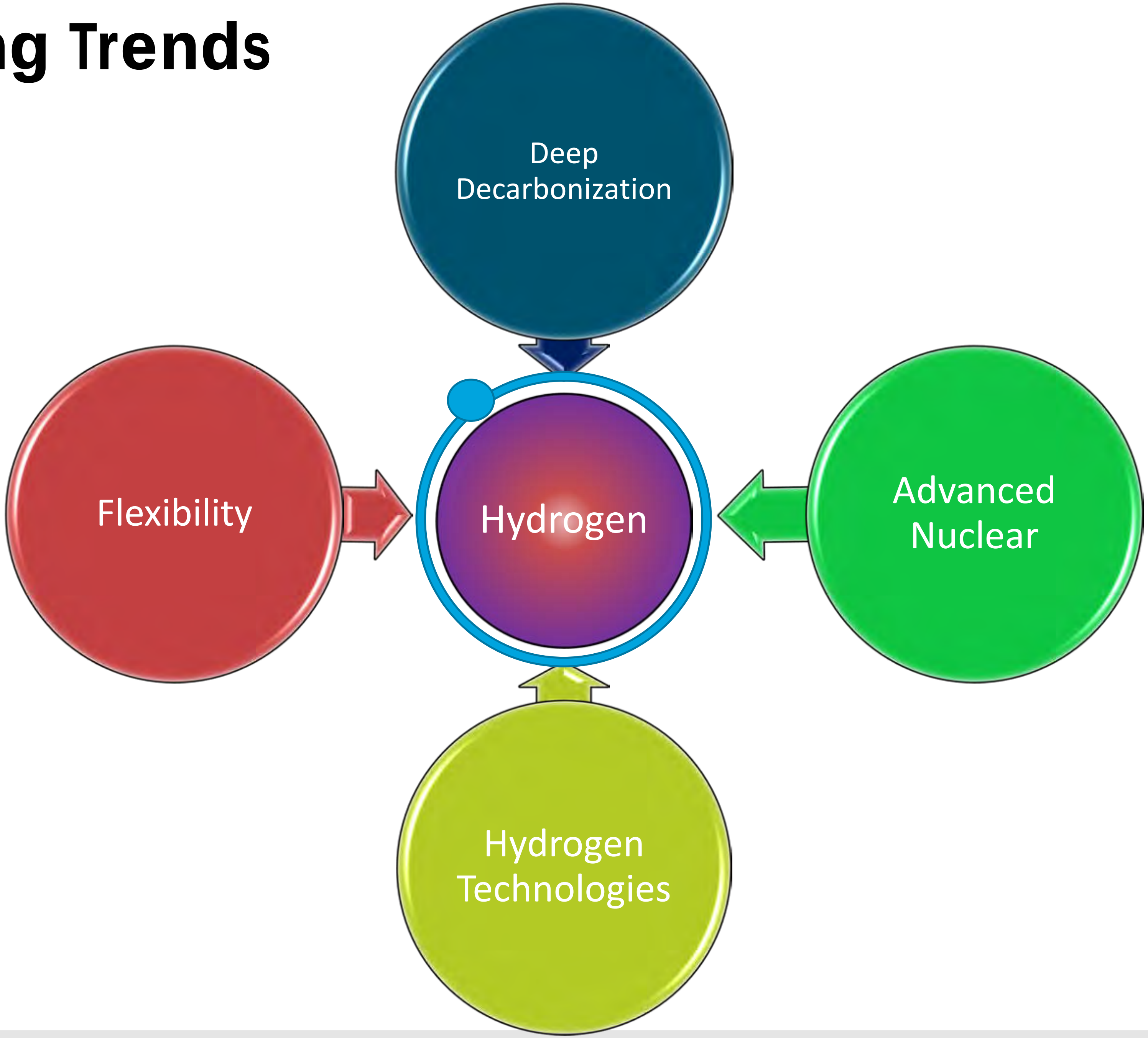


Next Generation Nuclear Plant, Image: Idaho National Laboratory



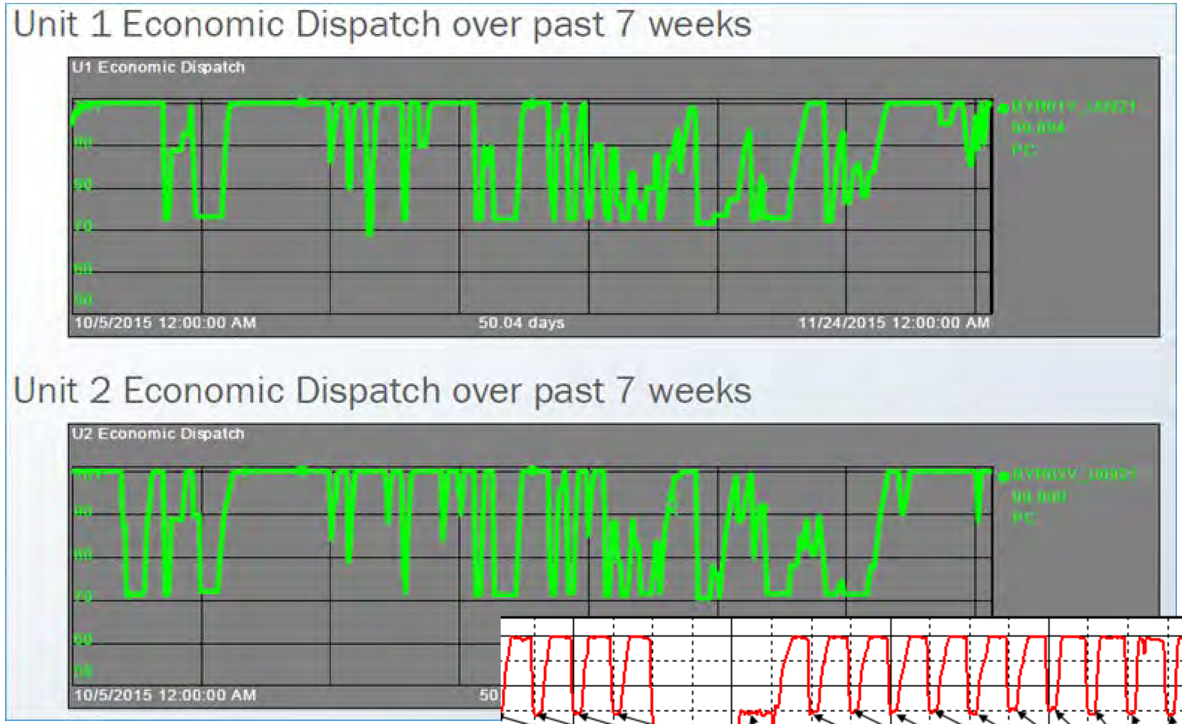
SuperGrid – The Next Steps, EPRI Report 1011746, March 2005

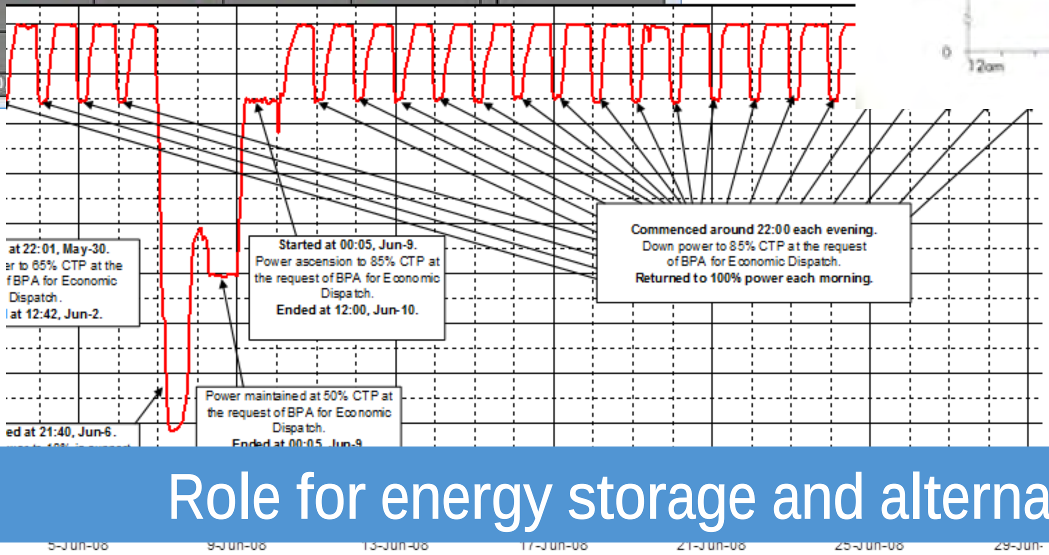
Converging Trends

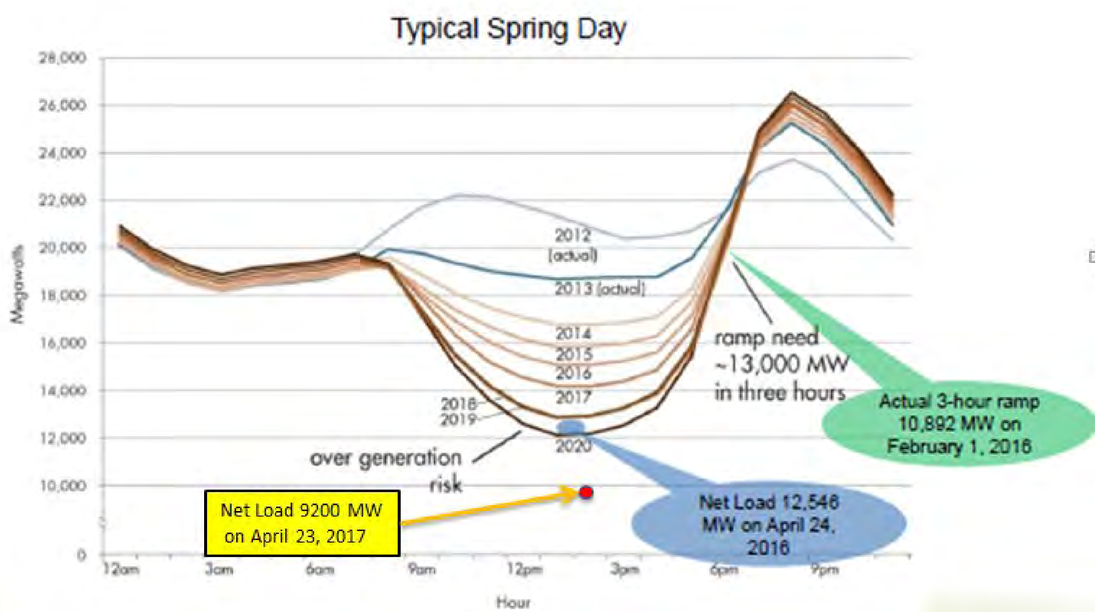


Flexibility

Managing Flexibility



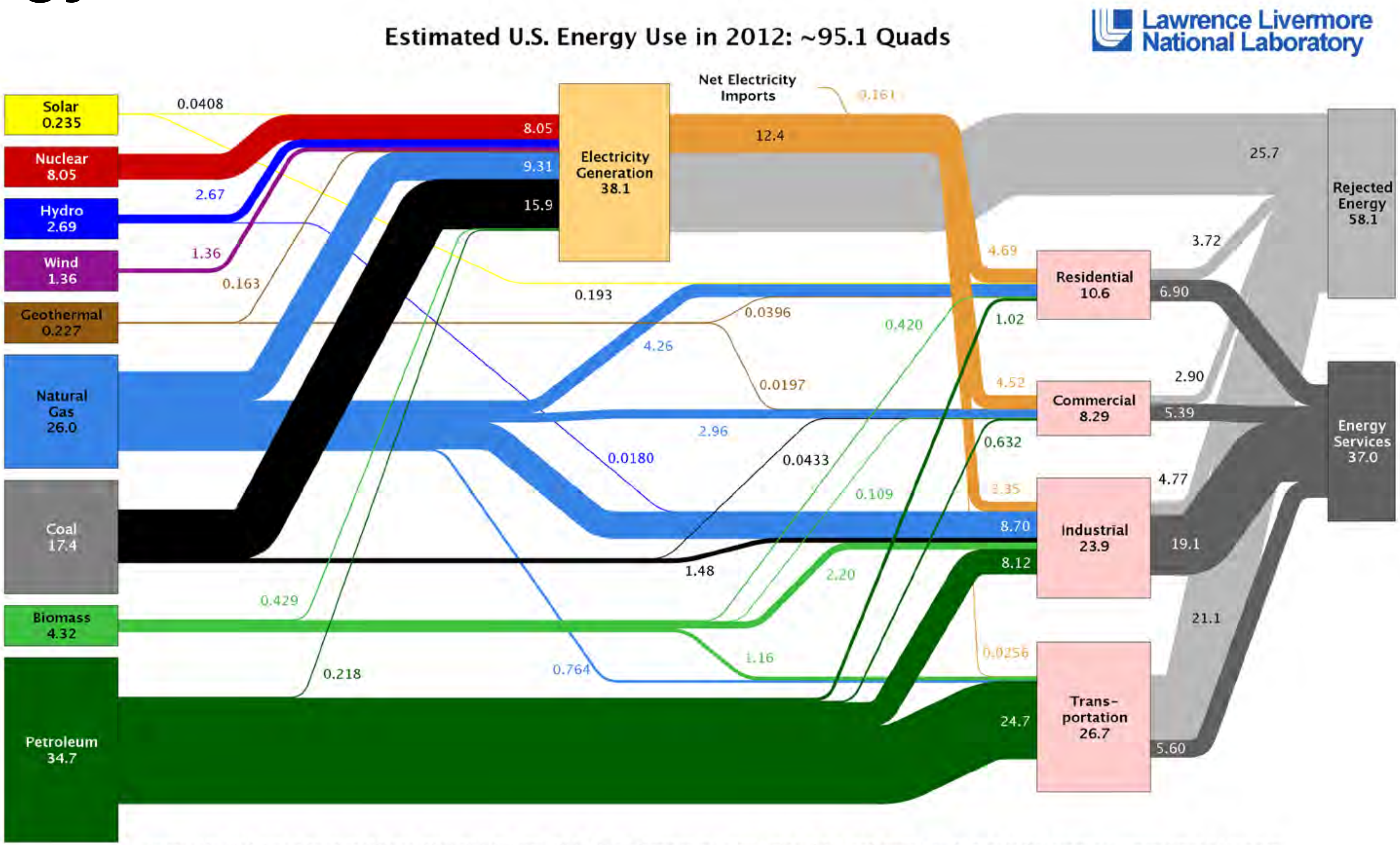




Role for energy storage and alternate products

Deep Decarbonization

US Energy Use & Decarbonization

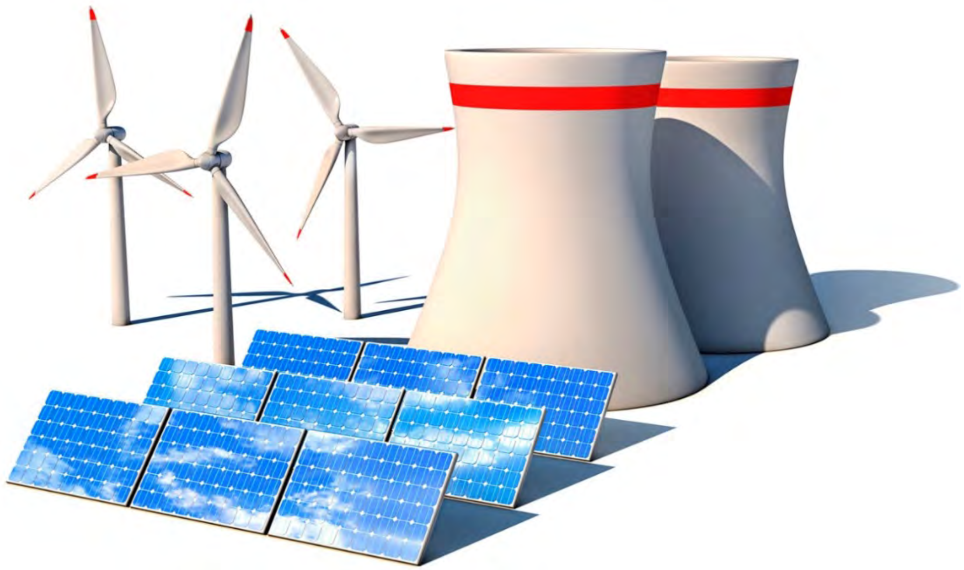


Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Advanced Nuclear Technologies

Advanced Nuclear

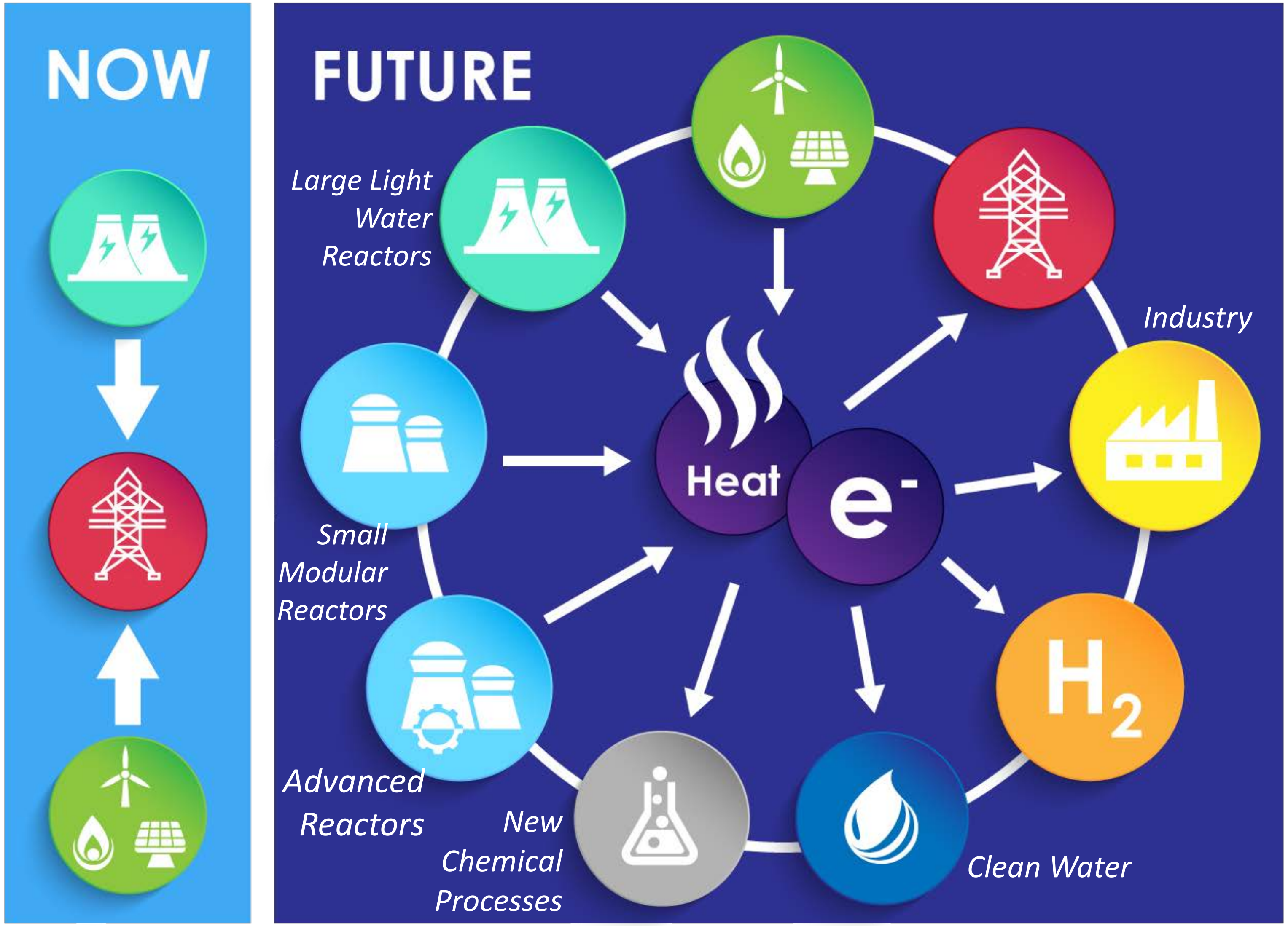
- Inherent safety
- Robust, competitive, sustainable economics
- Scalable, dispatchable, zero carbon energy
- **Diversified products and market access**
- Flexible operation
- Secure fuel supply

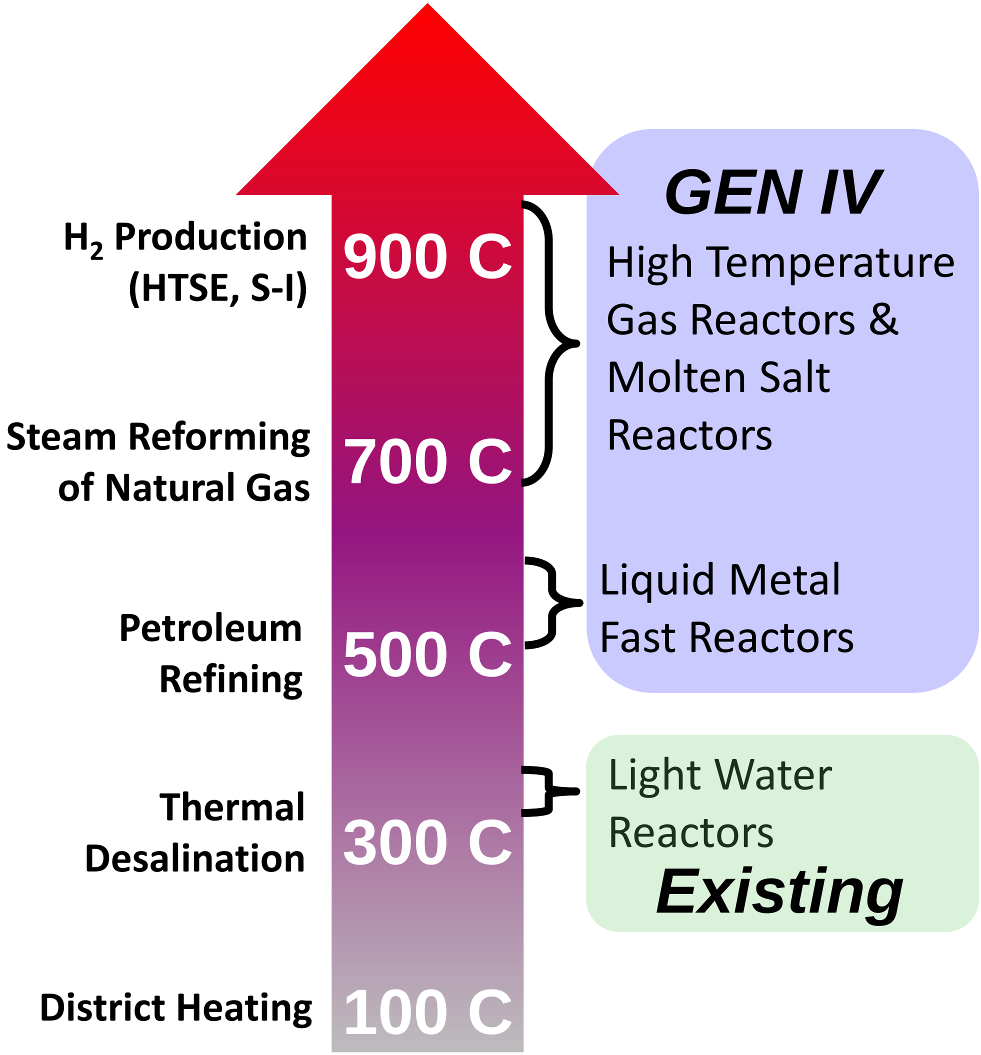


Advanced nuclear energy systems offer unique options for dispatchable, energy dense and non-emitting generation.

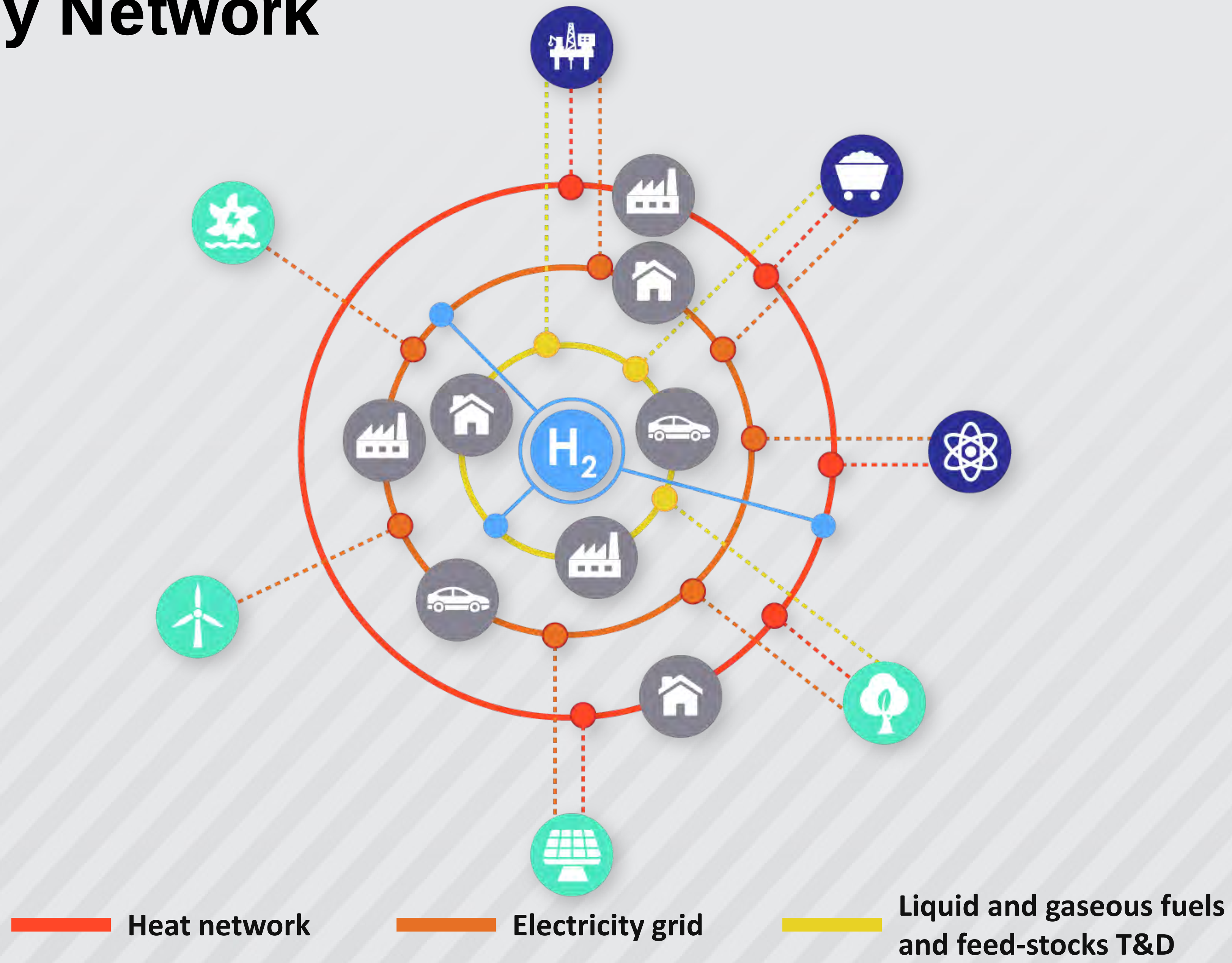
Hydrogen: Advanced Reactors' role

Nuclear Energy Reimagined:
Maximizing energy utilization through novel systems integration and process design.

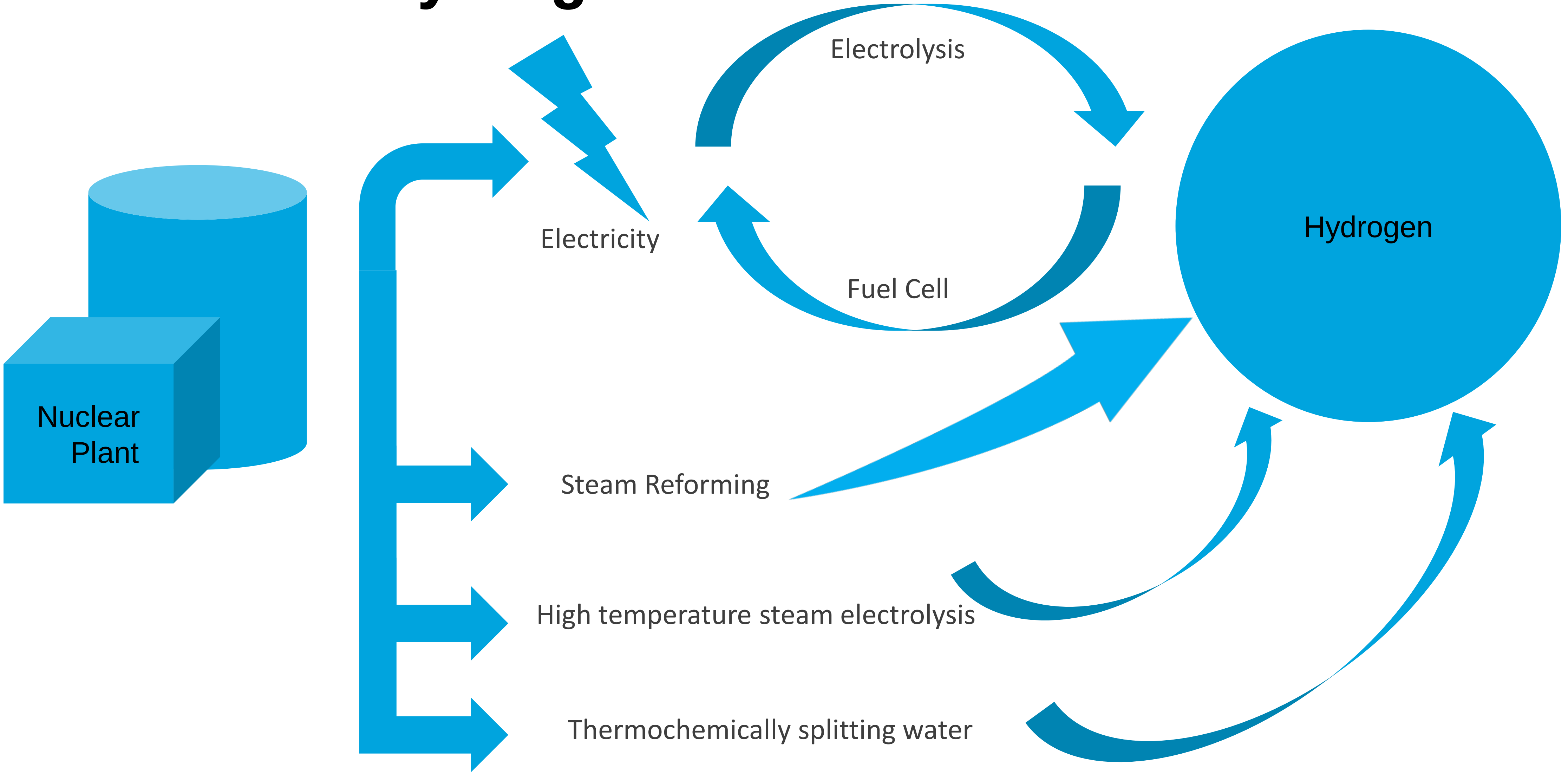




The Energy Network



Nuclear -> Hydrogen



Hydrogen Technologies

Additional Key Technologies in A Very Low-Carbon 2050

Zero-Carbon Electric Generation

- Carbon Capture & Storage
- Advanced Nuclear

Low Carbon Fuels:

cleaner electricity → cleaner energy carriers (H_2, NH_3) → heavy duty transportation, heating, & industry

Hydrogen blending leverages existing natural gas pipeline infrastructure for heating sector emission reduction

Advances in Hydrogen

Electrolyzer cell stacks

Proton Exchange Membrane Electrolyzer

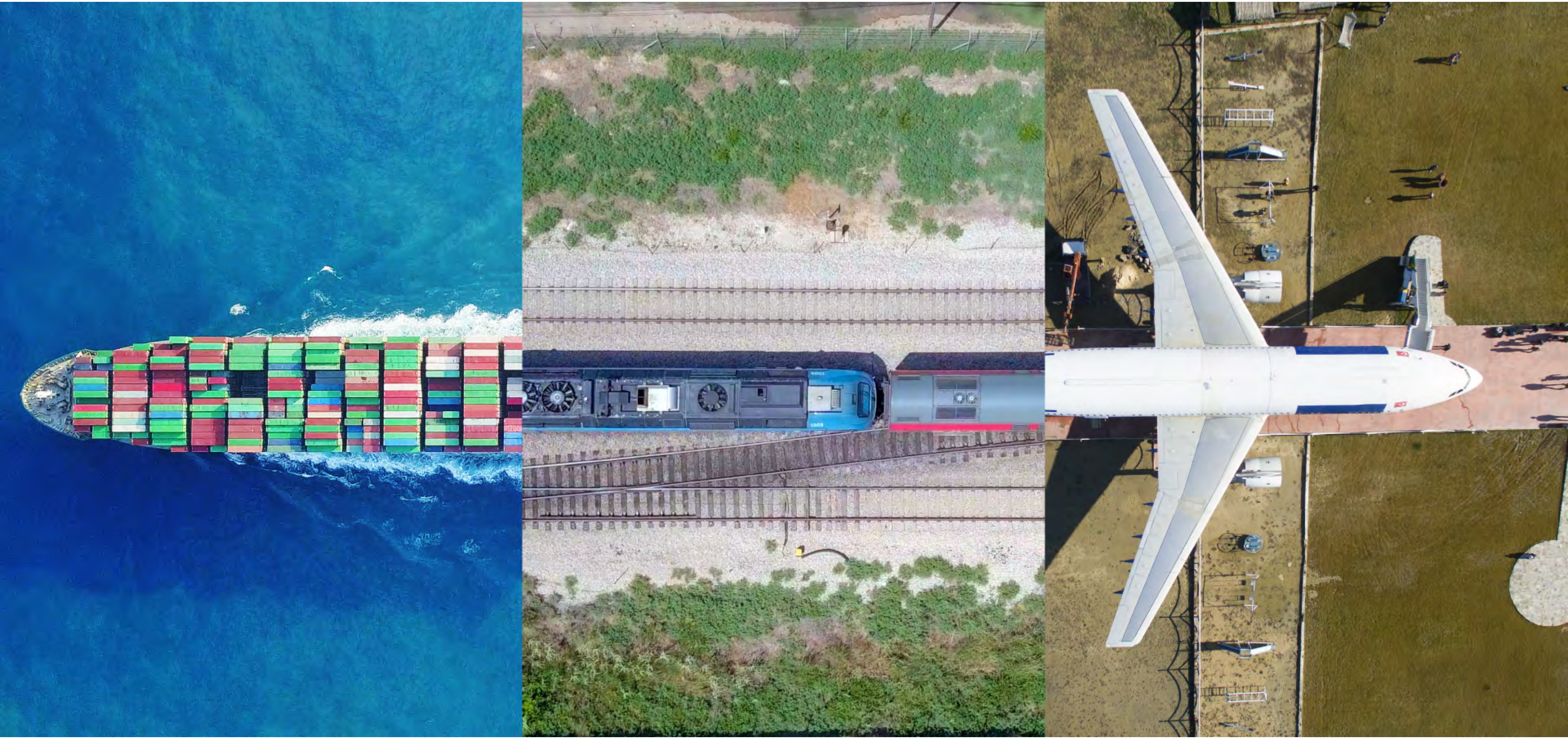
- Hydrogen as the dominant energy carrier for transportation
  - displacing petroleum
  - leap frogging battery technology

The Mirai, the world's first fuel cell vehicle for the mass market

http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/

"Toyota sees great potential in hydrogen and fuel cell vehicles."

What’s possible with Hydrogen?



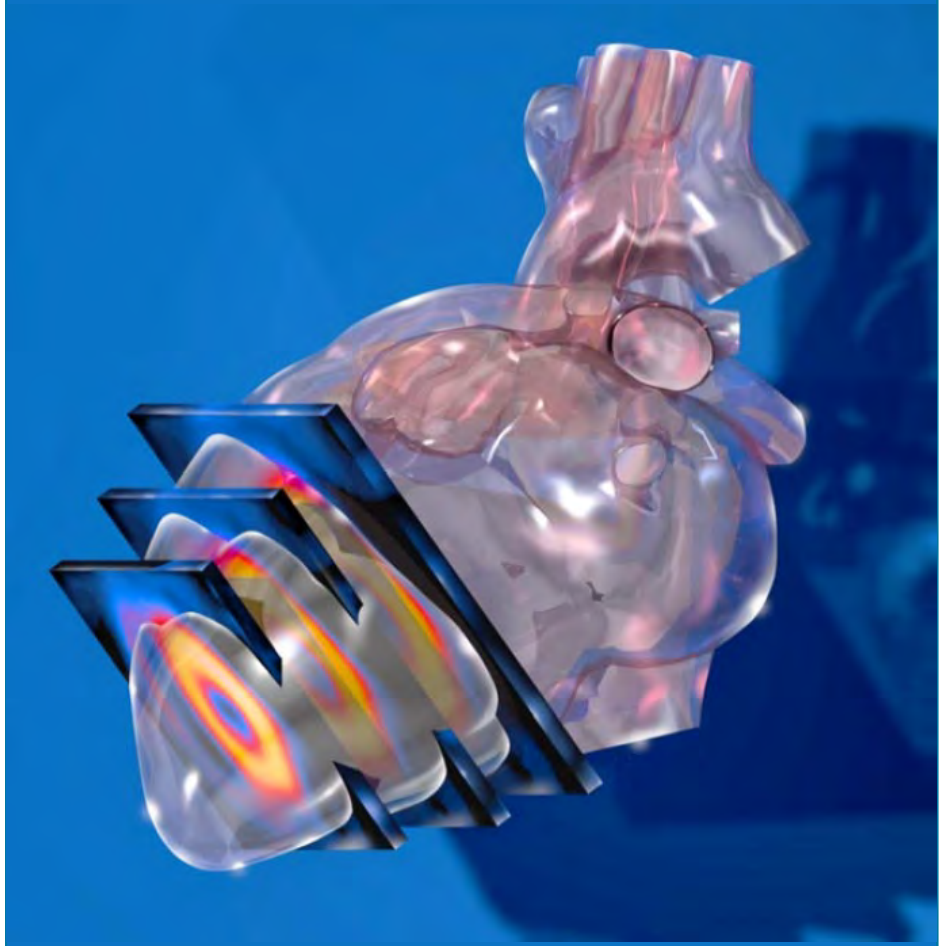
Together…Shaping the Future of Electricity


SHINE
Medical Technologies
NAYGN Presentation
SHINE Medical Technologies | June 2019
Health. Illuminated.™

SHINE®
Health. Illuminated.™

Mission

Dedicated to being the world leader in the safe, clean, affordable production of medical tracers and cancer treatment elements.

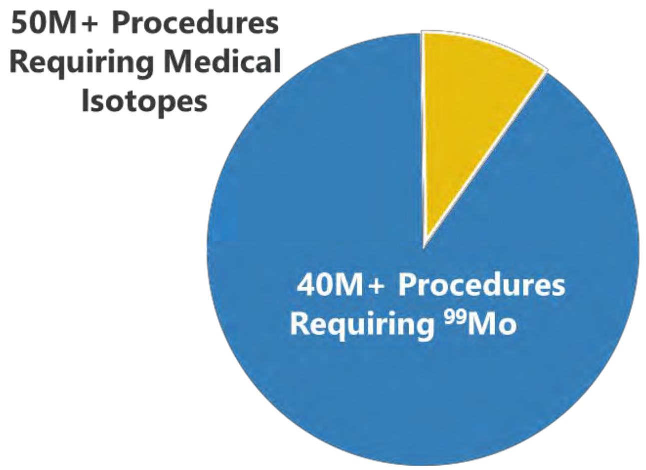


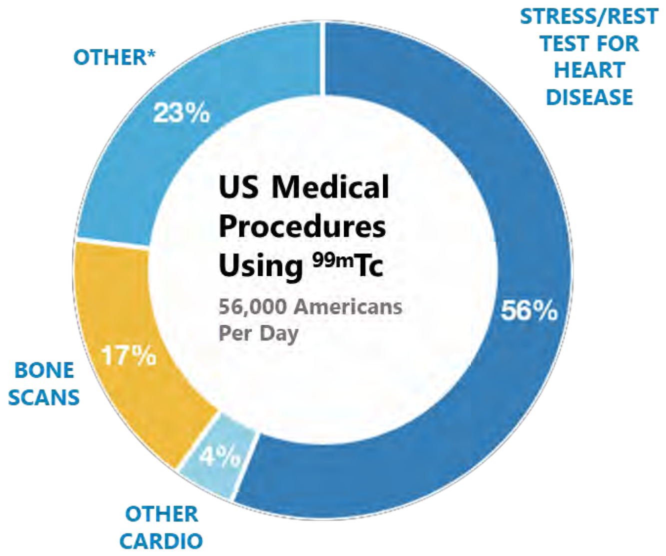
Health. Illuminated.™

Medical Isotopes

Medical isotopes allow doctors to diagnose and treat a wide range of diseases

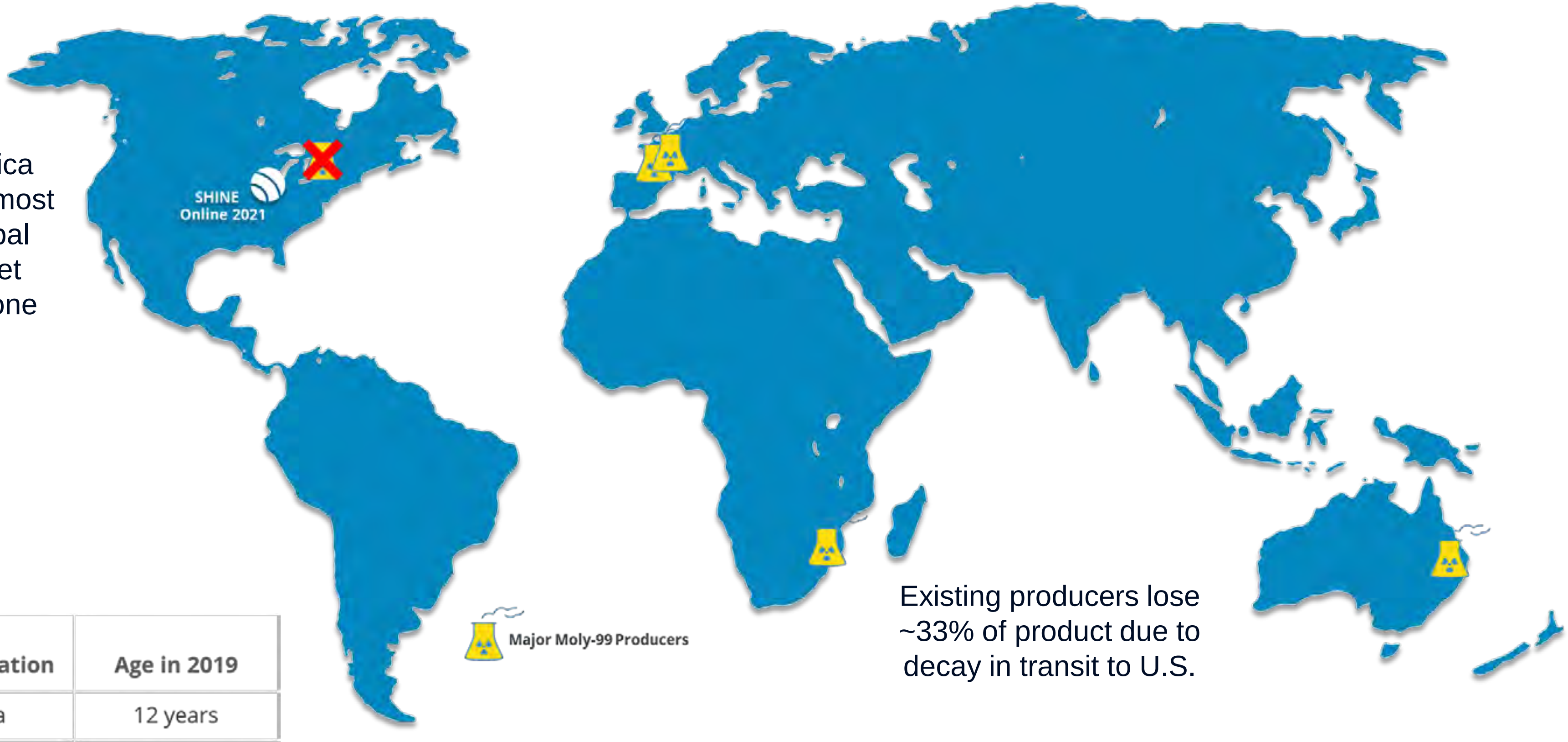
- Molybdenum-99 (Mo-99), the most widely-used medical isotope, decays into technetium-99m, which is used in more than 40 million doses annually
- “Workhorse” of nuclear medicine
- SHINE’s process will also generate the valuable isotopes iodine-131 and xenon-133





Mo-99 decays at ~1% per hour, making proximity to patients critical

North America consumes almost 50% of global demand, yet produces none



Existing producers lose ~33% of product due to decay in transit to U.S.

Reactor Location	Age in 2019
Australia	12 years
Belgium	58-62 years
Netherlands	45-58 years
South Africa	54 years
~~Canada~~	~~Decommissioned~~

The Mo-99 supply chain is increasingly vulnerable

Proven Technology

Technology proven by US National Laboratories and GE Healthcare

GE Healthcare

Argonne NATIONAL LABORATORY

SRNL

Los Alamos NATIONAL LABORATORY EST. 1943

OAK RIDGE National Laboratory

ACCELERATOR (ELIMINATES REACTOR)

+

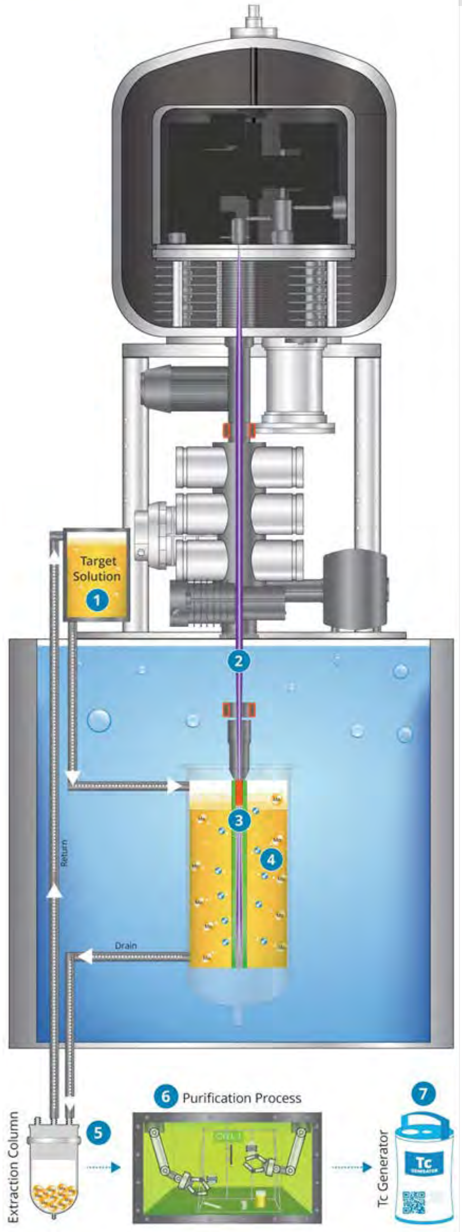
RE-USABLE LIQUID TARGET

=

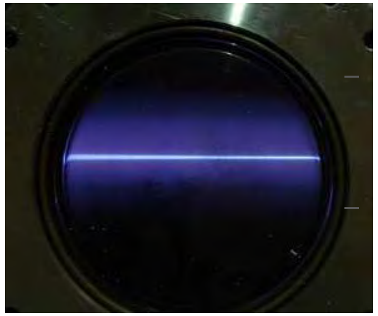
SAFER

100x LESS WASTE

LOWER COST



Technology Demonstrations



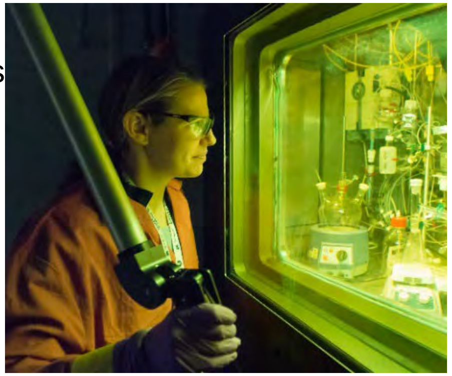
Phoenix Nuclear demonstrates production level beam current and voltage (Mar. 2012)

132 hour >97% uptime demonstration (Mar. 2016)

PHOENIX NUCLEAR LABS, LLC

Argonne National Laboratories demonstrates SHINE Process meets commercial purity requirements (June 2015)

Argonne NATIONAL LABORATORY



Data gathered at various laboratories prove feasibility of liquid target at scale (pre-2004)

SHINE and Los Alamos National Laboratory complete preliminary design and safety case for innovative, recoverable liquid target (Jun. 2013)

Los Alamos NATIONAL LABORATORY EST. 1943

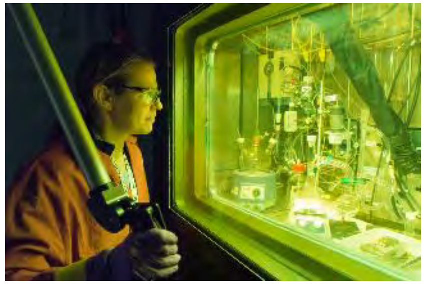
GE Healthcare tests product from SHINE process proving compatibility with GE Drytec distribution system (Nov. 2015)

GE further proves compatibility of SHINE Mo-99 by synthesizing Myoview and Ceretec injectables (Nov. 2015)

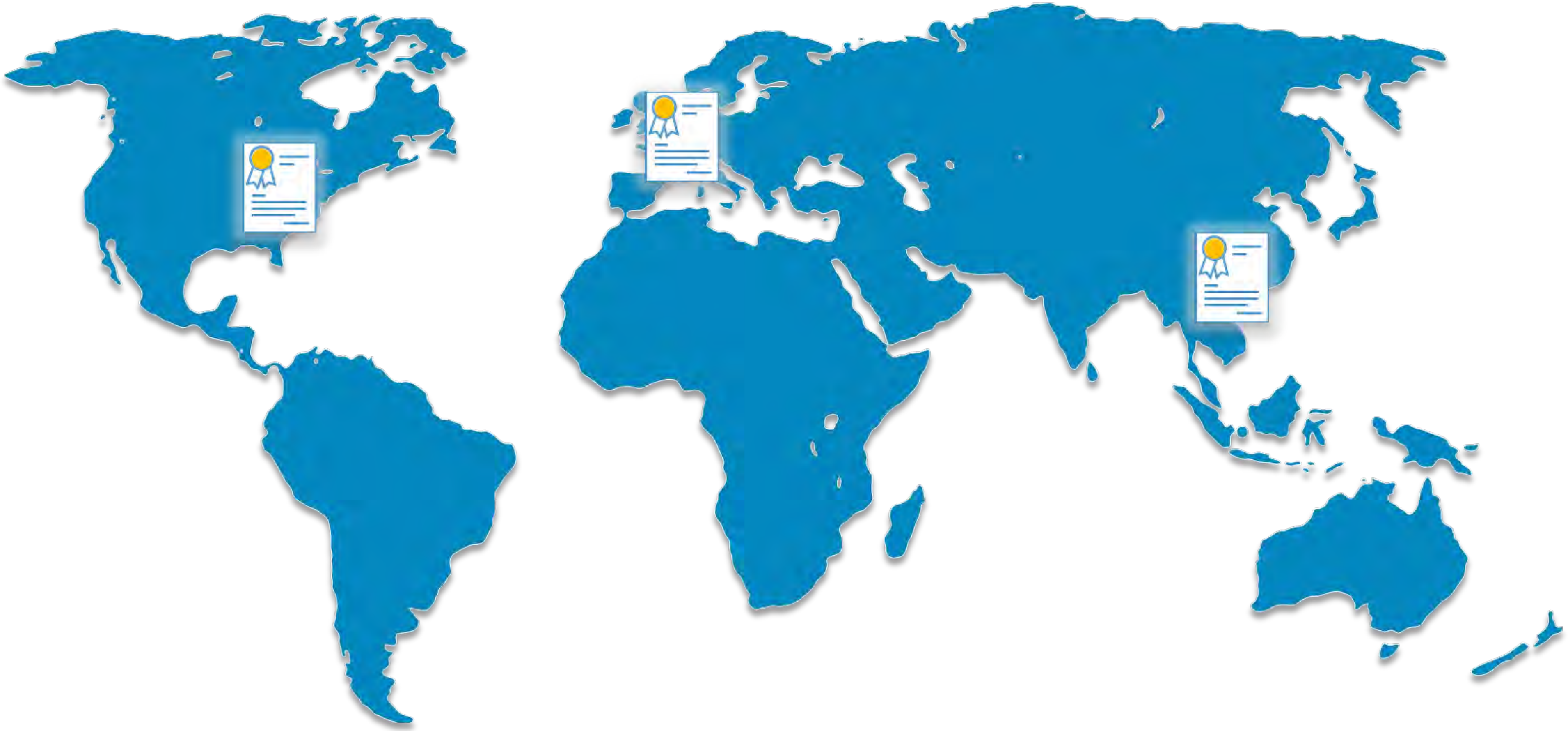
GE Healthcare

Every Part of the SHINE Process Has Been Demonstrated

Step	Demonstrated?
Accelerator	✓
Target Solution Irradiation	✓
Processing	✓
Generator loading	✓
Generator elution	✓
Kits	✓



Three signed customer contracts



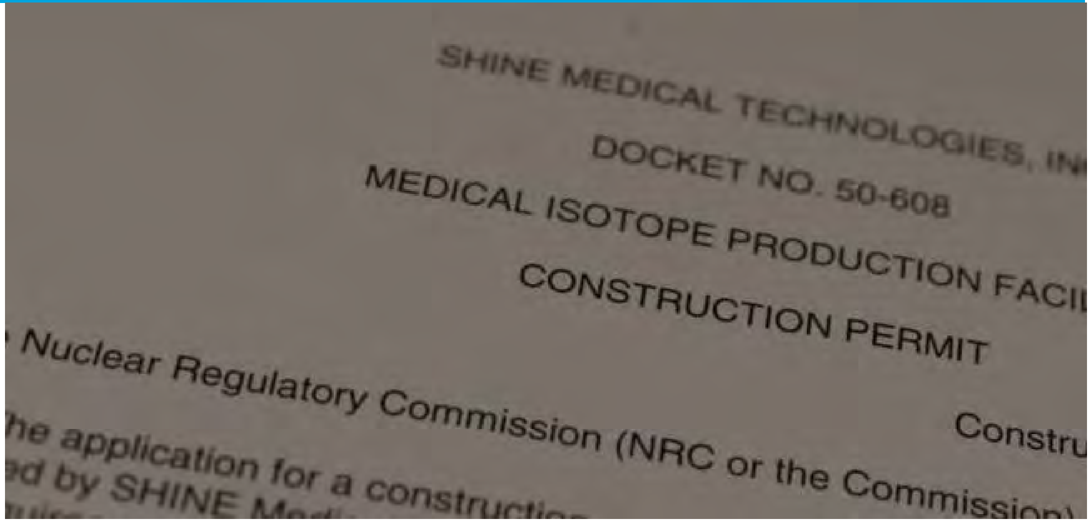
Lantheus Medical Imaging

GE Healthcare

原子高科股份有限公司
HTA CO. LTD.

Nuclear Regulatory Commission construction approval

- Issued Feb 2016
- Culmination of 4 years of work
- First approval of its kind since 1961


SHINE MEDICAL TECHNOLOGIES, IN
DOCKET NO. 50-608
MEDICAL ISOTOPE PRODUCTION FACIL
CONSTRUCTION PERMIT
Constru
Nuclear Regulatory Commission (NRC or the Commission)
he application for a construction
d by SHINE Me

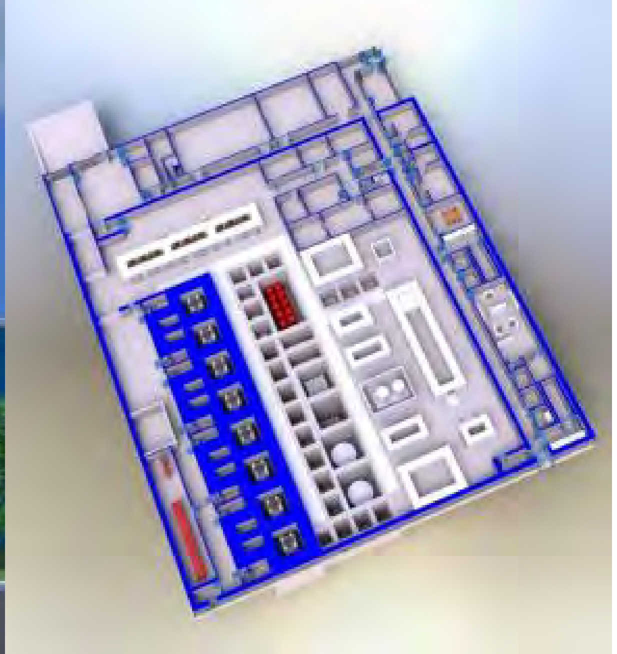
Building One: 1st building on the SHINE campus

- Groundbreaking August 2017
- Construction complete Q1 2018
  - Completed 3 weeks ahead of schedule
  - Zero OSHA-recordable incidents
- 11,400 square feet
- Licensed by State of Wisconsin
- Future use for employee training and technology development

Constructio
First Produc
demo Q1 20
Future use f
technology

Building One:
SHINE Technology Development Facility

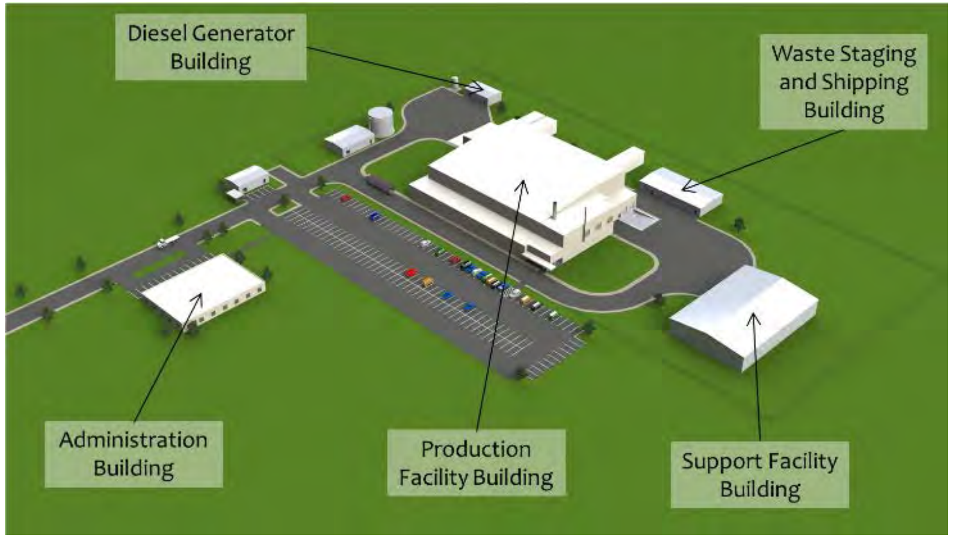
Next Steps



- Current key activities
  - Preparing OL application
  - Preparing for start of construction
  - Building One first production unit demo
  - Negotiating additional supply agreements
  - 80+ employees; 20 FT positions posted currently
- First production 2021

Production Facility Design

- To be built in Janesville, Wisconsin
- Mo-99 capacity >4,000 6-day Ci/wk
- Xe-133, I-131, Lu-177, Sr-89, others
- 8 independent irradiation units accelerators
  - High reliability
  - Flexible production schedule
- Close to regional airports
  - designed for logistical efficiency

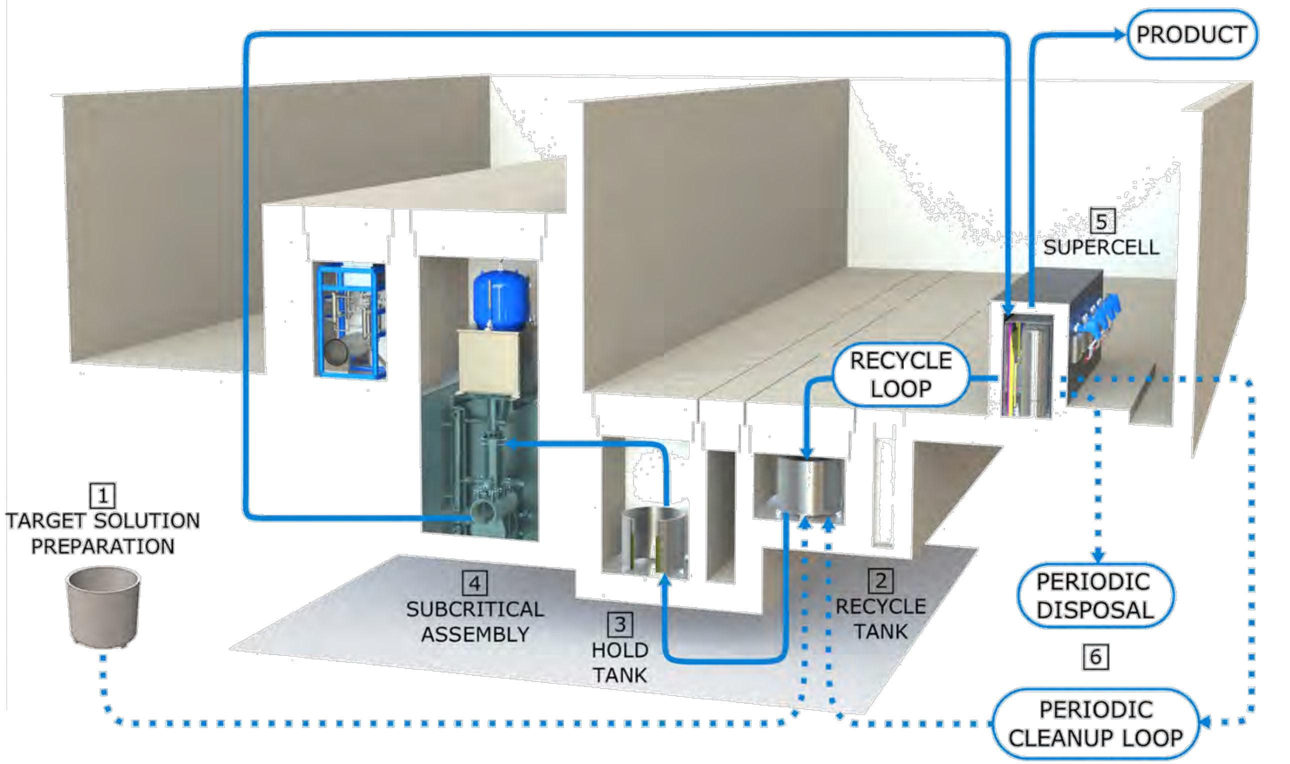


<50,000	8	3	>2/3
Square Feet	Accelerators	Independent Hot Cell Chains	Annual U.S. Demand Met

EPRI ELECTRIC POWER RESEARCH INSTITUTE

SHINE Process Overview

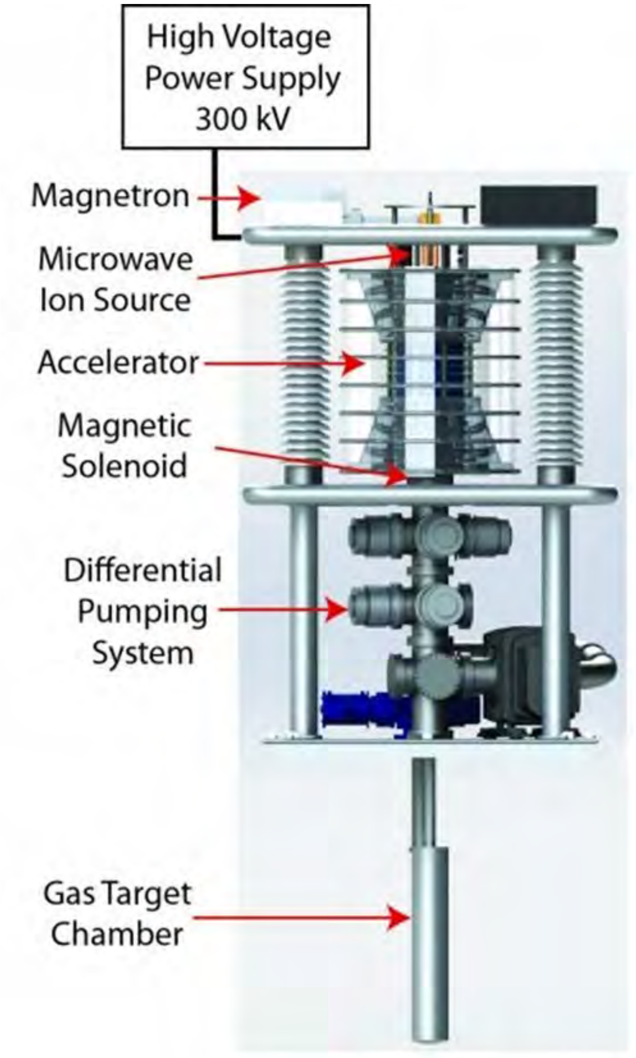
1. Periodic solution preparation
2. Solution chemistry check
3. Staging to fill target solution vessel
4. Irradiation
5. Extraction and purification
6. Periodic solution cleanup and disposal



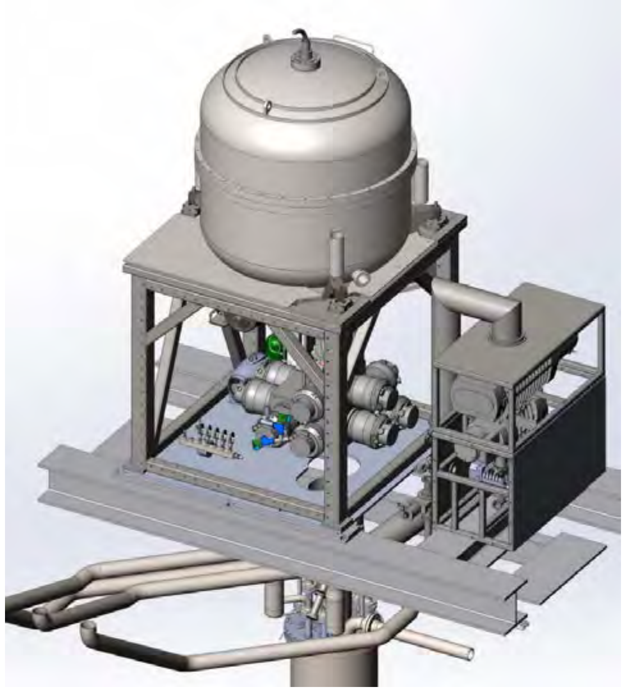
Technological Approach

- Small systems: Hundreds of times less power than isotope production reactors being used
- Low stored energy: low temperature and near atmospheric pressure
- Low enriched uranium (LEU) reusable target
- Driven by low-energy electrostatic accelerator
- Multiple units and trains provide operational scalability and flexibility

Neutron Generator



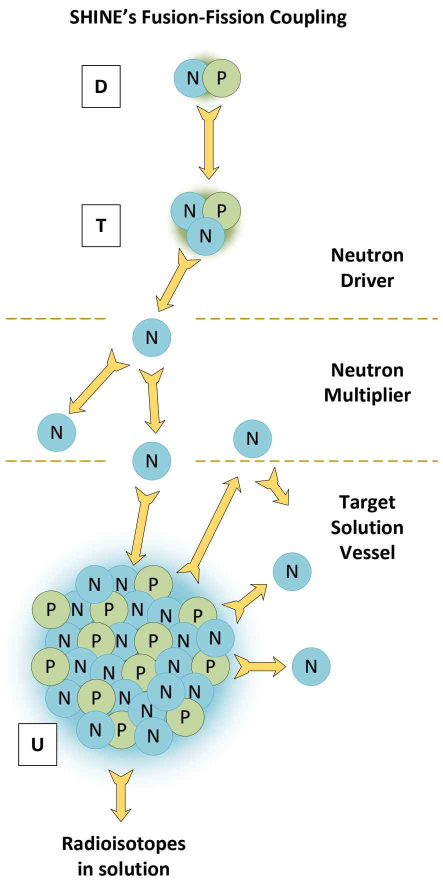
- Microwave ion source creates dense deuterium plasma
- Simple DC accelerator extracts deuterium ion beam (~300 keV, ~60 mA)
- Magnetic field focuses ion beam
- Differential pumping system keeps gas out of accelerator
- Beam strikes tritium gas target and generates neutrons
- 5 x 10^{13} neutrons/second total neutron output



Subcritical Assembly Overview

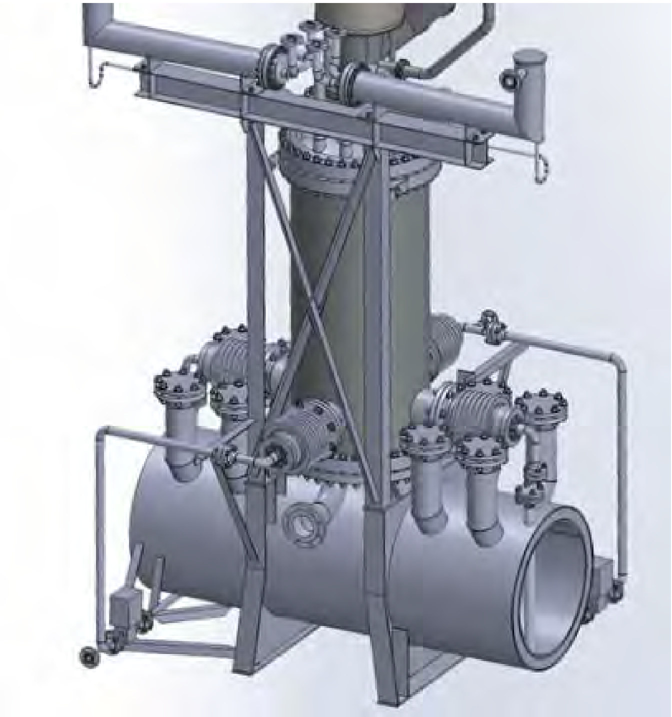
Subcritical assembly multiplies neutron yield, dramatically increasing isotope production

- Hybrid fusion-fission device
- How it functions
  - Neutrons from accelerator created in center of assembly (neutron spark plug)
  - Neutrons pass through neutron multiplier
  - Multiplied neutrons pass into uranium solution in TSV, where they cause fission
  - Extra neutrons further multiply and create more medical isotopes
  - Transfer solution to the processing facility for isotope removal



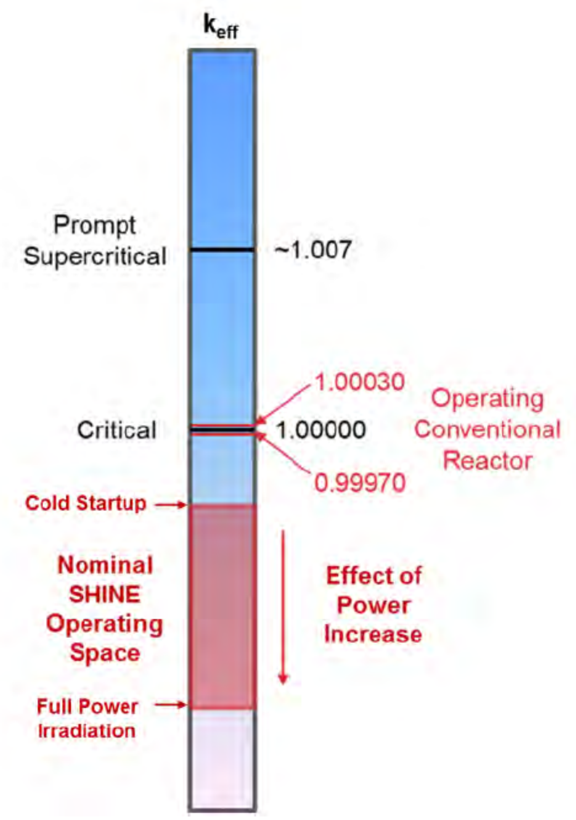
Subcritical Assembly

- Subcritical aqueous target allows high multiplication while keeping safely away from critical
- Small, bounded power changes in response to void and temperature
- No active reactivity control (i.e., control rods)
- Solution dumped if power limits exceeded
- Uranium target can be re-used
- Minimal decay heat after shutdown



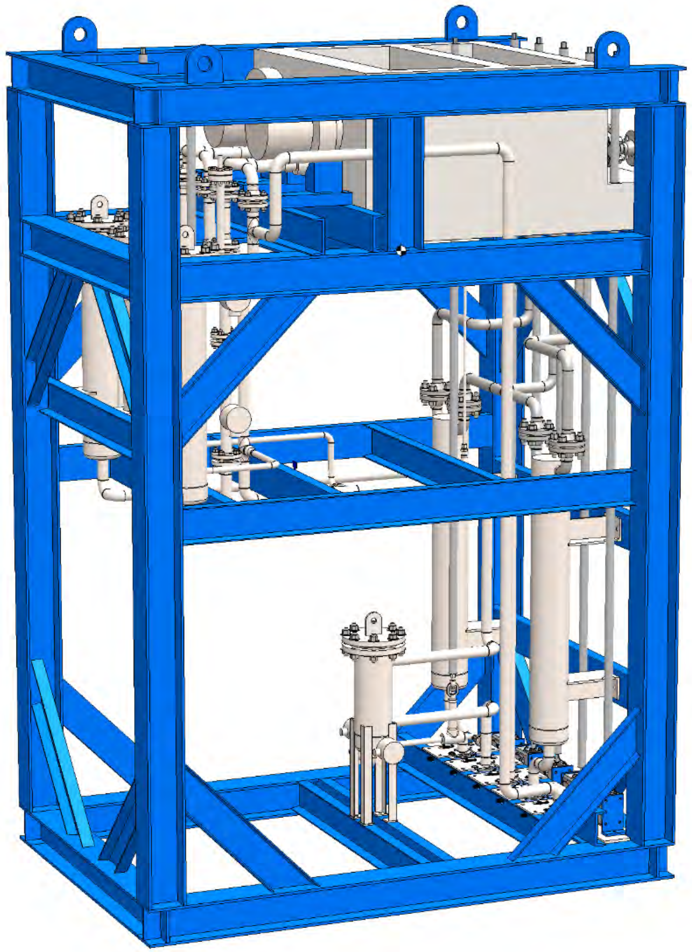
Neutronics Design - Startup

- Startup just like a reactor, except the endpoint is different
- Operators plot 1/M curve with solution volume
  - Add solution, allow flux to stabilize, record flux (1/M)
- Operators stop fill when 5% by volume below predicted criticality
- Nuclear systems become excellent predictors of critical states when near critical conditions
- Inherently slow reactivity additions
- Cold startup is most reactive state
- Driven further from critical during operation



Off-Gas System Design

- Provides continuous sweep gas through system
- Recombines hydrogen and oxygen from radiolysis
- Quickly returns the water to the system
- Regulates pressure within the system
- Skid designed for maintainability



Questions?

SHINE
PROSPECT 101
PROSPECT 101
SHINE™
Medical Technologies