Introduction to Advanced Nuclear

NARUC-DOE Nuclear Energy Partnership

FRIDAY, JUNE 4, 2021

2:00 – 3:00PM ET

WELCOME

Commissioner Tim Echols

Georgia Public Service Commission, Partnership Co-Chair

NARUC-DOE NUCLEAR ENERGY PARTNERSHIP

- Launched in March 2021 with support from the U.S. Department of Energy Office of Nuclear Energy
- An educational partnership that provides opportunities for state public service commissioners and commission staff to better understand barriers and possibilities related to the U.S. nuclear fleet, the nation's largest source of zero-carbon power
- Includes commissions and commission staff representing 20 states and territories
- Associate members from the Coalition for Advanced Reactor Solutions, University of Michigan Nuclear Engineering and Radiological Sciences, and the University of Illinois Nuclear, Plasma & Radiological Engineering

PANELISTS

- **Jeffrey Merrifield**, Partner, Pillsbury Law
- **Christine King**, Director, Gateway for Accelerated Innovation in Nuclear, Idaho National Laboratory
- **Nicholas McMurray**, Nuclear Program Director, ClearPath
- **Dr. Shannon Bragg-Sitton**, Lead, Integrated Energy Systems, Idaho National Laboratory

Latest Developments in Advanced Nuclear Technology

Jeffrey S. Merrifield, Partner, Energy Section Leader

June 4, 2021

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Introductions

- Honorable Jeffrey S. (Jeff) Merrifield
  - Energy Section Leader – Pillsbury Law Firm (2015-Present)
  - Commissioner – Appointed by Presidents Clinton and Bush to serve as U.S. NRC Commissioner (1998-2007)
  - Senior V.P. – Shaw Power Group/CBI – nuclear engineering, construction, maintenance and decommissioning (2007-2014)
  - Chairman, Advanced Nuclear Working Group – Nuclear Industry Council
  - Chairman – E4 Carolinas – Largest "All-in" U.S. Energy Association Outside of Washington
  - Chambers Ranked Attorney
- Pillsbury Winthrop Shaw Pittman LLP
  - International, 700+ attorney firm with 21 offices in key financial, energy, technology, and government centers (New York, Washington DC, London, Los Angeles, Houston, Austin, Silicon Valley, Beijing, Taipei, Shanghai, and Tokyo)
  - The oldest dedicated nuclear law group in the world
  - Industry-leading experience in energy and environmental regulatory and transactional law – 15 dedicated nuclear attorneys

Practice Areas/Industries

- Energy
- Nuclear Energy
- Strategic Planning
- Advanced Reactors
- Decommissioning
- Nuclear Security
- Mergers and Acquisitions
- Employee Concerns

U.S. Energy Companies that Have Pledged to Achieve 80-100% Carbon Free Generation By 2050

AEP American Electric Power

Xcel Energy

Consumers Energy

Southern Company

PSEG

DTE Energy

Ameren Missouri

OXY

nationalgrid

Alliant Energy

Duke Energy

Dominion Energy

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Advanced Nuclear Reactors – Definition/Classification

- Advanced nuclear is categorized in terms of electrical generation capacity
  - Microreactors: <10 MWe
  - Small-scale reactors: 10MWe - <300 MWe
  - Medium-scale reactors: 300-700 MWe
  - Large-scale reactors: >700 MWe
- Small-scale reactors are often characterized as small modular reactors (SMRs) to reflect method of fabrication and construction
- Further classified by type of moderator transferring heat from the fission reaction to the steam plant
  - Light water (LWRs)
  - High-temperature gas (HTGRs)
  - Liquid metal-cooled
  - Molten salt

Advanced nuclear largely represents innovative, evolutionary applications of historically proven design elements.

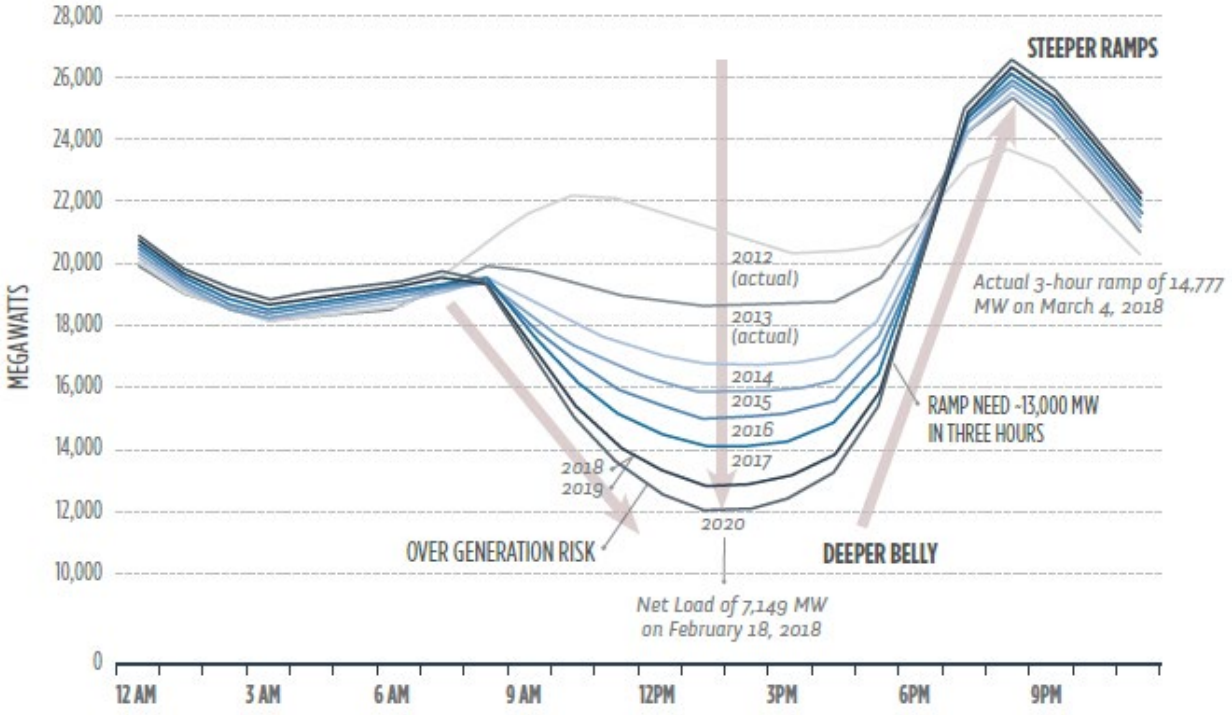
Shippingport: the first U.S. commercial nuclear power plant —and an SMR!

Representative Technologies

Design	Classification	Nameplate Capacity	Licensing Status
NuScale Reactor	Light Water	60 MWe	NRC Approved Final SER on 08/28/20. $1.4 billion DOE funding for UAMPs demonstration of 12-module reactor at Idaho National Laboratory.
GE Hitachi BWRX-300	Light Water	300 MWe	Selected as 1 of 3 designs for potential deployment by Ontario Power Generation (OPG). First licensing topical report submitted to NRC.
X-Energy XE-100	High-Temp Gas (Pebble Bed)	50 MWe	Selected for ARDP - $80 million by DOE. Selected as 1 of 3 designs by OPG. NRC pre-application discussions.
Terrestrial Energy IMSR	Molten Salt	195 MWe	Selected for USNRC/CNSC pilot project. Selected as 1 of 3 designs by OPG. NRC pre-application discussions.
TerraPower Natrium Reactor	Sodium Fast Reactor with Molten Salt Storage System	345 Mwe 500 MWe (5 ½ hours) - with Molten Salt	Selected for ARDP- $80 million by DOE.
Oklo Aurora	Metal	1.5 MWe	Filed a combined construction and operations license with the NRC on March 11, 2020.
Kairos Power	Pebble Bed with Molten Salt Coolant	140 MWe	Selected for $30 million risk reduction award by DOE.
Westinghouse eVinci	Solid Core Heat Pipe	200 kWe to 5 MWe	Selected for $30 million risk reduction award by DOE

Technical Advantages

- Smaller size/modularity
- Lower accident risk from improved safety features
- Emissions-free generation
- Load-following capability



The famous CAISO duck curve—illustrating the system challenges from pursuing decarbonization primarily through intermittent resources on a typical spring day (CPUC 2019, based on 2018 CAISO data)

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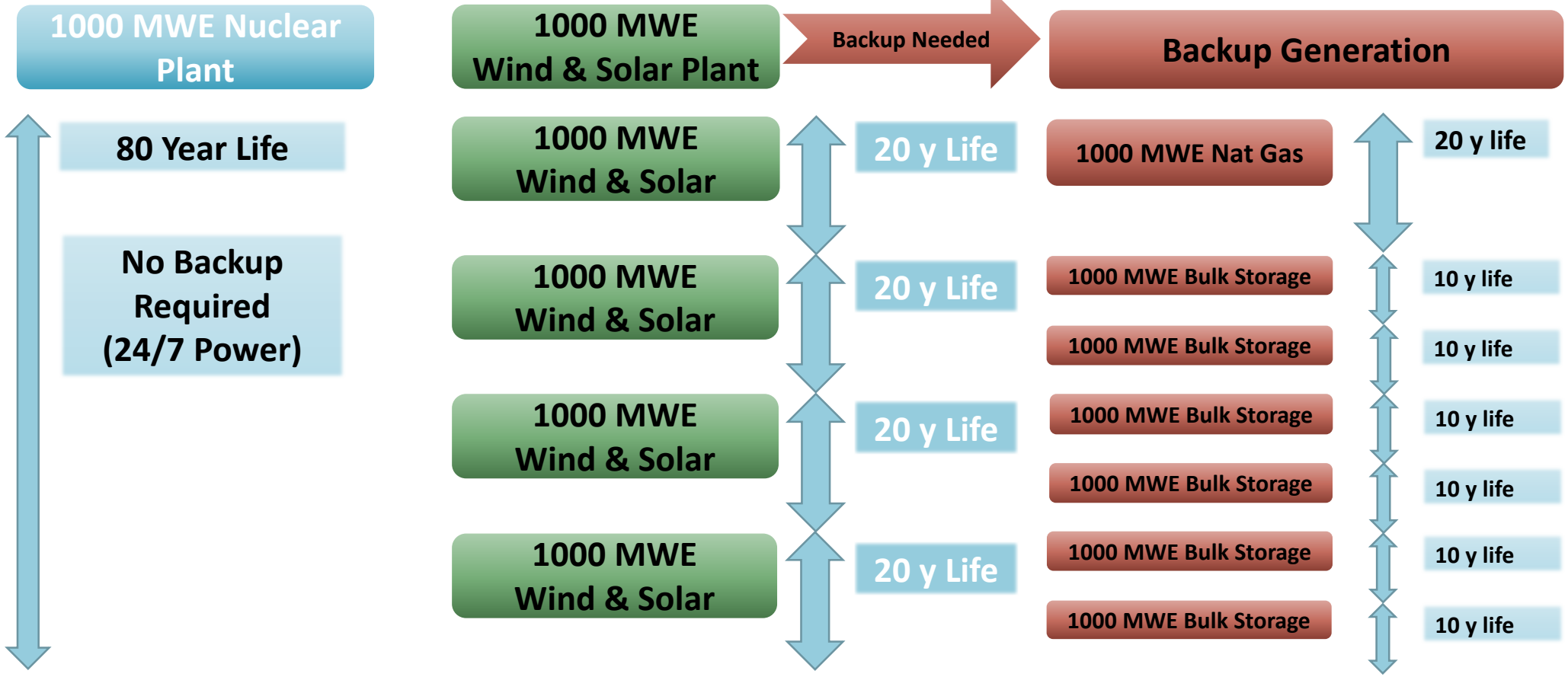
System/Operational Benefits

- No deep decarbonization without MORE nuclear
- Deep decarbonization will require electrification of new and energy-intensive economy sectors
- Resulting in increased electric demand and shifts in the demand curve
- A cost-efficient, farsighted approach to closing that gap integrates 24/7 advanced nuclear generation

Cost-Effective Element of a Deep Decarbonization Portfolio



Other Commercial/Regulatory Benefits

- Scalable, 24/7 power to meet incremental electric demand growth.
- Reduced overnight costs
  - Target cost $2,250-$3,500 KW
- Simplified regulatory and licensing structure
- Unique resilience benefits
- Greater flexibility means more potential applications, including…
  - Repowering existing fossil fuel sites
  - Process heat for industrial applications and water purification/desalination
  - Critical service applications

Oklo's Aurora reactor: construction at INL expected to start in mid-2020s. (Oklo 2019)

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Federal Action Expediting Commercialization

- Bipartisan Congressional support for advanced nuclear
  - FY2021 nuclear funding increased to $1.5 billion
  - Bipartisan nuclear legislation (NELA, etc.)
- Strong executive branch support for advanced nuclear—has been continued by incoming Biden Administration
  - FY2022 – Biden Administration Budget request of $1.86 billion
- October 2020: DOE announced first 2 Advanced Reactor Demonstration Program recipients (Terrapower and X-energy) providing in Year 1:
  (1) $160 million in DOE cost-sharing to deploy two advanced reactor demonstration projects, and
  (2) an additional $30 million (each) in DOE cost-sharing to support other five other advanced reactor designs
- U.S. NRC has directed significant resources toward adapting its licensing regime for advanced nuclear
- Development Finance Corporation announced it will provide loans and equity support for nuclear generation outside of the U.S.

THE WHITE HOUSE
WASHINGTON

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

U.S.NRC

NASA

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FY 2021 Omnibus (Authorizations – 5 years)

- $2.286 billion ($457 million per year): Nuclear Energy Research Infrastructure
- $174 million ($34.8 MPY): Production of High Assay Low Enriched Uranium
- $625 million ($125 MPY): Advanced Nuclear Fuels Research
- $2.14 billion ($428 MPY): Advanced Reactor Demonstration Program
- $275 million ($55 MPY): Advanced Reactor Technology Research
- $325 million ($65 MPY): Fusion Energy Research Program
- $300 million ($60 MPY): Nuclear Fuel Cycle Research and Development
- $100 million ($20 MPY): University Nuclear Research Program

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Summary

- Advanced nuclear energy in the U.S. is a strong bi-partisan issue
- Political recognition in Washington that global carbon reduction targets require nuclear
- President Biden, the DOE Secretary Grandholm and Secretary Kerry have endorsed the role of advanced nuclear in fighting global climate change
- Growing view among mainstream environmental groups - nuclear needs to be part of the solution
- Carbon reduction/avoidance benefits of nuclear is the major selling point today
- Jobs, export potential and ability to counter Russia and China are key motivators
- Increasing view that Canada and the U.S. would benefit from a coordinated approach

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Closing Thoughts and Contact Information

Questions?

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Introduction to Advanced Nuclear

NARUC-DOE Nuclear Energy Partnership

Christine King, Director Gateway for Accelerated Innovation in Nuclear

Shannon Bragg-Sitton, Director Integrated Energy Systems

June 4, 2021

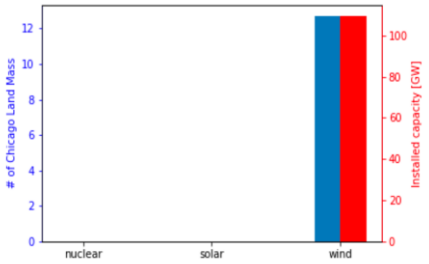
GAIN
Gateway for Accelerated Innovation in Nuclear

@GAINnuclear
gain.inl.gov

GAIN Energy Calculator

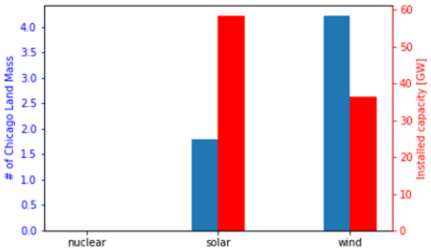
Energy Calculator is available here (https://gain.ornl.gov/#/)

GAIN POC: Andy Worrall



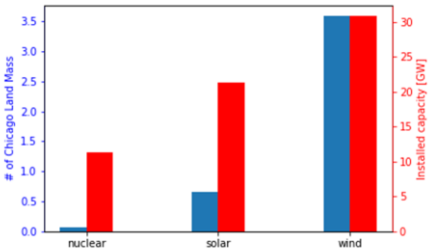
100% Wind Scenario

20 times expansion of wind
Land mass of 12-Chicagos



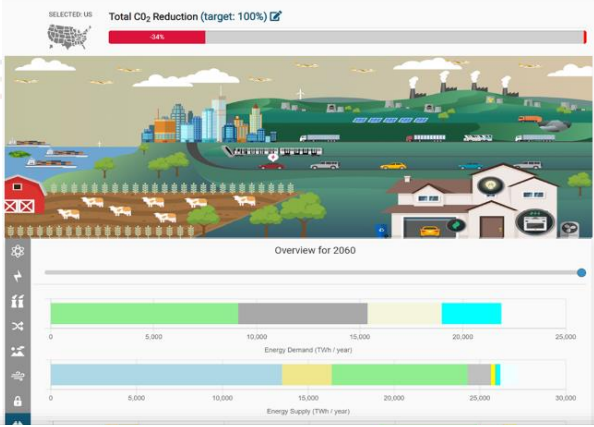
50% Solar, 50% Wind Scenario

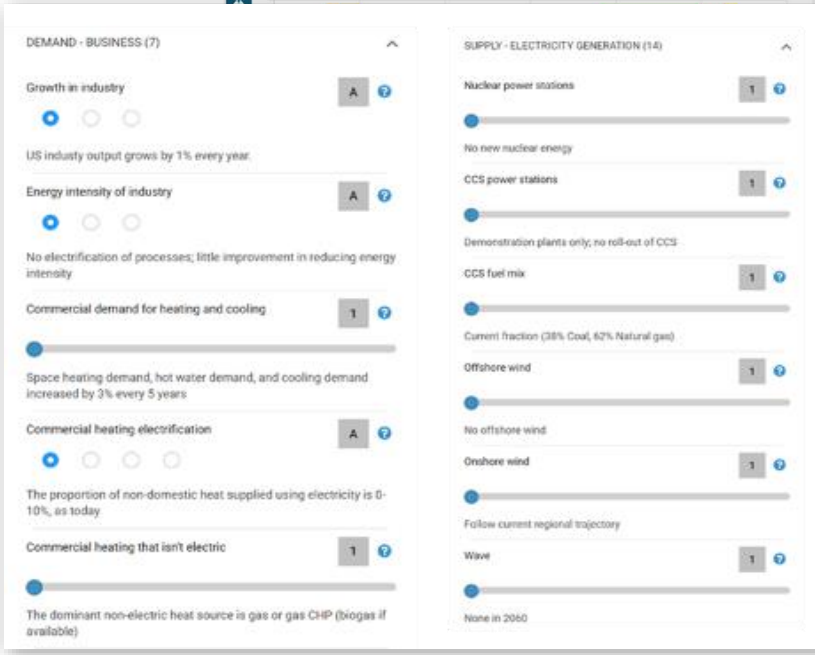
Substantial expansion of solar and wind
Land mass of 6-Chicagos



Mixed Scenario

50% Nuclear, 15% solar, 35% wind
60% reduction in land mass required
< 5-Chicagos

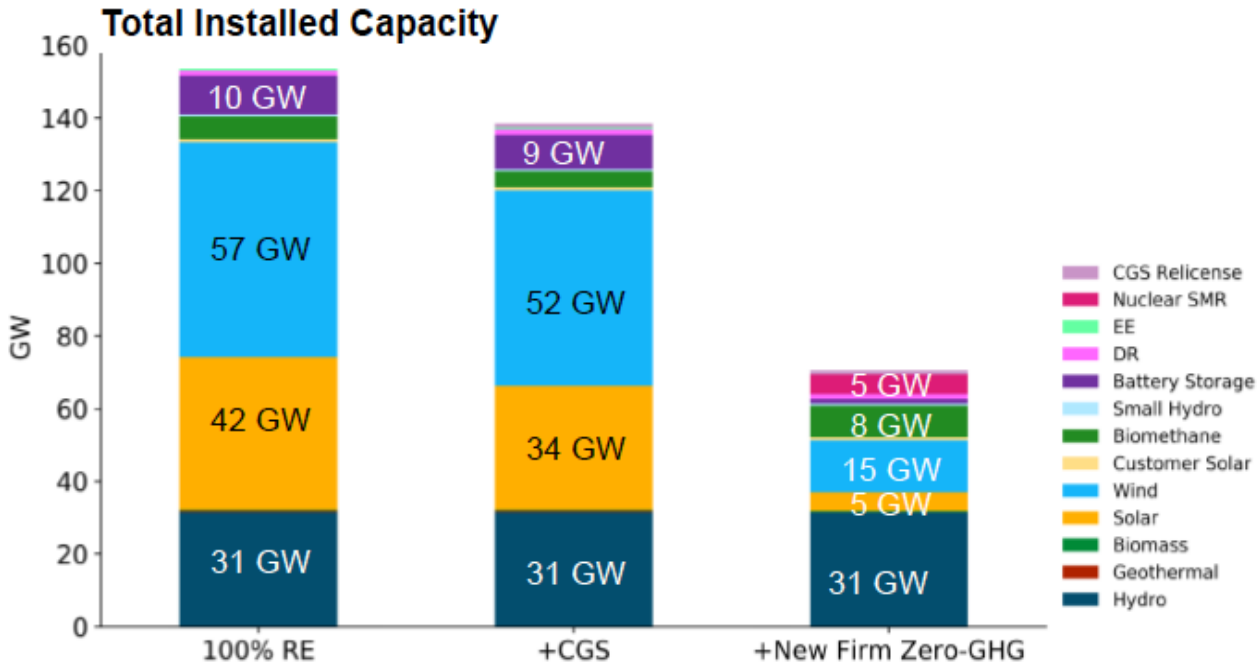




Advanced Reactor Future State: One size does not fit all

Meeting Emissions Goals with Nuclear: Example Case

- E3 study for Energy Northwest on achieving 100% carbon free by 2045:
  - Firm zero-emitting resources like nuclear reduce costs up to $8B per year
  - Adding 6.5GW firm avoids 91GW non-firm
- Other studies have been shared publicly



Pacific Northwest Zero-Emitting Resources Study, Energy and Environmental Economics, Inc. https://www.ethree.com/wp-content/uploads/2020/02/E3-Pacific-Northwest-Zero-Emitting-Resources-Study-Jan-2020.pdf


Stage 1
Research
Stage 2
Development
Stage 3
Demonstration
GAIN
&
NRIC
Concept
Commercial
Product

Public-Private Partnerships

Name	#	Size, Length	Cost Share	Federal ($M)	Private ($M)	Total ($M)
NE Voucher (GAIN)	60	<$500K, 1 year	80/20	19	5	24
Industry Funding Opportunity Announcement (FOA) -1817						
First of a Kind	6	$10-40M, 3 year	50/50	70	72	142
Adv Rx Dev	23	$500K – 20M, 2 year	80/20	89	38	127
Reg Assist	9	$50 – 500K, 1 year	80/20	4.2	1.5	5.7
Advanced Reactor Demonstration Program						
Demo	2	$160M, within 5-7 years	50/50	2,620	2,620	5,240
Risk Reduction	5	$30M, within 10-14 years	80/20	602	403	1,005
Adv Rx Con	3	$20M, demo in mid 2030s	80/20	56	14	70
				3,460	3,153	6,614

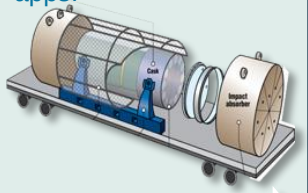
2016 $2M **2017 $4M** **2018 $157M** **2019 $87M** **2020+ $6.4B**

Vision for Advanced Reactor Demonstrations and Deployment

Opportunities ahead of us

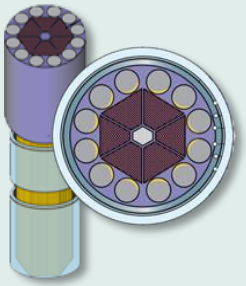
Demonstrate First Microreactors in Early 2020s

- Resolve key advanced reactor issues
- Open new markets for nuclear energy
- Provide a “win” to build positive momentum
- Civilian and federal apps.



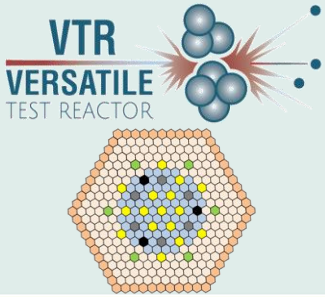
Microreactors Deployed

- Support deployment for remote site power and process heat customers
- RD&D to enable broader deployment



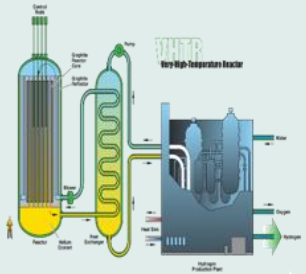
Versatile Test Reactor (VTR) Operating

- Establish fast-spectrum testing and fuel development capability
- Support non-LWR advanced reactor demonstrations



Advanced Reactor Demonstrations

- DOE-NE Advanced Reactor Demonstration Program
- Demonstrate two advanced reactors



Small Modular Reactor Operating

- Enable deployment through siting and technical support
- 2029 - First NuScale module (UAMPS) to commence commercial operation

2025 — **2028** — **2029**

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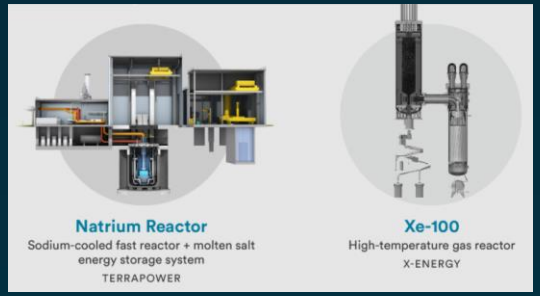
Advanced Reactor Demonstration Projects

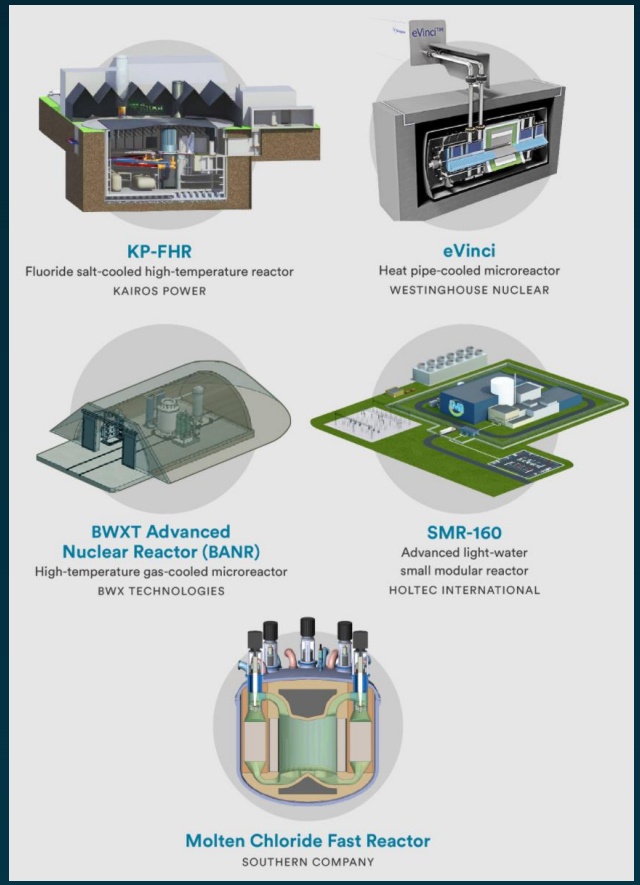
Demonstration



Natrium Reactor
Sodium-cooled fast reactor + molten salt energy storage system
TERRAPOWER

Xe-100
High-temperature gas reactor
X-ENERGY

Risk Reduction



KP-FHR
Fluoride salt-cooled high-temperature reactor
KAIROS POWER

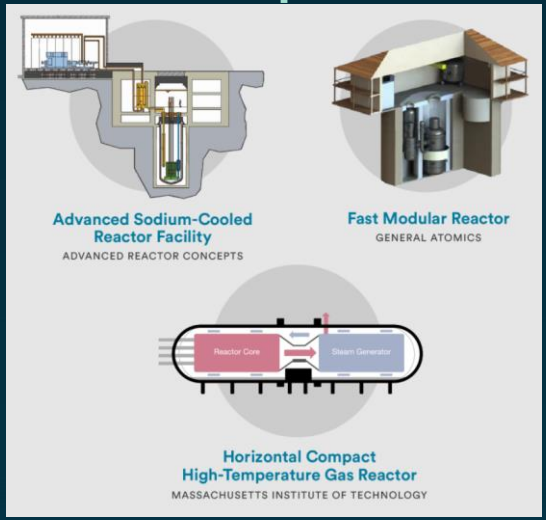
eVinci
Heat pipe-cooled microreactor
WESTINGHOUSE NUCLEAR

BWXT Advanced Nuclear Reactor (BANR)
High-temperature gas-cooled microreactor
BWX TECHNOLOGIES

SMR-160
Advanced light-water small modular reactor
HOLTEC INTERNATIONAL

Molten Chloride Fast Reactor
SOUTHERN COMPANY

Concept Development



Advanced Sodium-Cooled Reactor Facility
ADVANCED REACTOR CONCEPTS

Fast Modular Reactor
GENERAL ATOMICS

Horizontal Compact High-Temperature Gas Reactor
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Slide content courtesy of U.S. DOE-NE

Additional Projects with National Reactor Innovation Center Support

- Oklo
- Micronuclear
- Radiant
- DOD SCO Pele
- MARVEL

OKLO

RADIANT

Westinghouse

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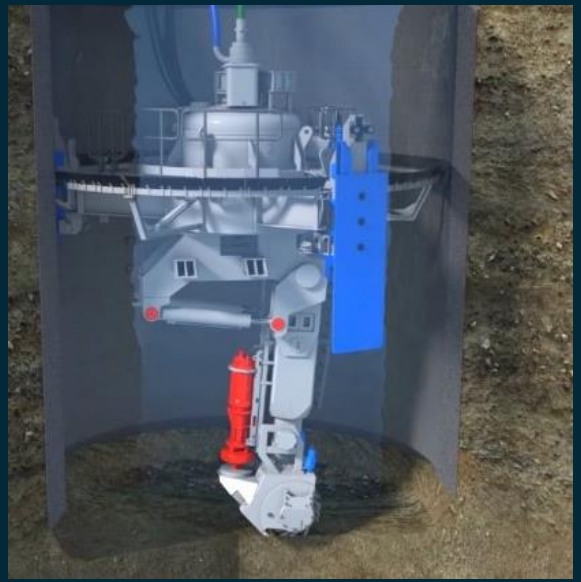
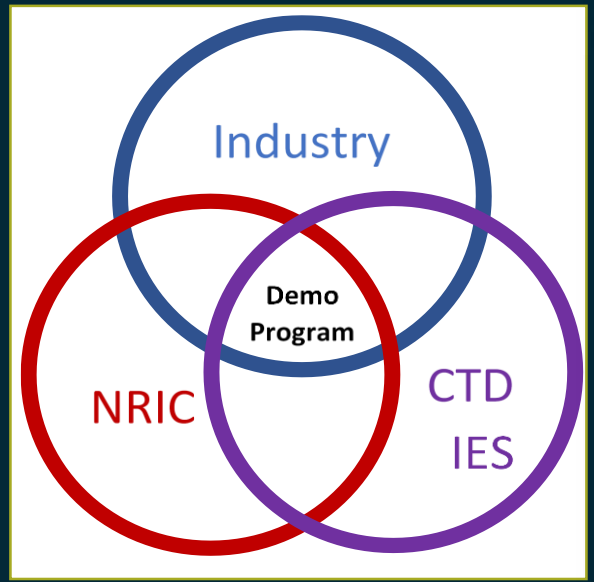
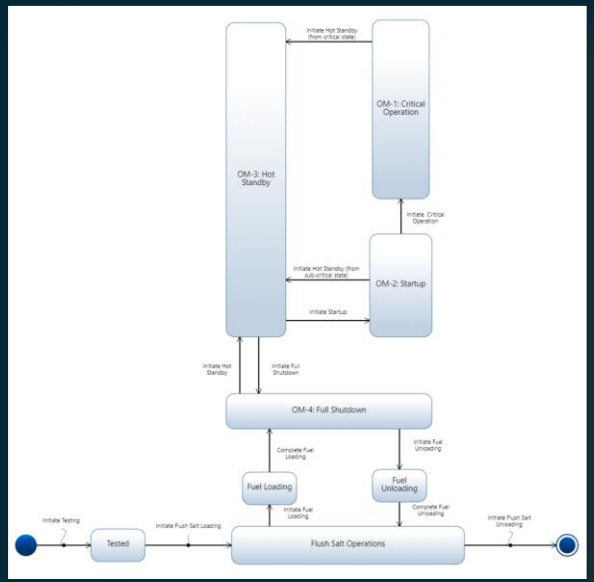
Addressing Cost and Markets

- Advanced Construction Technologies
- Digital Engineering
- Construction Readiness
- Integrated Energy Systems
  - Expression of Interest (EOI) released April 22, 2021







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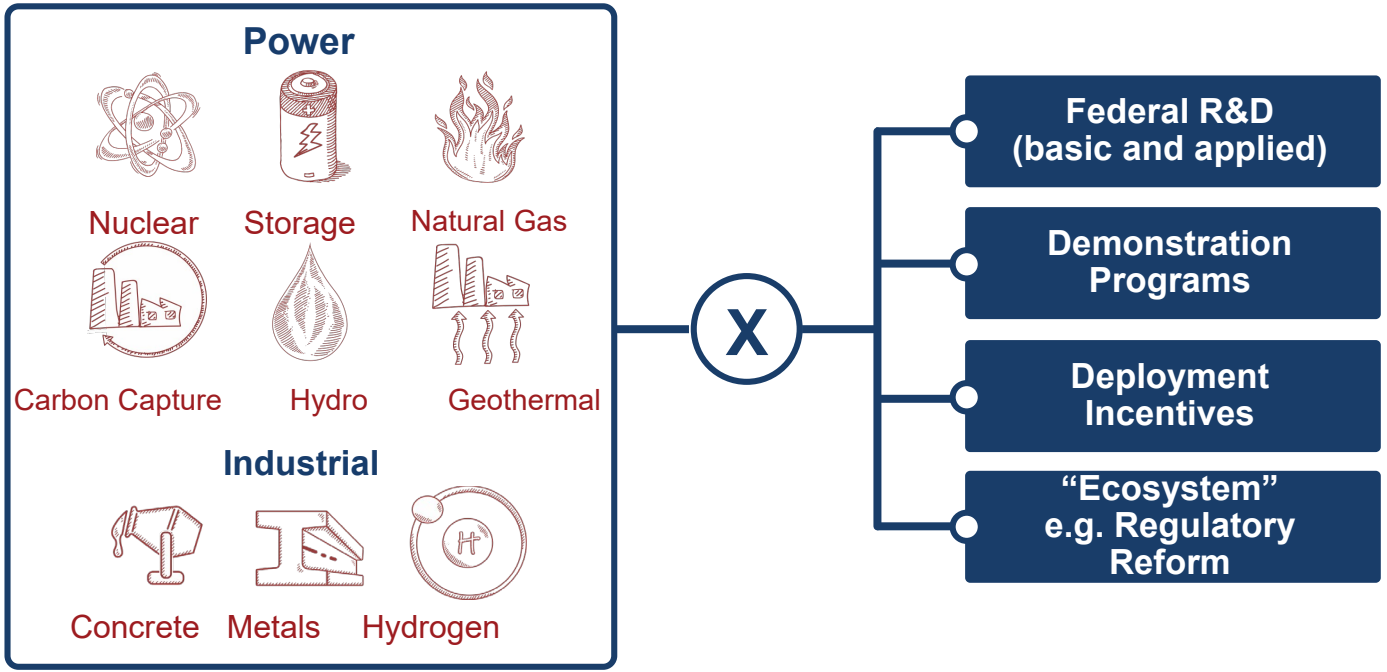
CLEARPATH

NARUC
NEP June Webinar
Intro to Advanced Nuclear

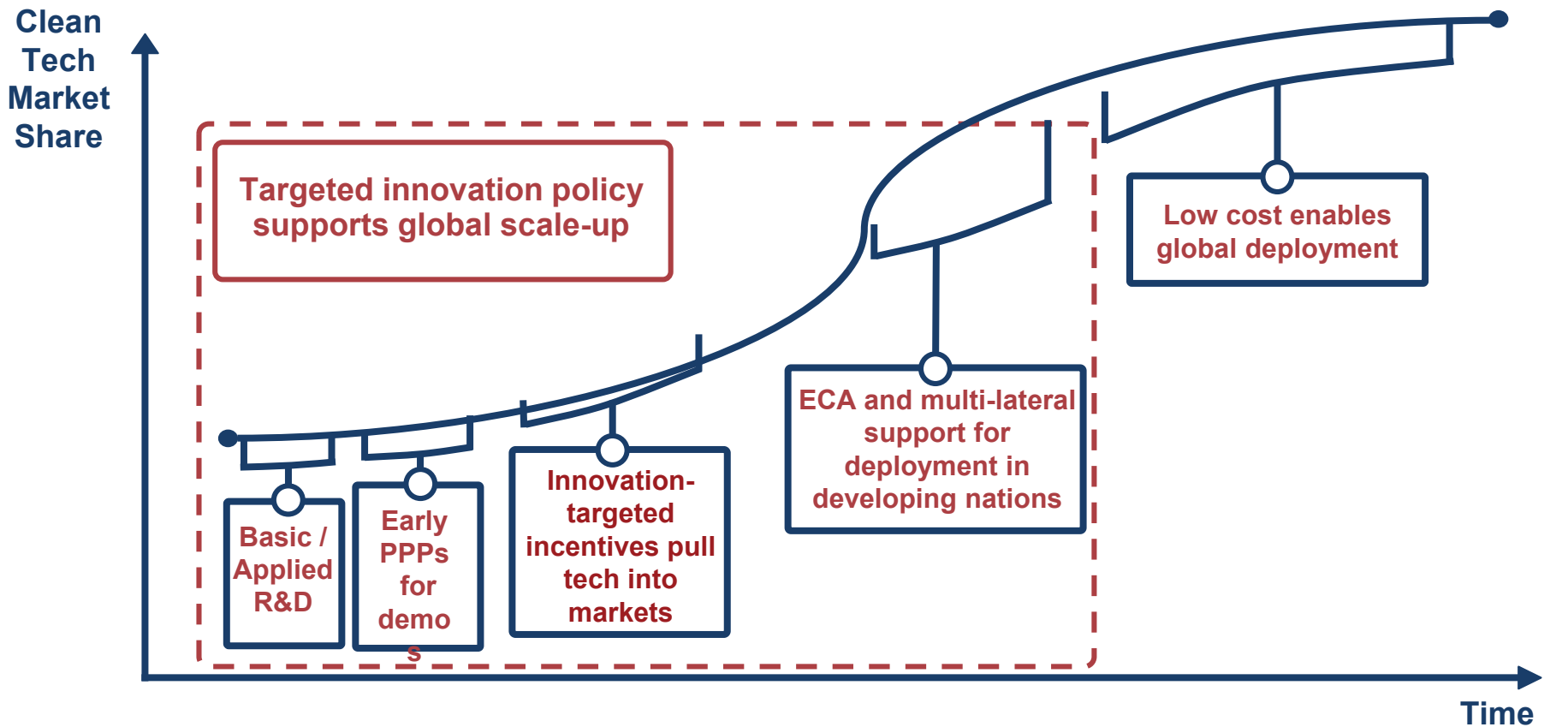
June 4, 2021

CLEARPATH

Key technologies and policy areas



From gas to solar, cheap clean technology has received public policy support to move it up the the global “S curve”



Biggest Climate Policy Success in Over a Decade

The Energy Act of 2020

20+ Large-Scale Clean Energy Demonstrations

- Advanced Nuclear
- Carbon Capture, Utilization, Storage
- Enhanced Geothermal Systems
- Grid-scale Energy Storage
- Industrial Decarbonization Technologies

Early to Mid-2020s

Advanced Nuclear Fuel Availability Program

Integrated Energy Systems and Hydrogen Demos

Enhancements to Loan Guarantee program

- No fees until financial closing
- Ability to reduce fees, provide a credit subsidy
- Project eligibility expansion, more transparency

Research, development, demonstration, and technical assistance for industrial energy

- Plan to develop and deploy smart manufacturing technologies

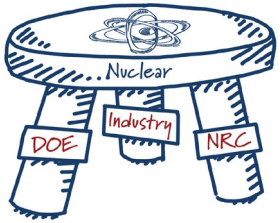
Elevate the DOE Office of Technology Transitions

- Empowers office to better support American entrepreneurship

NRC Modernization

Recent Actions

- Advanced reactors are different than currently operating reactors
- NRC is modernizing its requirements to account for unique design features (NEIMA)
- Many ongoing, interconnected efforts



Part 53

- **Create a new licensing process for advanced reactors**
- Rulemaking plan SECY-20-0032 (ML19340A056)
- 10/2024 - Final rule
  10/2022 - Proposed rule

Emergency Planning

- **Ongoing rulemaking**
- Codifies the approval in Clinch River Early Site Permit

AdvRx GEIS

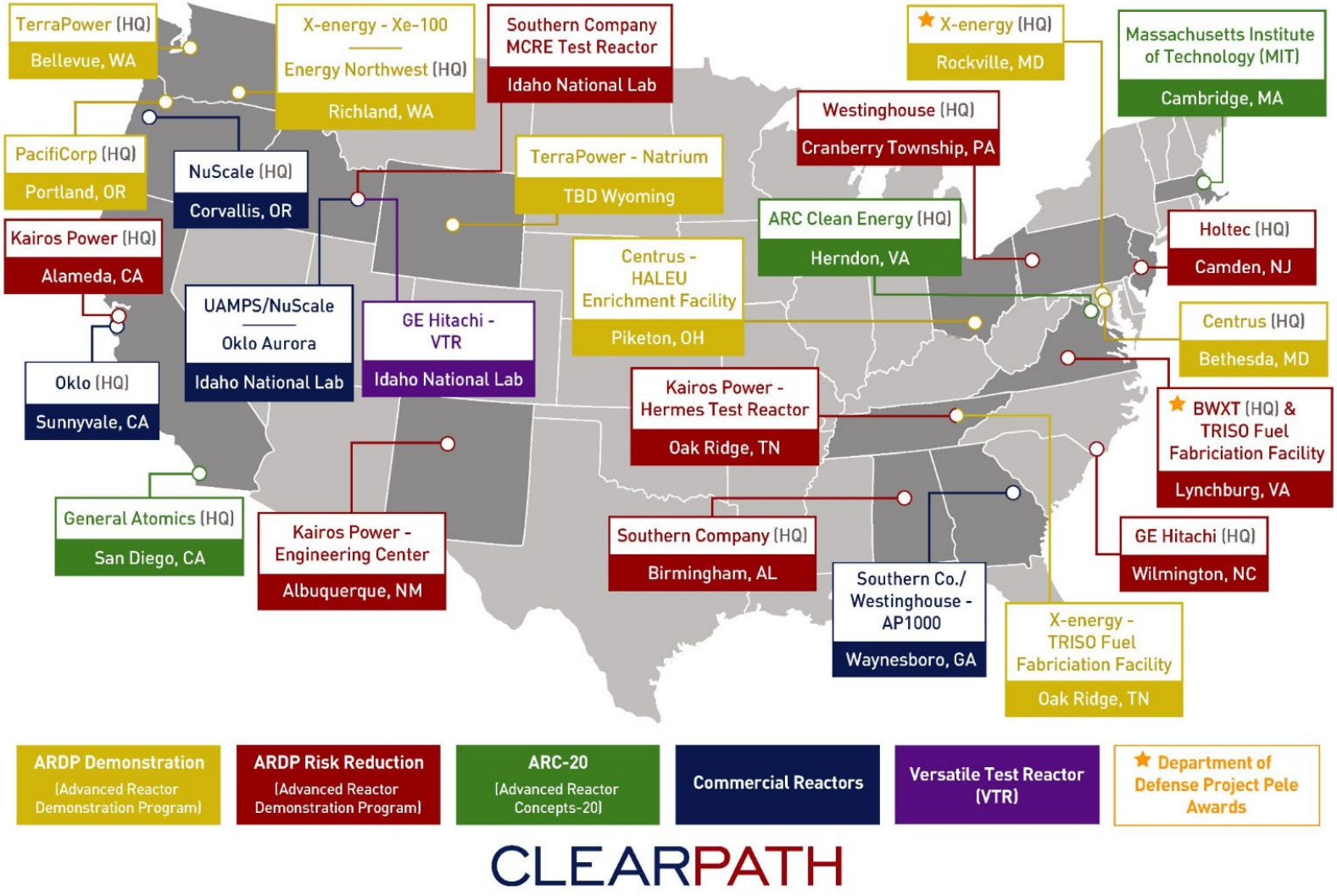
- **Scoping completed**
- Treat some concepts generically, similar to other NRC GEIS
- May 2022 - Draft GEIS issued for comment

Environmental Rulemaking

- **Multiple actions to modernize environmental review**
- Rulemaking plan, SECY-21-0001
- **Commission still has to vote**
- 2024 - Expected final rule

Other Topics

- Align with NRC AdvRx Vision and Strategy
- Technical topics, like design codes, fuel, and PRA
- Security, siting, fees, insurance, microreactors


TerraPower (HQ)
Bellevue, WA
X-energy - Xe-100
Energy Northwest (HQ)
Richland, WA
Southern Company
MCRE Test Reactor
Idaho National Lab
X-energy (HQ)
Rockville, MD
Massachusetts Institute of Technology (MIT)
Cambridge, MA
Westinghouse (HQ)
Cranberry Township, PA
PacifiCorp (HQ)
Portland, OR
NuScale (HQ)
Corvallis, OR
TerraPower - Natrium
TBD Wyoming
ARC Clean Energy (HQ)
Herndon, VA
Holtec (HQ)
Camden, NJ
Kairos Power (HQ)
Alameda, CA
Centrus - HALEU Enrichment Facility
Piketon, OH
UAMPS/NuScale
Oklo Aurora
Idaho National Lab
GE Hitachi - VTR
Idaho National Lab
Centrus (HQ)
Bethesda, MD
Oklo (HQ)
Sunnyvale, CA
Kairos Power - Hermes Test Reactor
Oak Ridge, TN
BWXT (HQ) & TRISO Fuel Fabriciation Facility
Lynchburg, VA
General Atomics (HQ)
San Diego, CA
Kairos Power - Engineering Center
Albuquerque, NM
Southern Company (HQ)
Birmingham, AL
GE Hitachi (HQ)
Wilmington, NC
Southern Co./ Westinghouse - AP1000
Waynesboro, GA
X-energy - TRISO Fuel Fabriciation Facility
Oak Ridge, TN
ARDP Demonstration
(Advanced Reactor Demonstration Program)
ARDP Risk Reduction
(Advanced Reactor Demonstration Program)
ARC-20
(Advanced Reactor Concepts-20)
Commercial Reactors
Versatile Test Reactor (VTR)
Department of Defense Project Pele Awards

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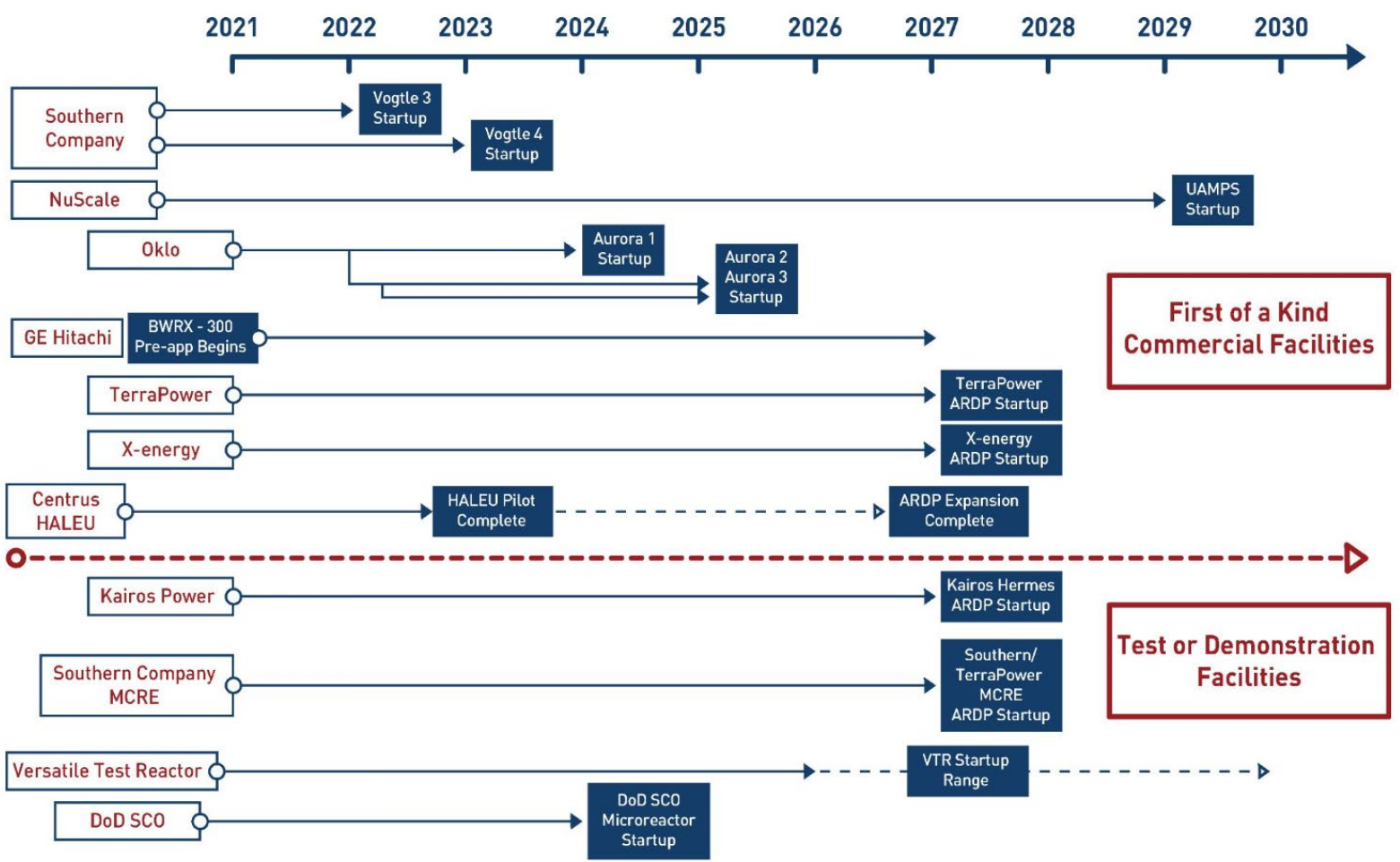

2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Southern Company
Vogtle 3 Startup
Vogtle 4 Startup
NuScale
UAMPS Startup
Oklo
Aurora 1 Startup
Aurora 2 Aurora 3 Startup
First of a Kind Commercial Facilities
GE Hitachi
BWRX - 300 Pre-app Begins
TerraPower
TerraPower ARDP Startup
X-energy
X-energy ARDP Startup
Centrus HALEU
HALEU Pilot Complete
ARDP Expansion Complete
Kairos Power
Kairos Hermes ARDP Startup
Test or Demonstration Facilities
Southern Company MCRE
Southern/ TerraPower MCRE ARDP Startup
Versatile Test Reactor
VTR Startup Range
DoD SCO
DoD SCO Microreactor Startup

CLEARPATH

IES
Integrated Energy Systems

The Role of Nuclear Energy in the Future Grid and Energy Markets

IAEA Virtual Workshop

Economics of Emerging Reactor Concepts, including Micro- and Small Modular Reactors

4 June 2021

Shannon Bragg-Sitton

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

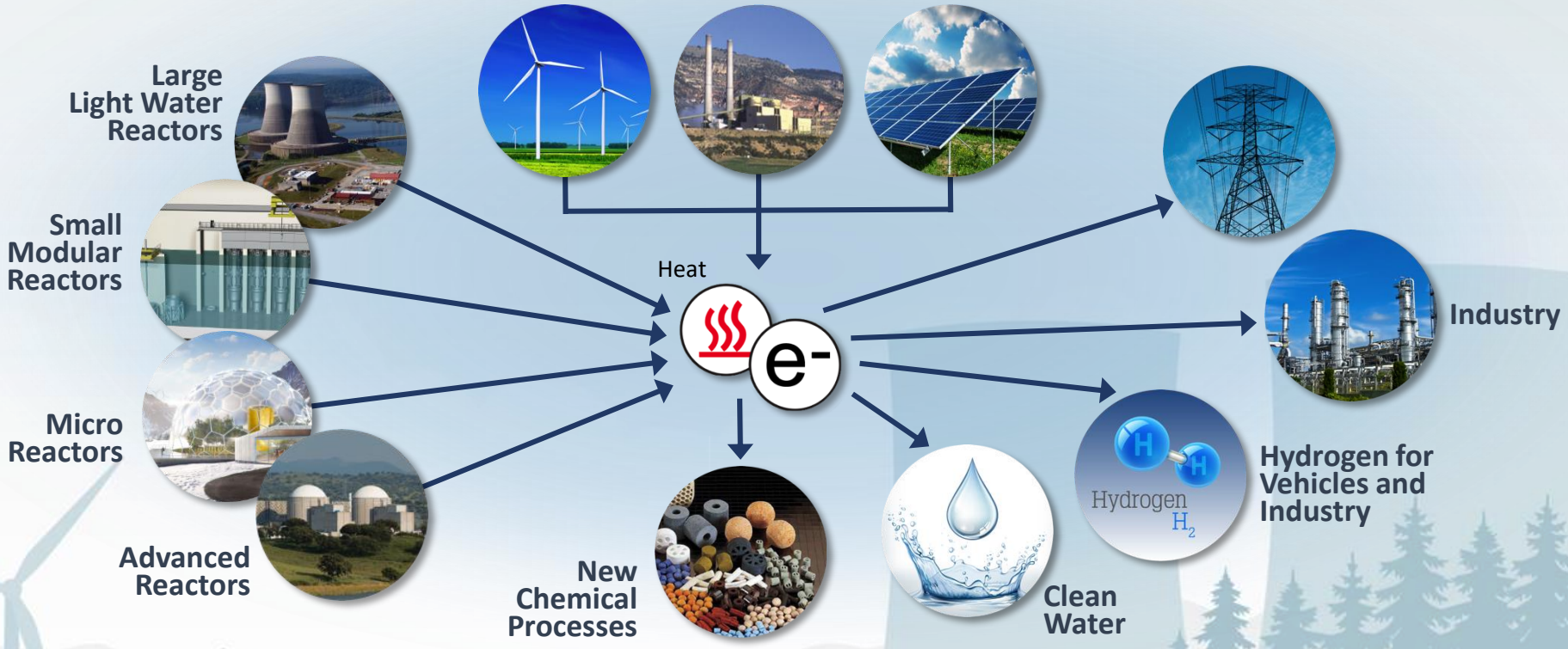
National Technical Director, DOE-NE Integrated Energy Systems

shannon.bragg-sitton@inl.gov

INL
Idaho National Laboratory

IES
Integrated Energy Systems

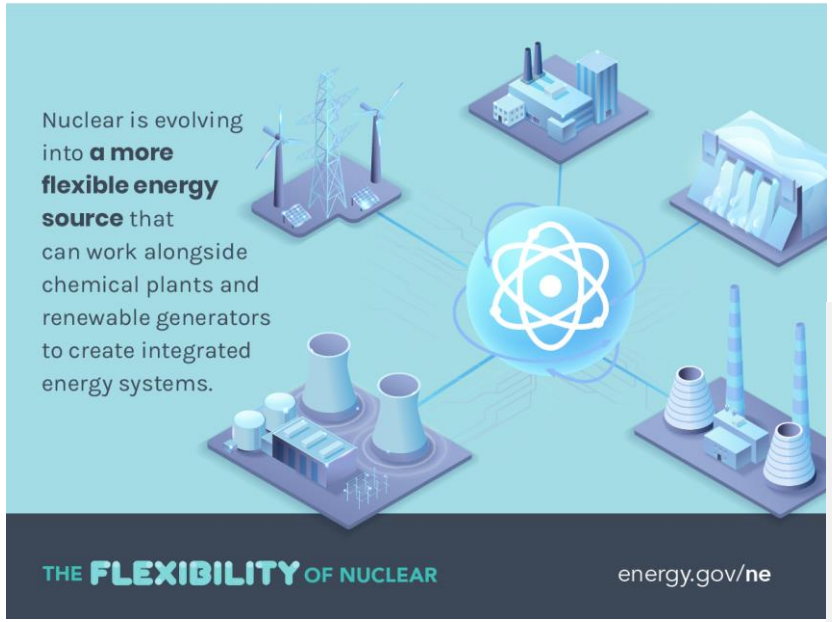
Future clean energy systems would leverage contributions from low emission energy generation for electricity, industry, and transportation



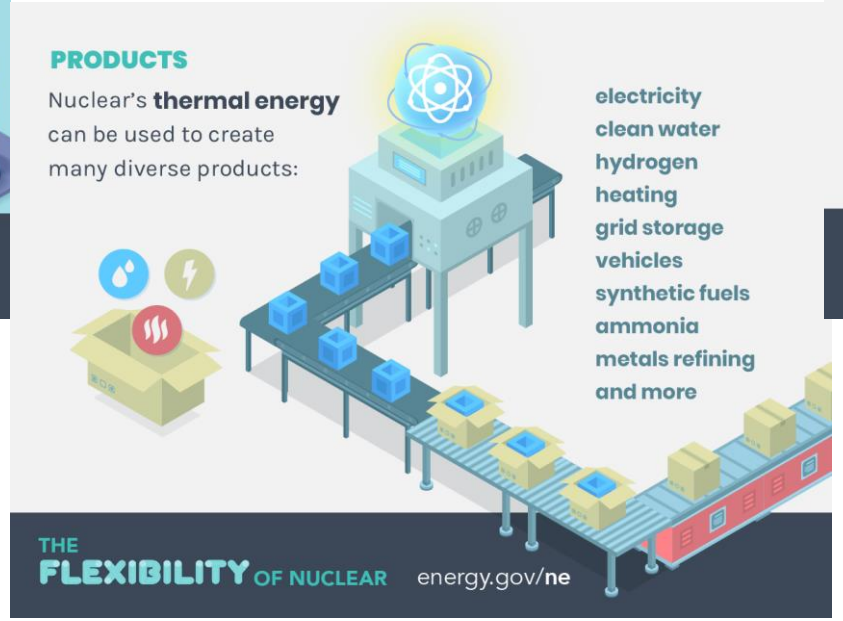
Goals

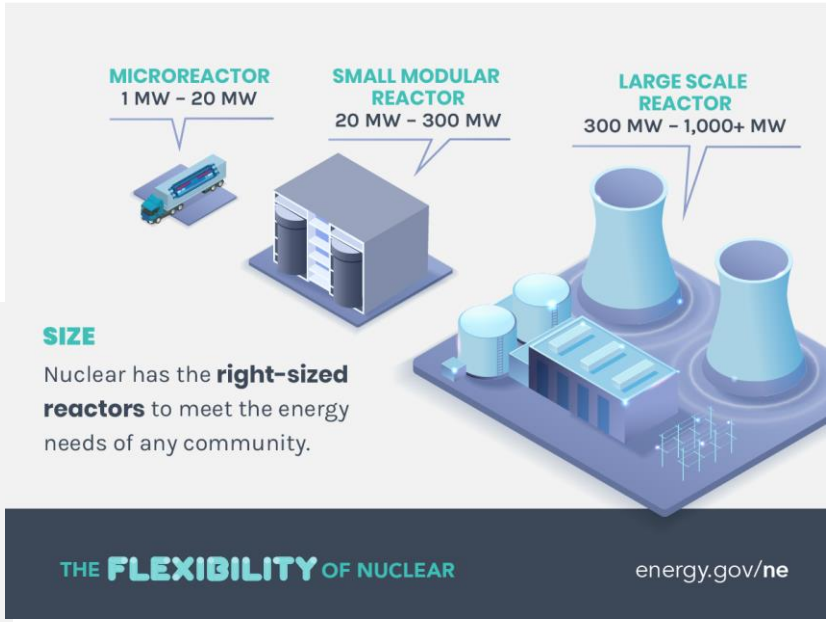
- Maximize energy utilization and generator profitability
- Minimize environmental impacts
- Maintain affordability, grid reliability and resilience

New operational paradigms—nuclear energy flexibility



Nuclear flexibility can be key in enabling other clean energy generators.





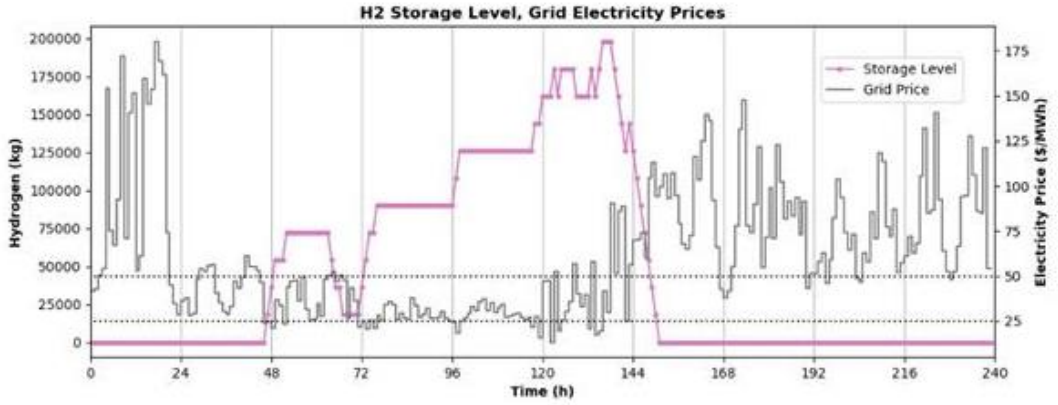
- ***Operational* flexibility**
  - ***Product* flexibility**
    - ***Deployment* flexibility**

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

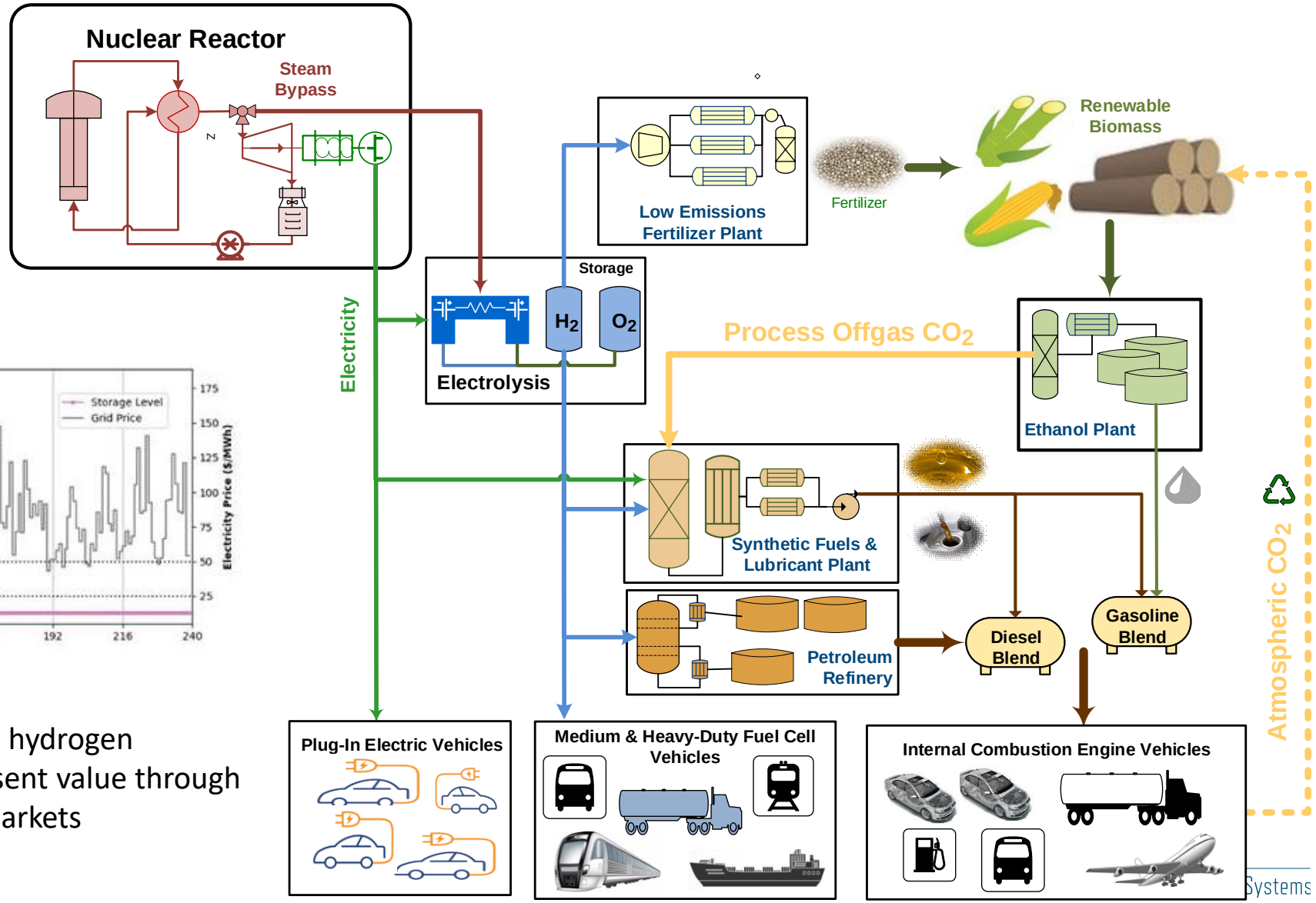
Flexible Nuclear Energy for Clean Energy Systems, September 2020
https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems

IES Integrated Energy Systems

Nuclear plants can support variable grid demand while transforming energy and feedstocks into fuels and other manufactured commodities



Example case:
Light water reactor for grid electricity and hydrogen production; optimization of plant net present value through sale of electricity and hydrogen to local markets

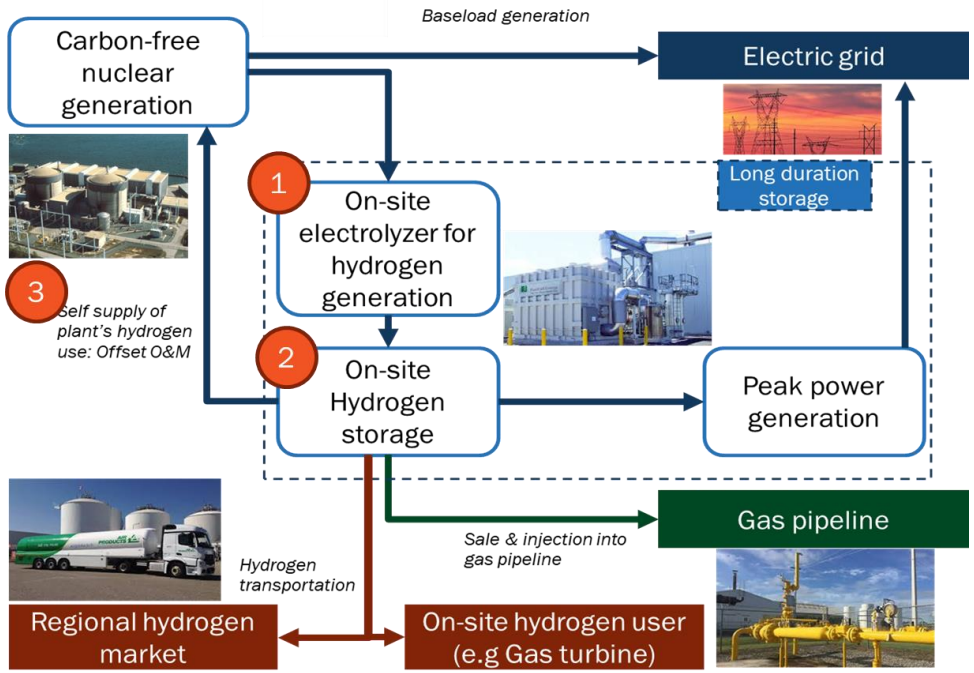


Private-public partnerships for LWR-H_2 demonstration

Exelon

Nel Hydrogen, ANL, INL, NREL (via DOE)

Purpose: Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant



Analysis Report: *Evaluation of Hydrogen Production for a Light Water Reactor in the Midwest*

**Exelon plans commence testing in 2021

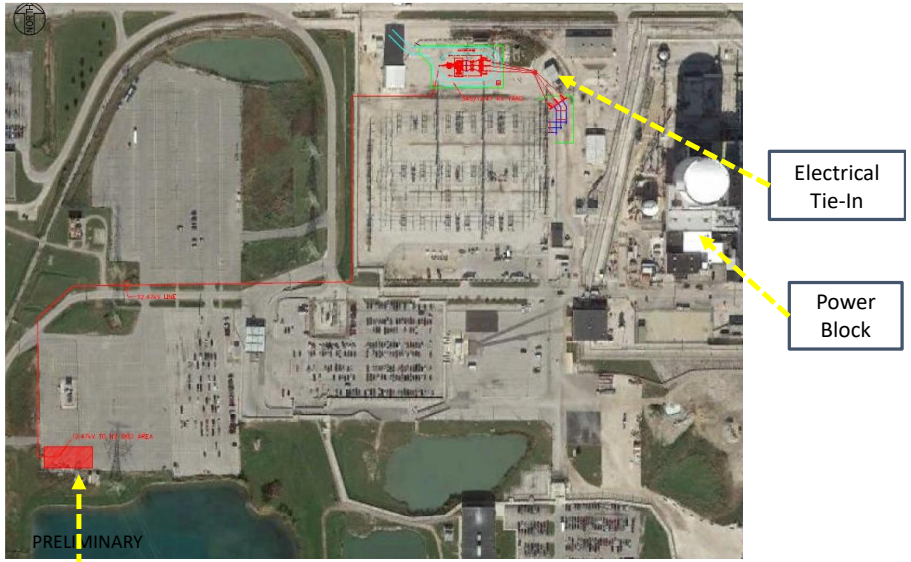
Both projects are public-private partnerships funded via collaboration among DOE and industry.

energy harbor

Xcel Energy

aps

Purpose: Produce hydrogen for first movers of clean hydrogen; fuel-cell buses, heavy-duty trucks, forklifts, and industrial users

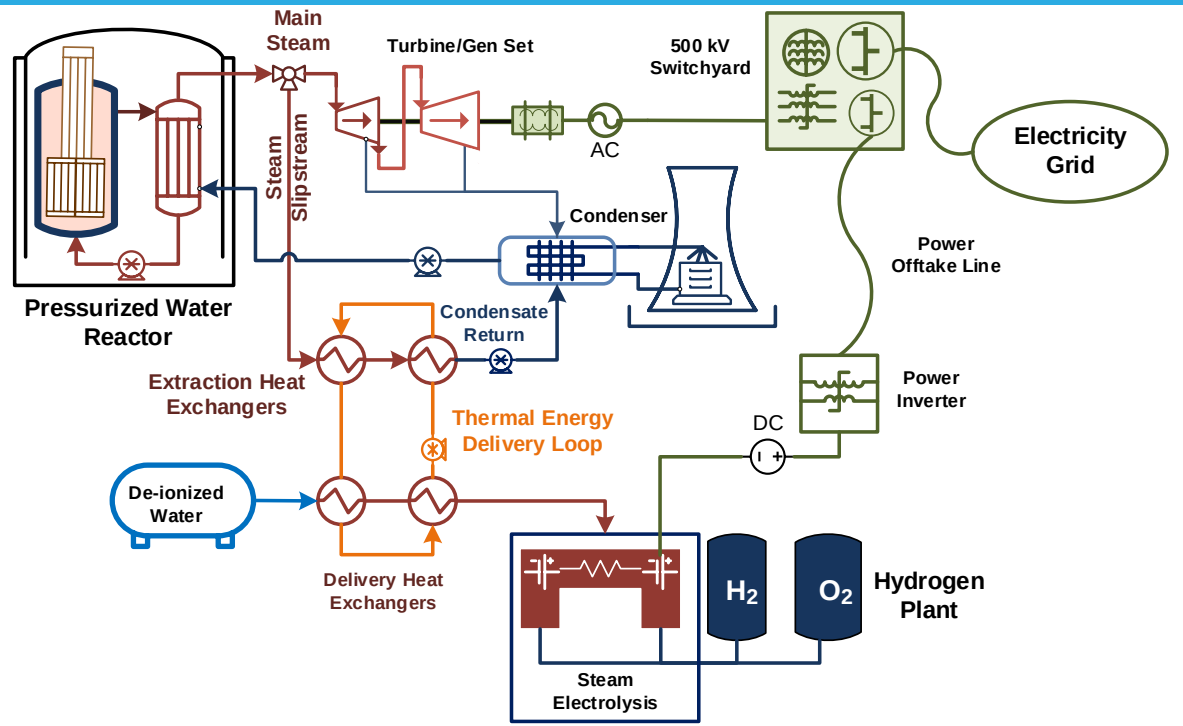


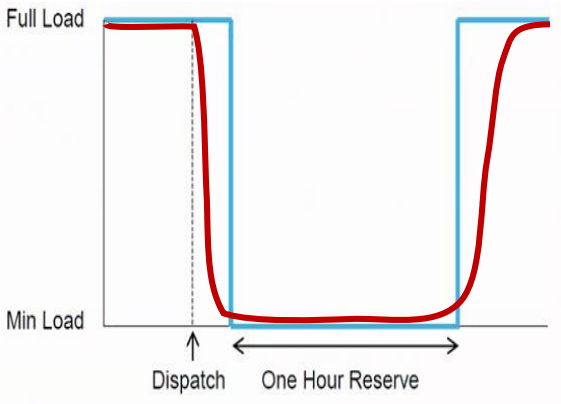
**Energy Harbor plans to commence testing in 2022

Analysis Report: *Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest*

Private-public partnerships for LWR-H_2 demonstration

- Two Low-Temperature Electrolysis (LTE) (1-3 MWe pilot plant)
  - Exelon Generation (2021)
  - Energy Harbor (at Davis-Besse, 2022)
- High Temperature Electrolysis (HTE) (250 kWe pilot plant)
  - Xcel Energy
    - Project award under negotiation with DOE
    - Xcel is currently selecting a technology option from top vendors
    - Nonnuclear HTE skid testing before delivery to an Xcel plant in Minnesota
    - Testing to commence in ~2022

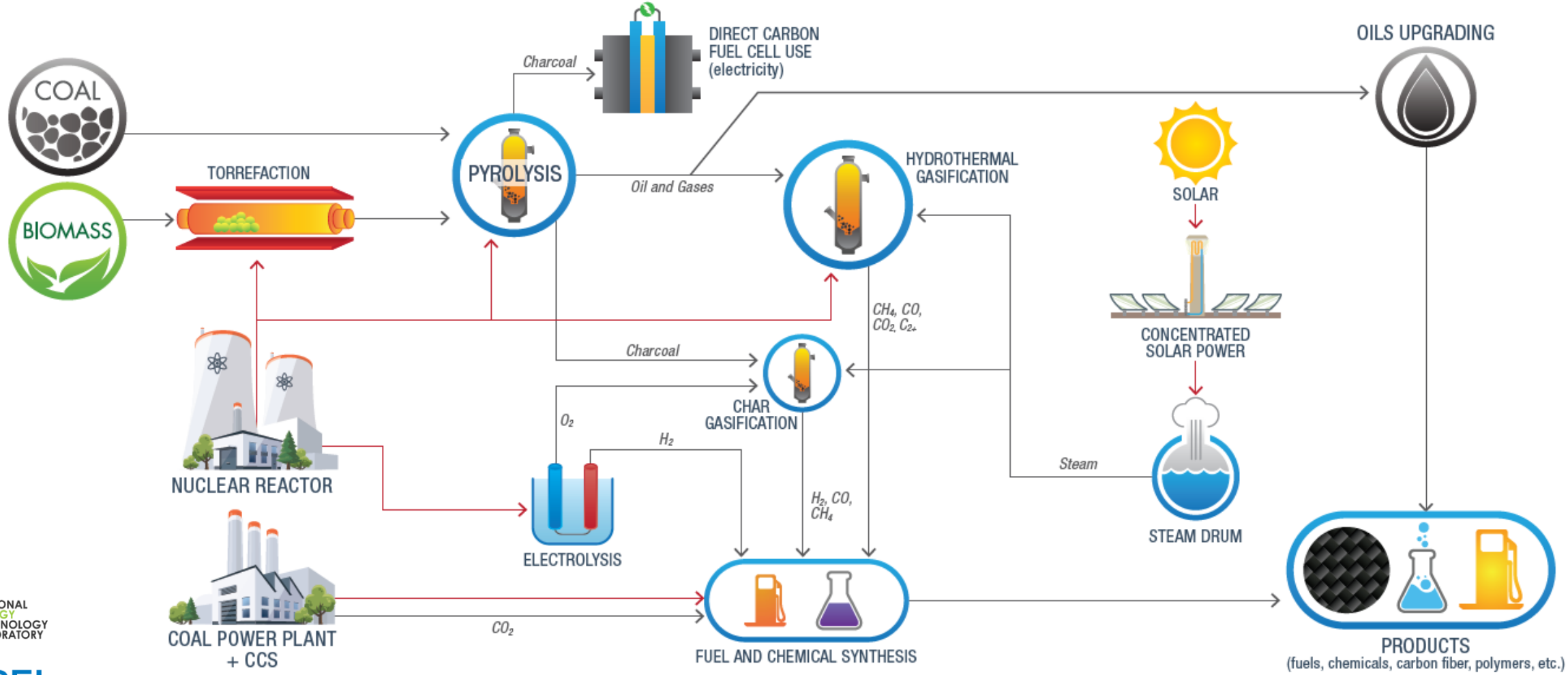




LWRS LIGHT WATER REACTOR SUSTAINABILITY

IES Integrated Energy Systems

More than just hydrogen: Carbon feedstock refinery



Initial report: Worsham, Rabiti and Kerber, *Case Study: Hybrid Carbon Conversion Using Low-Carbon Energy Sources in Coal-Producing States,* February 2021.

Multiple generation options
~
Multiple opportunities for decarbonization

Images courtesy of GAIN and Third Way, inspired by the *Nuclear Energy Reimagined* concept led by INL. Learn more about these and other energy park concepts at thirdway.org/blog/nuclear-reimagined

QUESTIONS?

Please submit your questions using the Q&A feature in the tool bar at the bottom of your screen

UPCOMING PARTNERSHIP WEBINARS

- June 11, 2021 – Quarterly Partnership meeting, *members only*
- July TBD – Advanced nuclear workshop, *members only*
- August 6, 2021 – How nuclear energy can advance grid reliability and resilience
- September 10, 2021 – Quarterly Partnership meeting, *members only*
- October 8, 2021 – Compensating carbon-free power

naruc.org/cpi-1/energy-infrastructure-modernization/nuclear-energy

THANK YOU

Chair Tim Echols, Georgia

Chair Anthony O'Donnell, Maryland

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