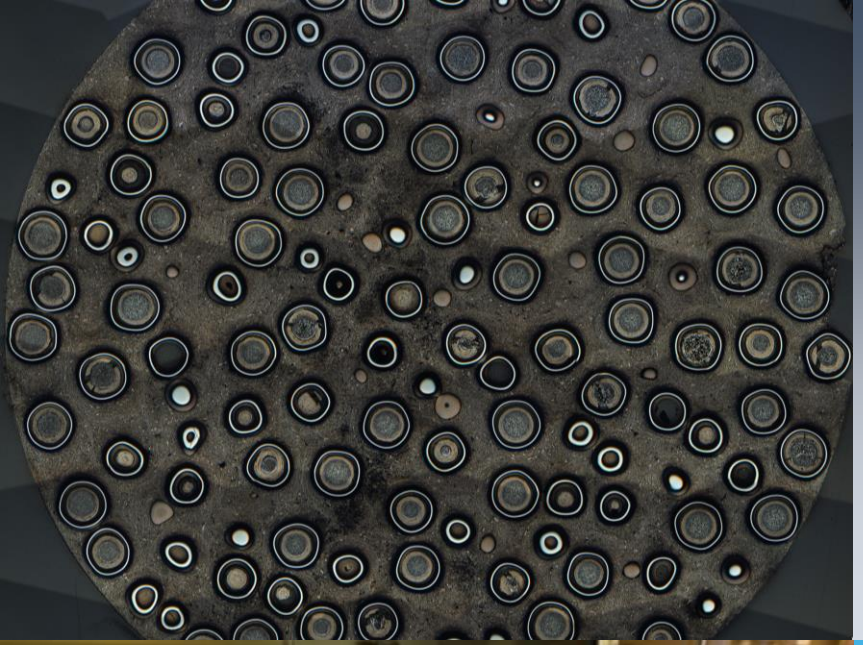
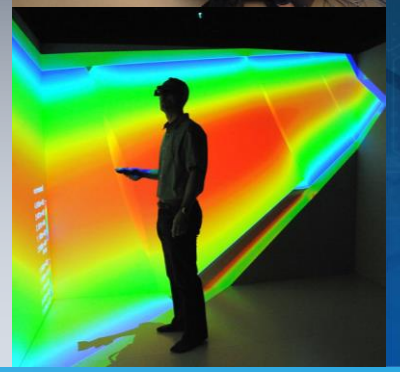




August 12, 2021

**Dr. Richard Boardman**

**Dr. Steve Aumeier**

# An New Energy Business for Wyoming

Idaho National Laboratory

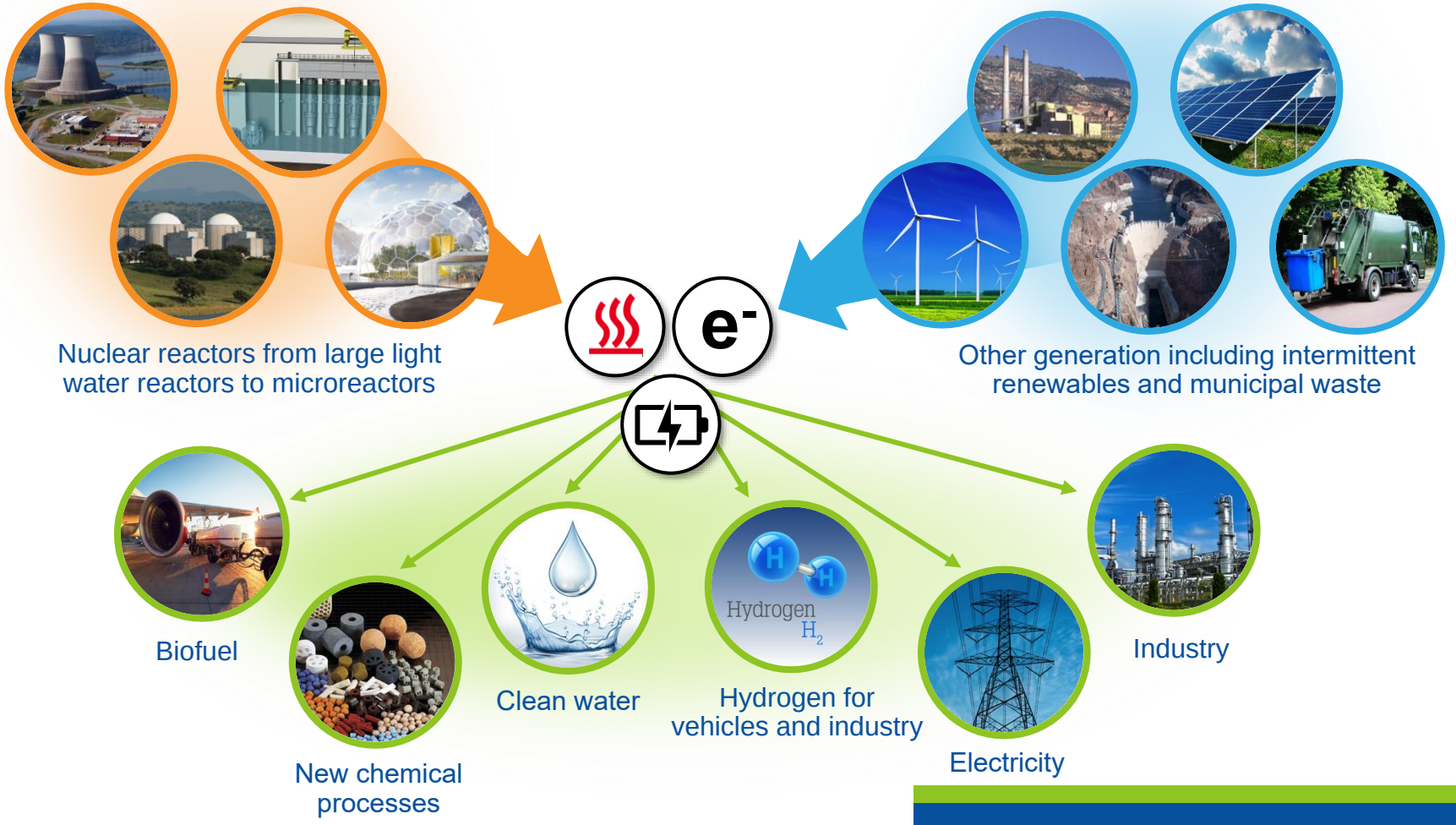
# Transforming the energy paradigm

## Today

Electricity-only focus

## Future Energy System

Integrated grid system leverages contributions from nuclear fission beyond electricity

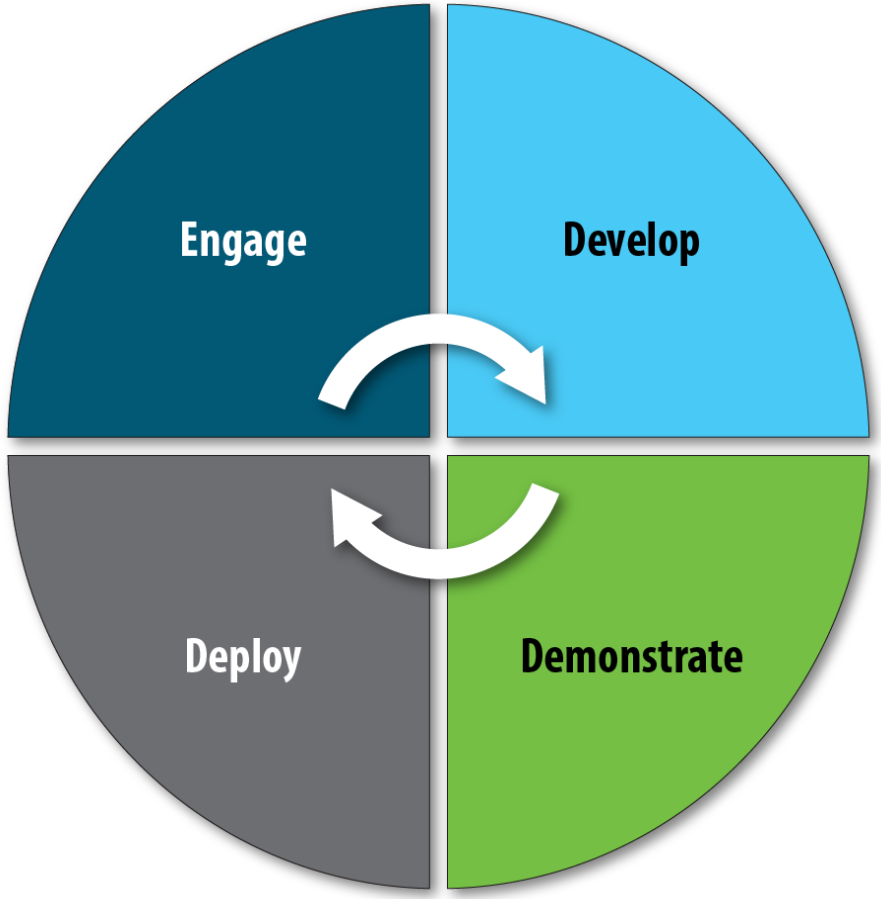


# Wyoming 2021:
# Economic Growth with Zero-Emissions Energy Sources

## Is there a role for nuclear in Wyoming?

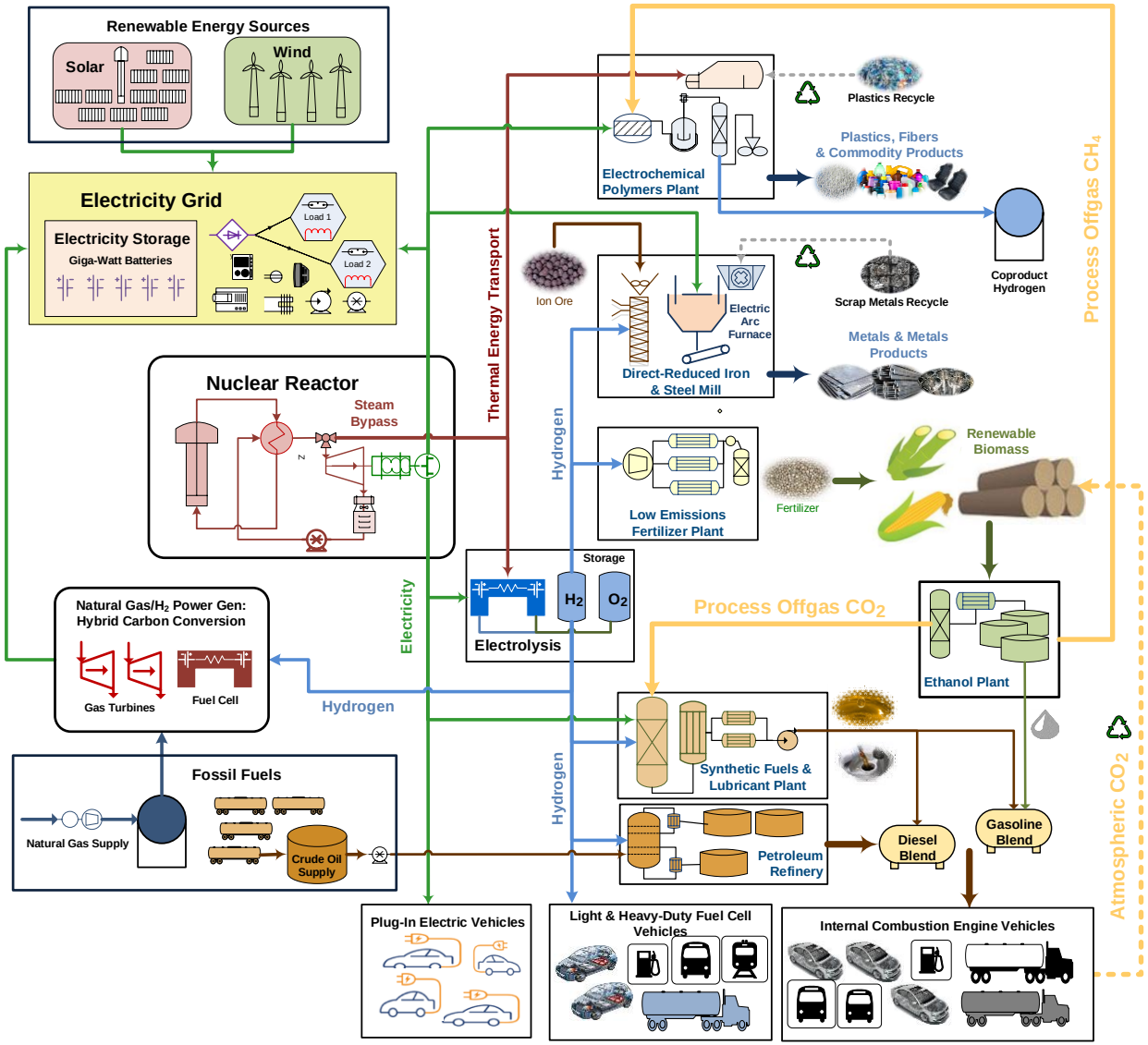
1. **Production** – the creation of value-add products using clean energy
2. **Manufacturing** – design and fabrication of components and systems to do so

- ❑ For national and global markets
- ❑ Key is "incremental provisioning"
- ❑ Scalable capital build-out
- ❑ Broadens the clean energy products value chain of Wyoming resources



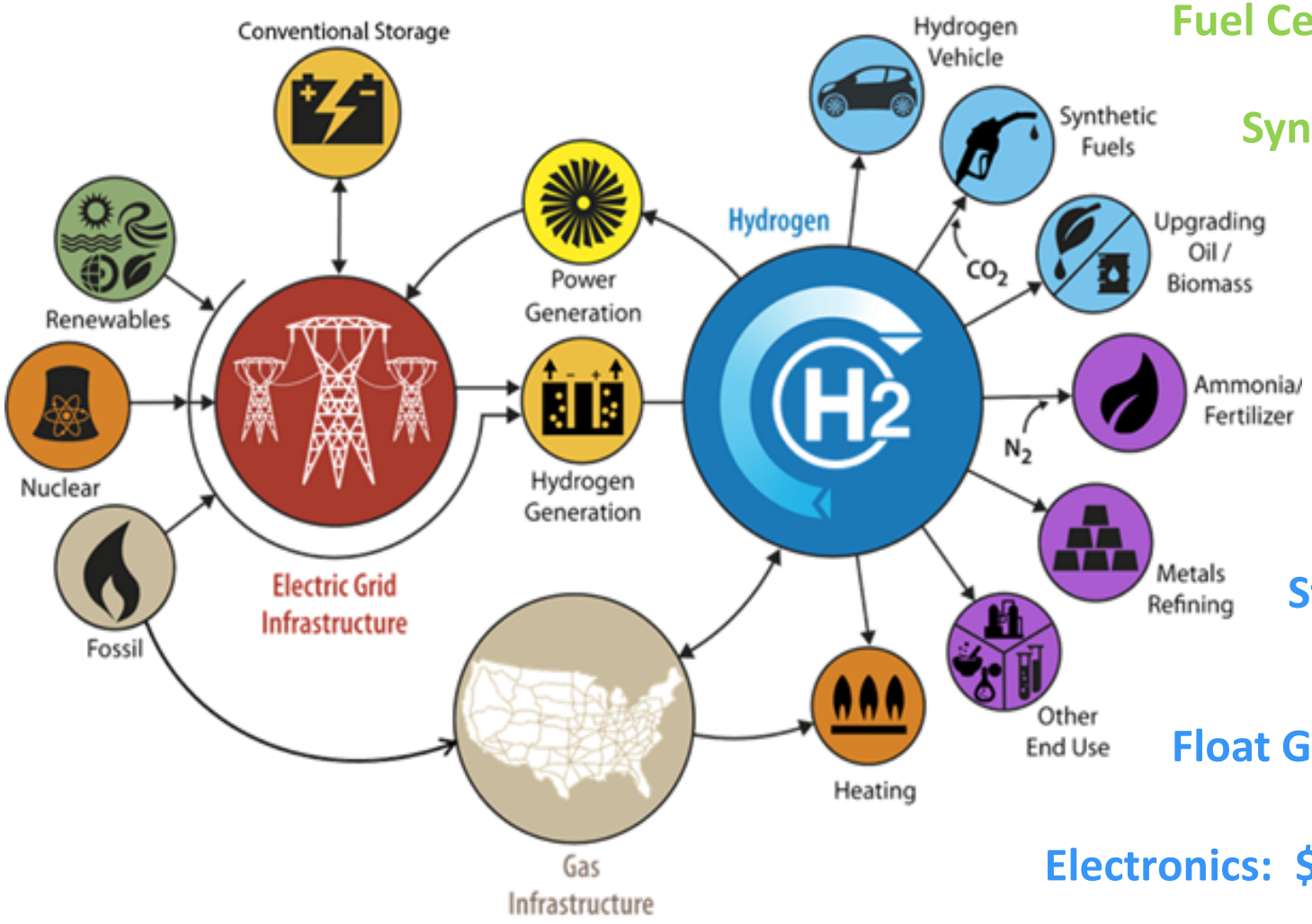

- ❑ **Net-Zero Energy Services & Products**
- ❑ **Supply Chain Reactors and Components**

# A new Paradigm: Integrated Energy Systems with Nuclear




- **Industrial energy needs**
  - Electricity
  - Steam
  - Heat (Thermal Power)
- **Target Large Industries**
  - Transportation fuels
  - Fired heaters / Steam boilers
  - Polymers & Plastic
  - Iron & Steel
  - Fertilizers
  - Minerals
- **Keys to success**
  1. Hydrogen is key energy currency
  2. Flexible operations cansupport the grid
  3. Energy storage is imperative

# Large-Scale Hydrogen Markets




Fuel Cell Vehicles: $1.50 – 3.00 / kg-$H_2$

Synthetic Fuels: $1.50 – 1.75 / kg-$H_2$

Refining: $1.25 – 2.00 / kg-$H_2$

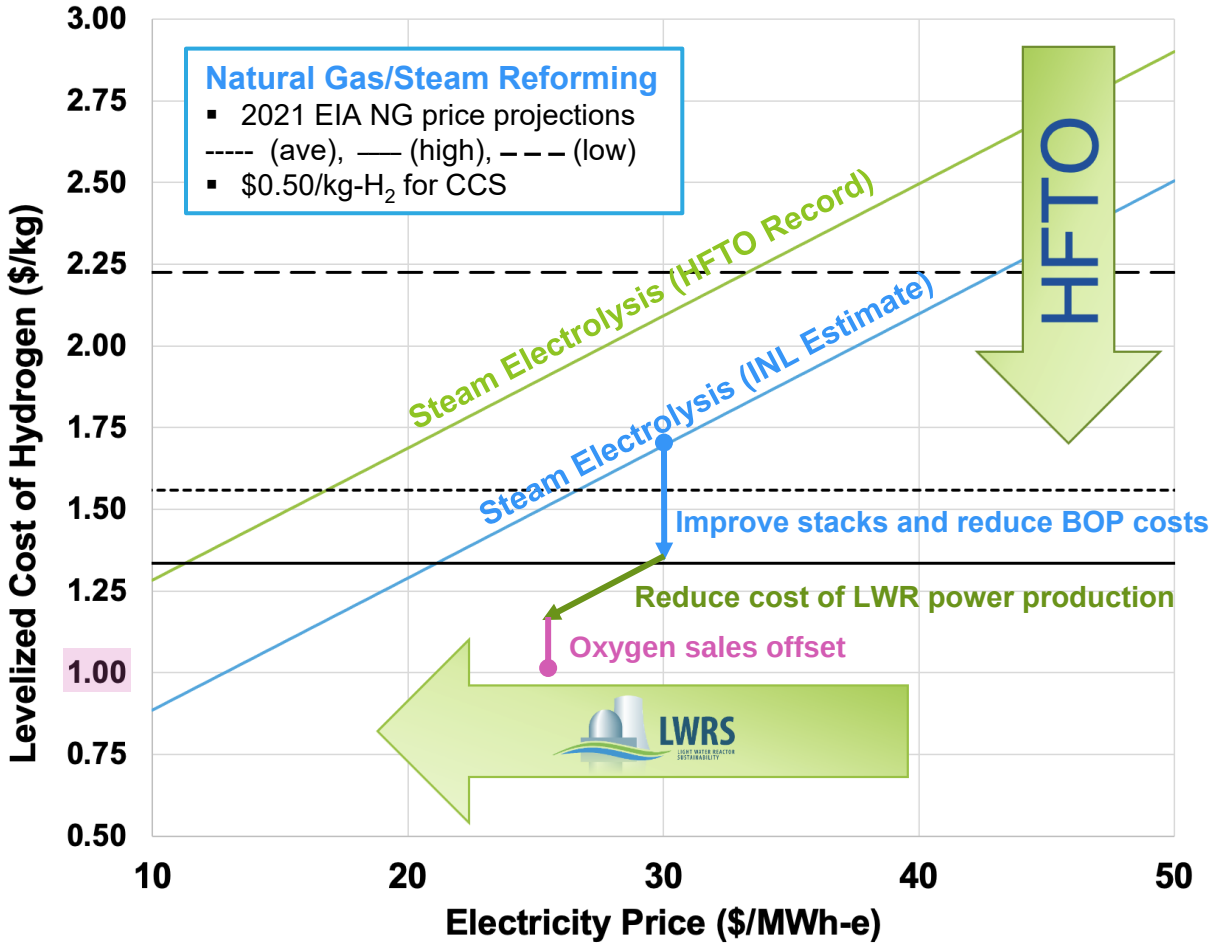
Ammonia: $1.50 – 1.75 / kg-$H_2$

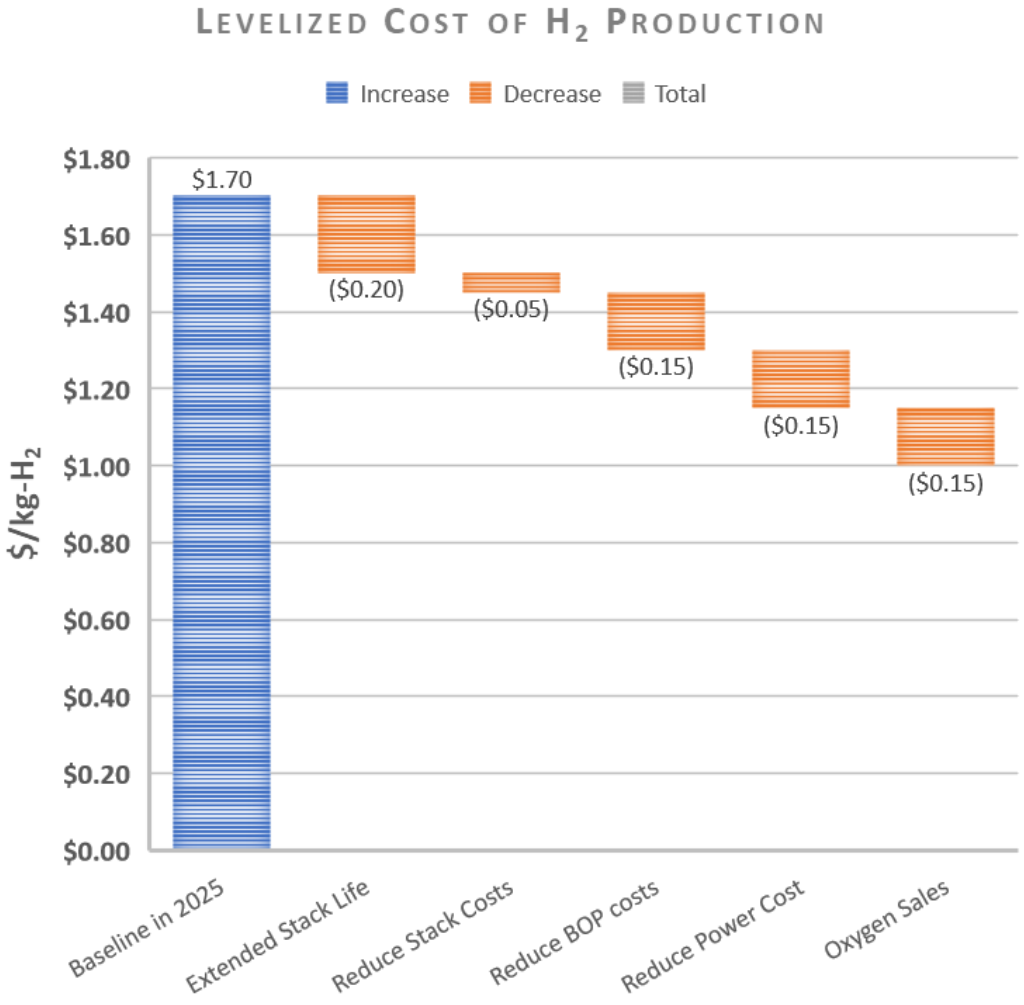
Steel: $1.00 – 1.25 / kg-$H_2$

Float Glass: $1.25 – 1.75 / kg-$H_2$

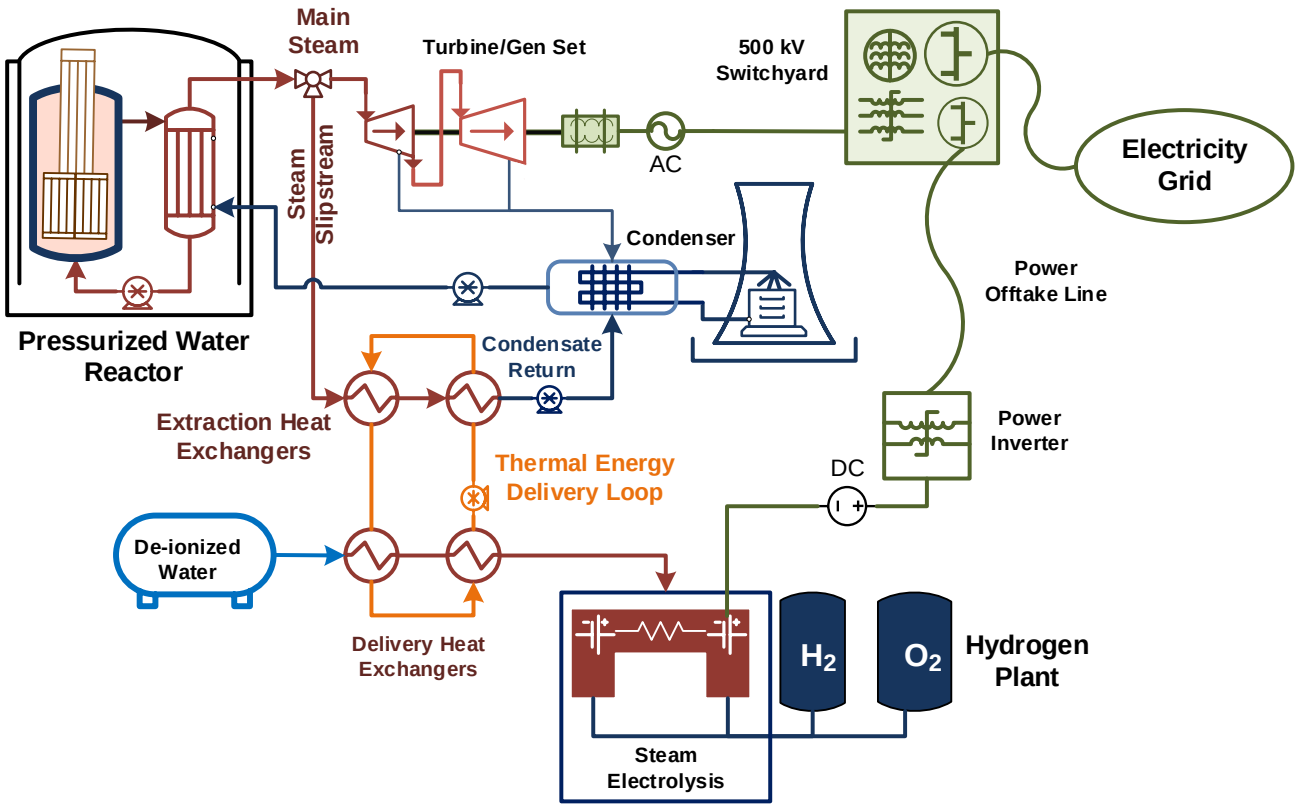
Electronics: $3.00 – 5.00 / kg-$H_2$

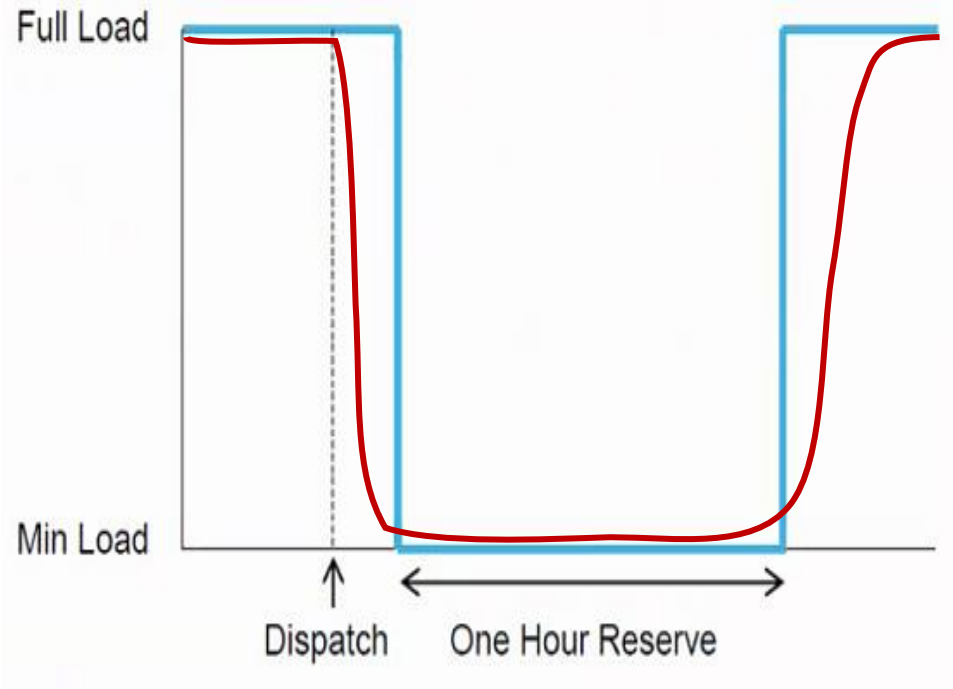
# Two paths to $H_2$ Earthshot Target
## ($1/kg-$H_2$ within a decade)



# Electrolysis while dispatching as spinning or non-spinning reserves



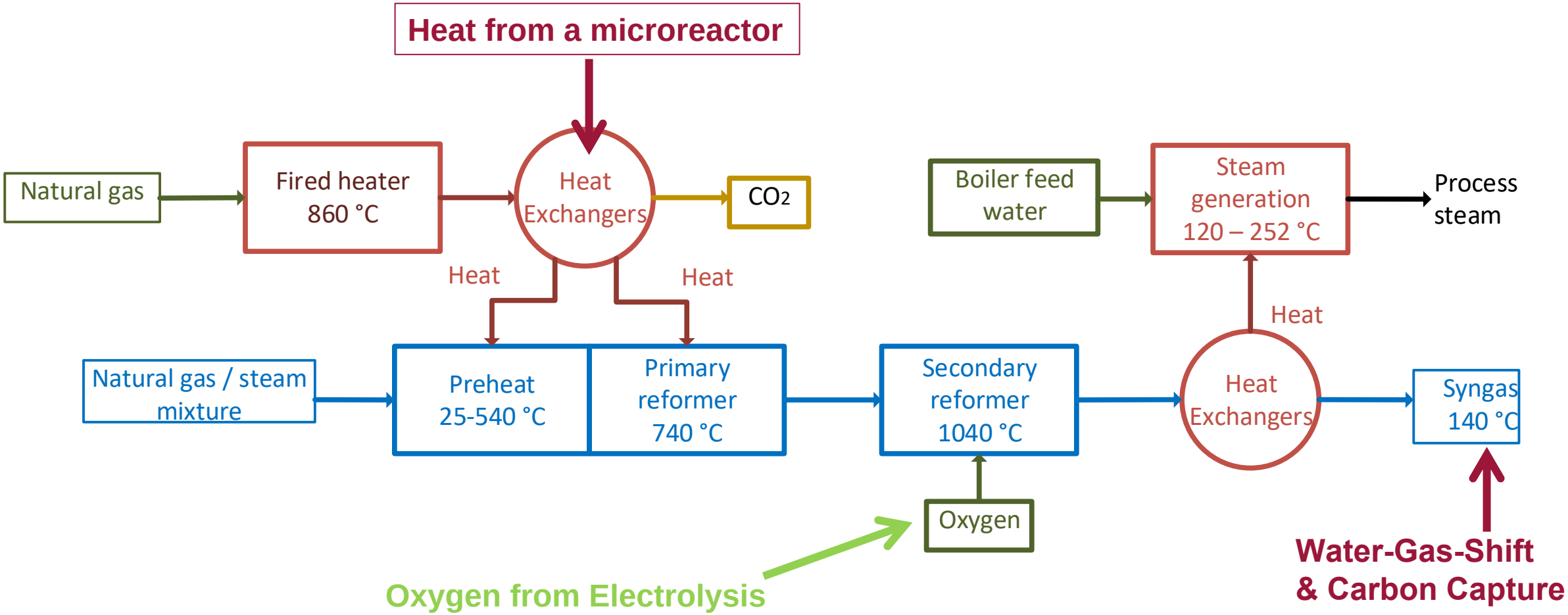




LWRS LIGHT WATER REACTOR SUSTAINABILITY

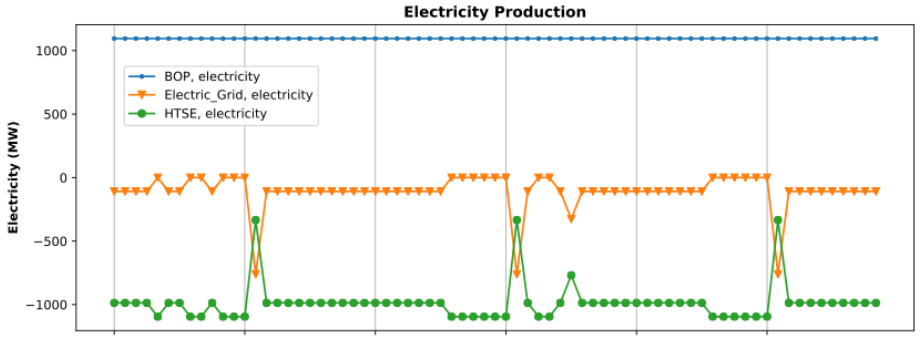
H2@Scale U.S. Department of Energy

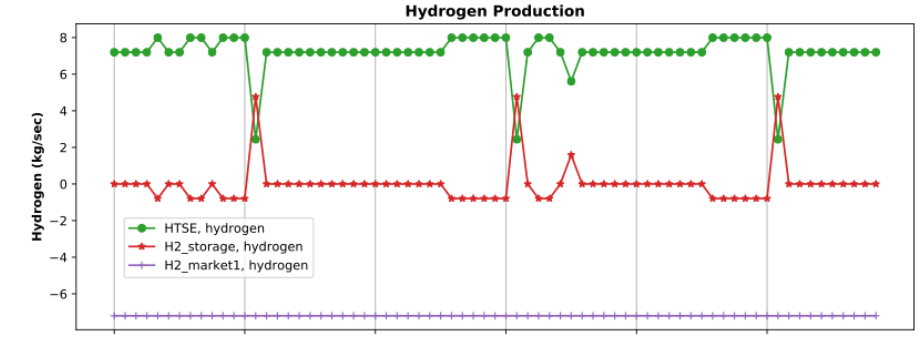
# Zero-Emissions Hydrogen from Steam-Methane Reforming

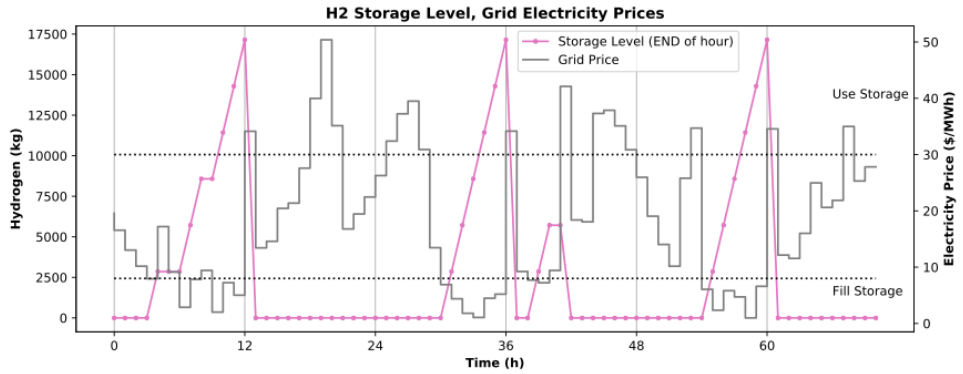
## Natural Gas Reforming: CCS with nuclear microreactor energy enhancement

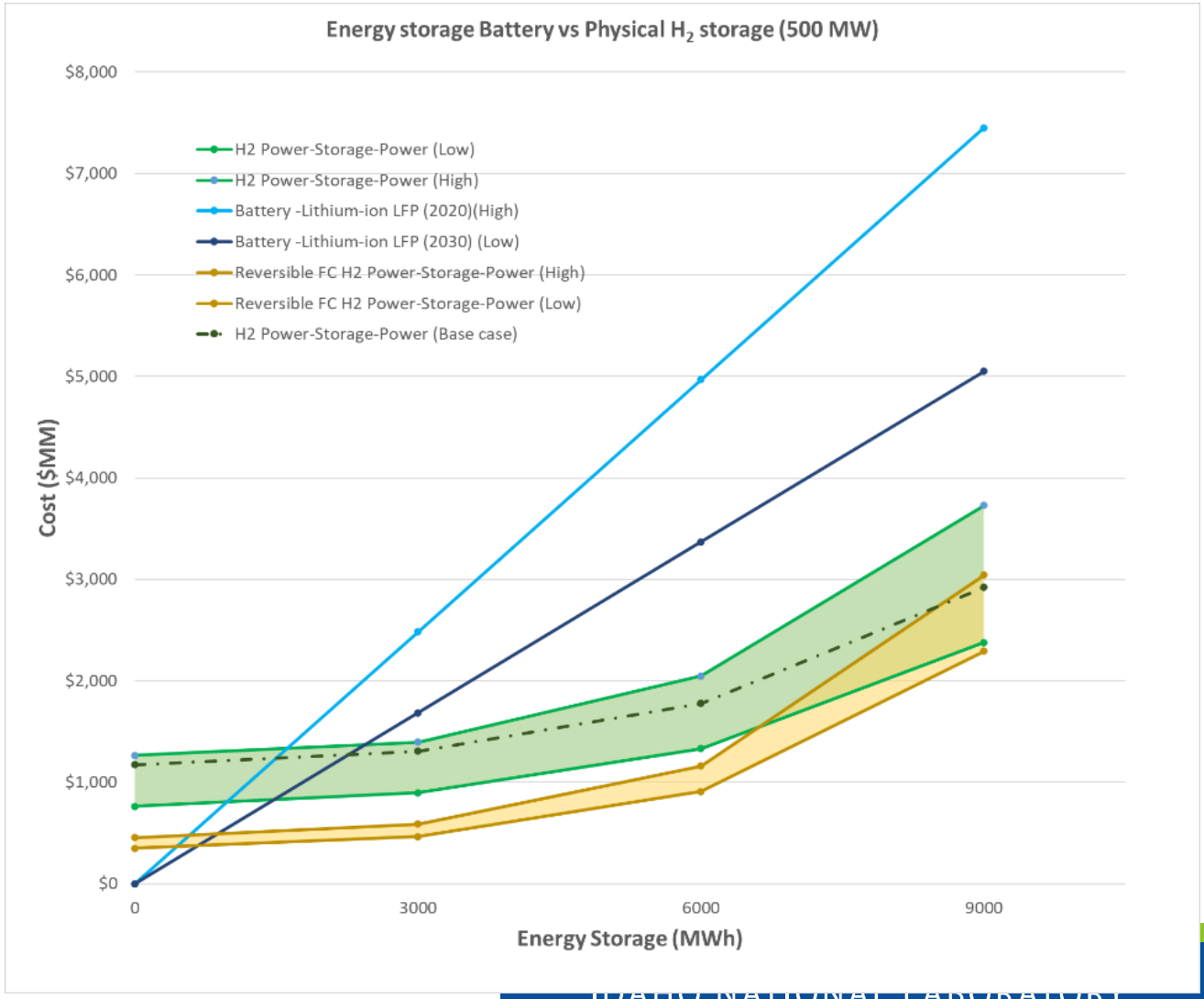


# Market Arbitrage: Buy low, Sell high

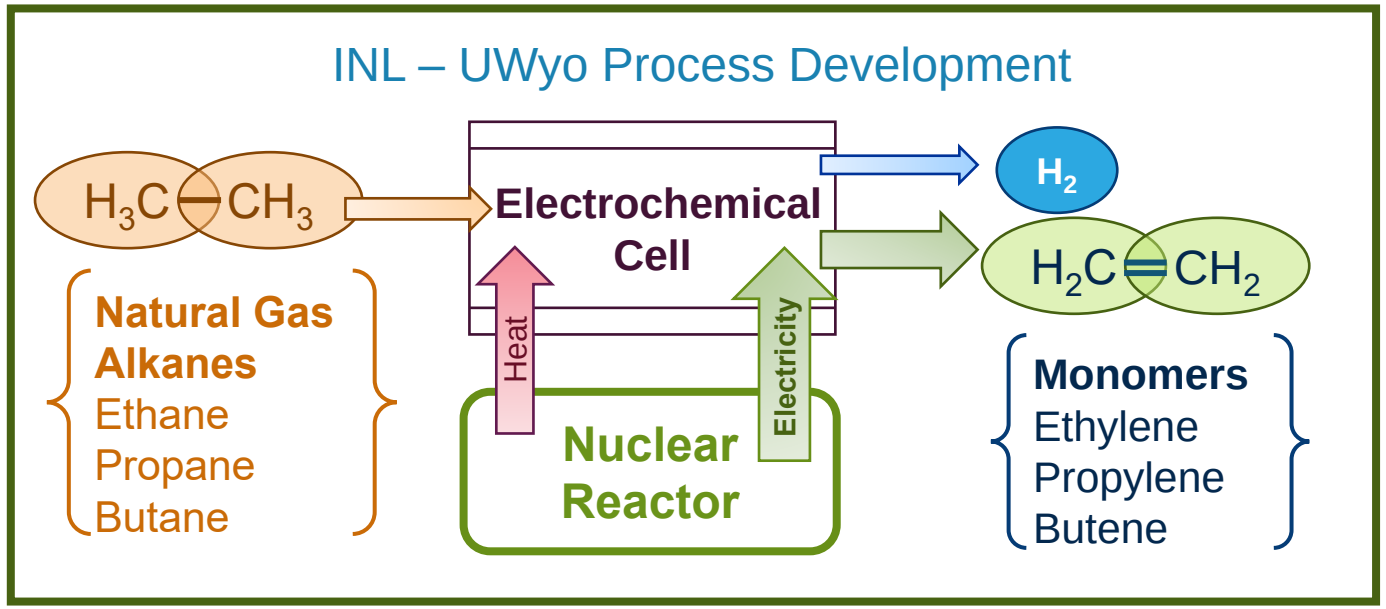


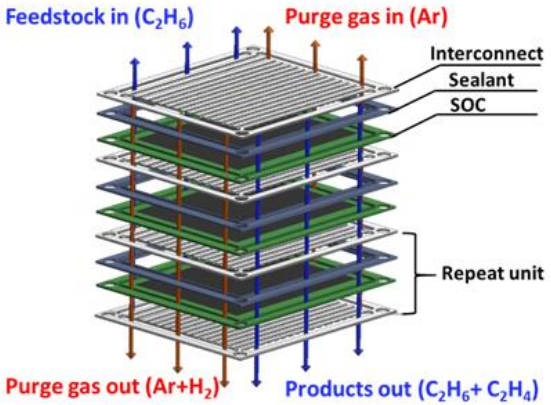



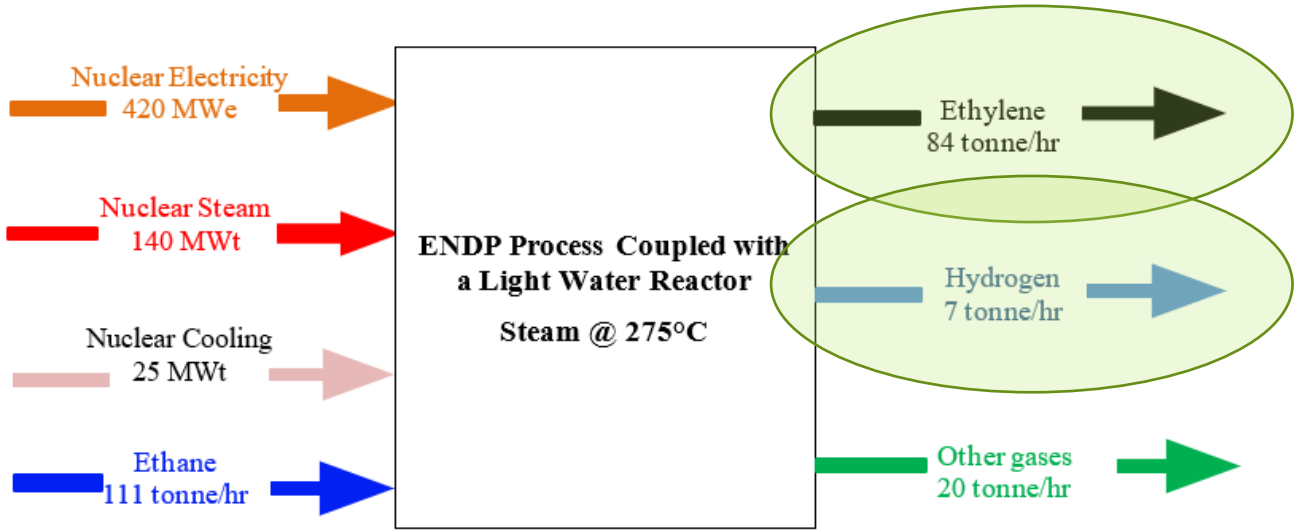



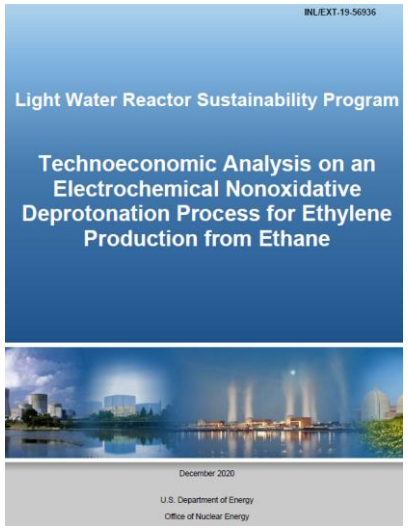
# Electrochemical Conversion of Natural Gas Condensates into Polymers & Hydrogen



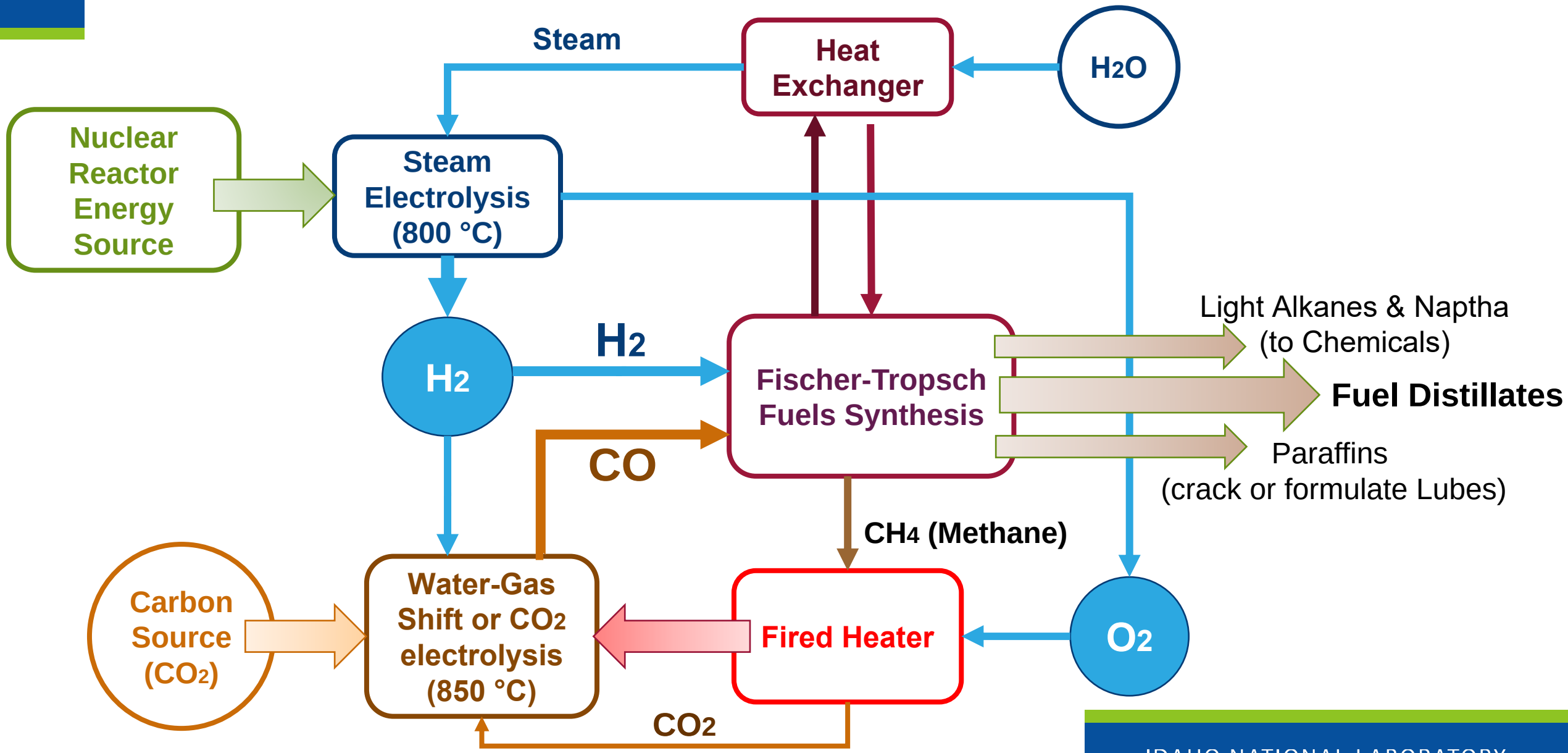




**High Value Premium Products**



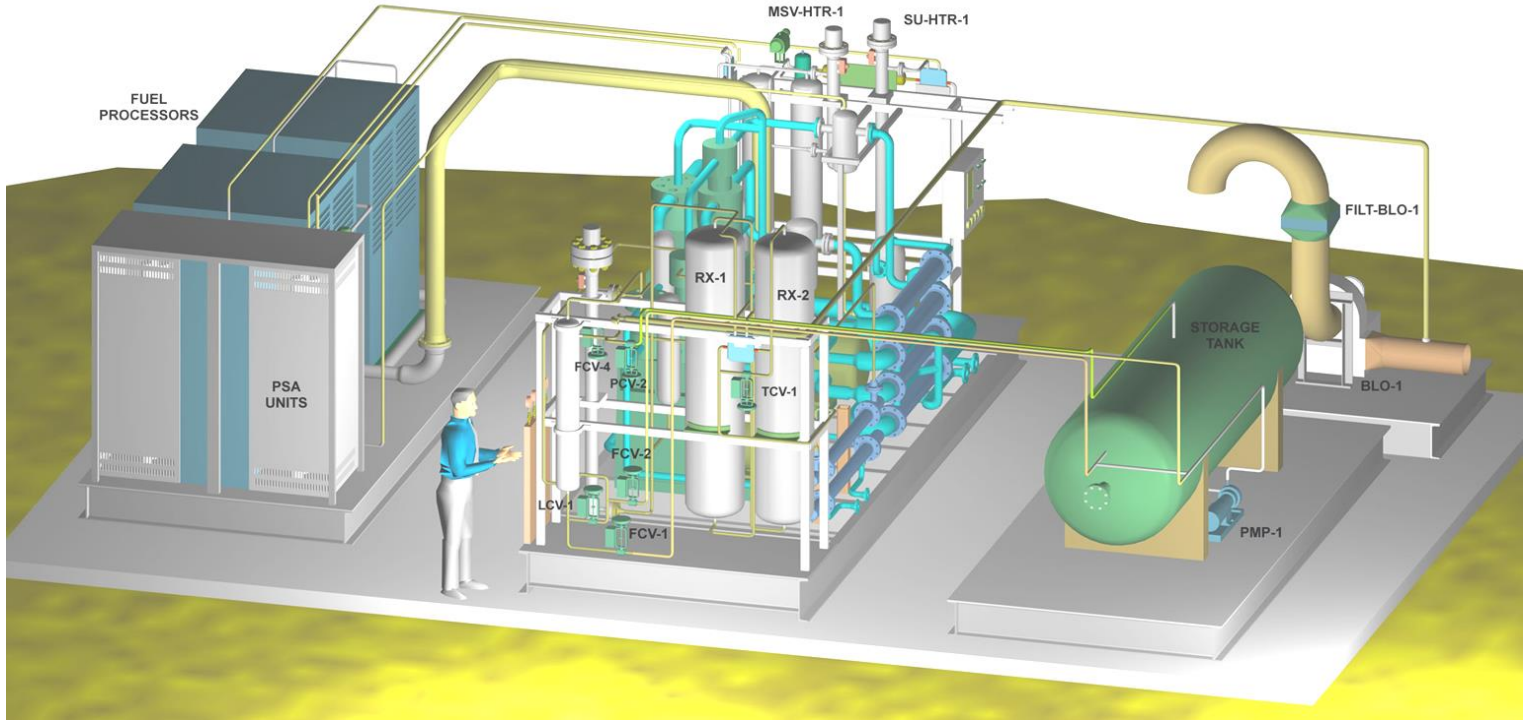
# F.T. Carbon Conversion to Fuels and Chemicals (CCU)



# Modular Ammonia Plants

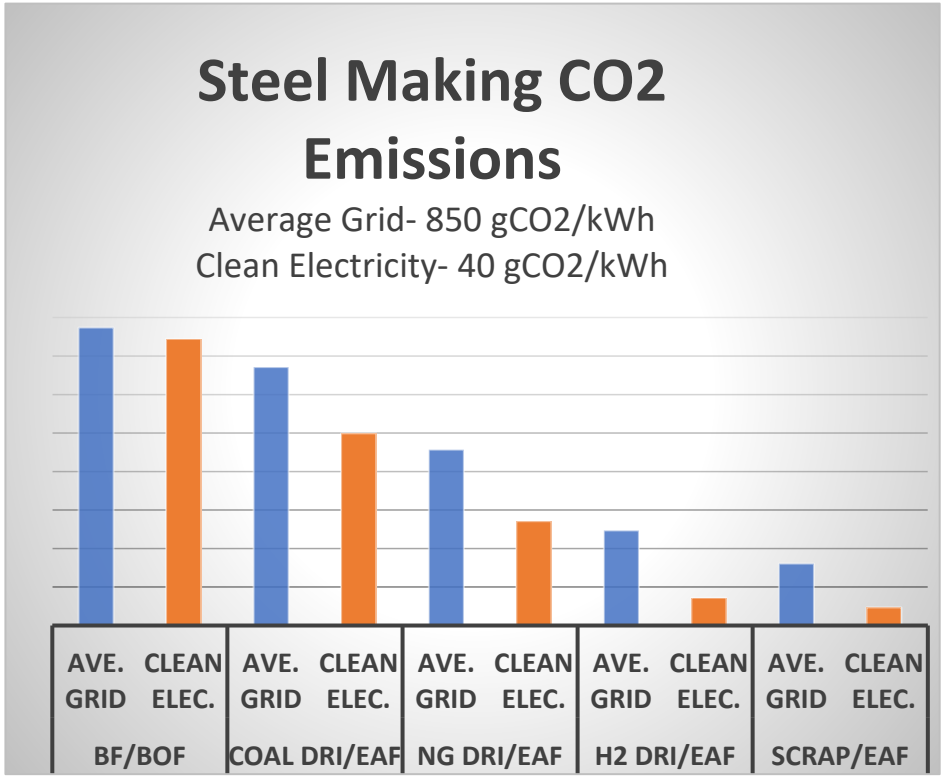
## *3.0 Tonne/day skid-mounted production system*

- Local production for agriculture Co-Ops
- Use by power plants for NOx Selective Catalytic Reduction



# Iron and Steel Making

- Flash-Iron Technology
- Direct reduced iron with hydrogen
- Scalable to mini-mills
- Fed directly to electric-arc furnace




Large-scale bench reactor facility layout
*Photo credit Berry Metal Company*

Pilot plant at University of Utah:
Professor HY Sohn

# Advanced reactor future state: One size does not fit all

Researchers at Idaho National Laboratory are collaborating with industry and academia to develop nuclear reactor concepts of various sizes for various use cases.

# Advanced Reactor Design Concepts

## Benefits:

- Enhanced safety
- Versatile applications
- Reduce waste
- Use advanced manufacturing to save money

*60+ private sector projects under development*

## SIZES

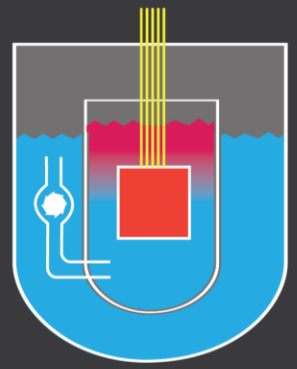
**SMALL**
**1 MW to 20 MW**
Micro-reactors
*Can fit on a flatbed truck. Mobile. Deployable.*

**MEDIUM**
**20 MW to 300 MW**
Small Modular Reactors
*Factory-built. Can be scaled up by adding more units.*

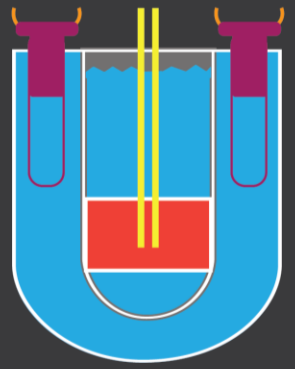
**LARGE**
**300 MW to 1,000 + MW**
Full-size Reactors
*Can provide reliable, emissions-free baseload power*

*Advanced Reactors Supported by the U.S. Department of Energy*

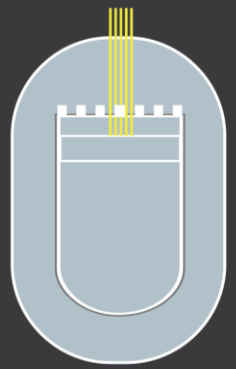
## TYPES



**MOLTEN SALT REACTORS –** Use molten fluoride or chloride salts as a coolant. Online fuel processing. Can re-use and consume spent fuel from other reactors.



**LIQUID METAL FAST REACTORS -** Use liquid metal (sodium or lead) as a coolant. Operate at higher temperatures and lower pressures. Can re-use and consume spent fuel from other reactors.



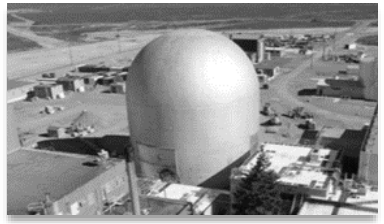
**GAS-COOLED REACTORS –** Use flowing gas as a coolant. Operate at high temperatures to efficiently produce heat for electric and non-electric applications.

# Accelerating advanced reactor demonstration and deployment

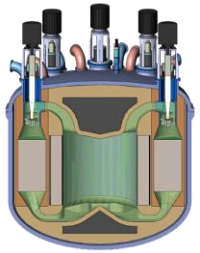
**MARVEL**
**DOE**
2022-2023

**Project Pele Microreactor**
**DoD**
2023-2024

**DOME Test Bed**
**NRIC**
2023-2024

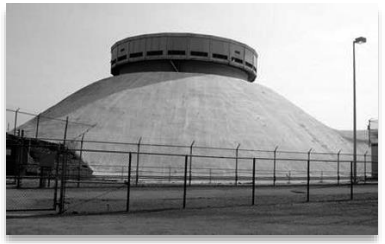


**LOTUS Test Bed**
**NRIC**
2024



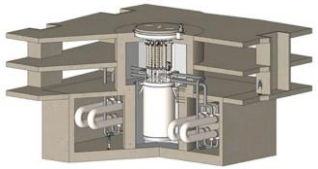
**MCRE**
**Southern Co. & TerraPower**
2025

TerraPower
Southern Company



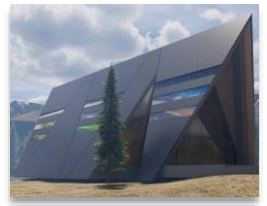
**Aurora**
**Oklo Inc.**
TBD

OKLO



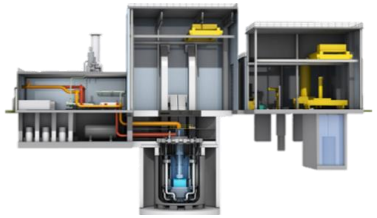
**Hermes**
**Kairos**
2026

Kairos Power



**Xe-100**
**X-energy**
2027

energy



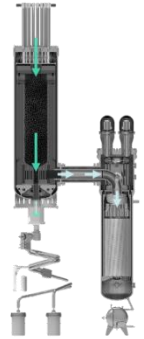
**Natrium Reactor**
**TerraPower & General Electric**
2028

TerraPower
HITACHI

**2030**

**SMR**
**UAMPS &**
**NuScale**
2029

UAMPS
NUSCALE
Power for all humankind



NRIC National Reactor Innovation Center

# Wyoming Business Development

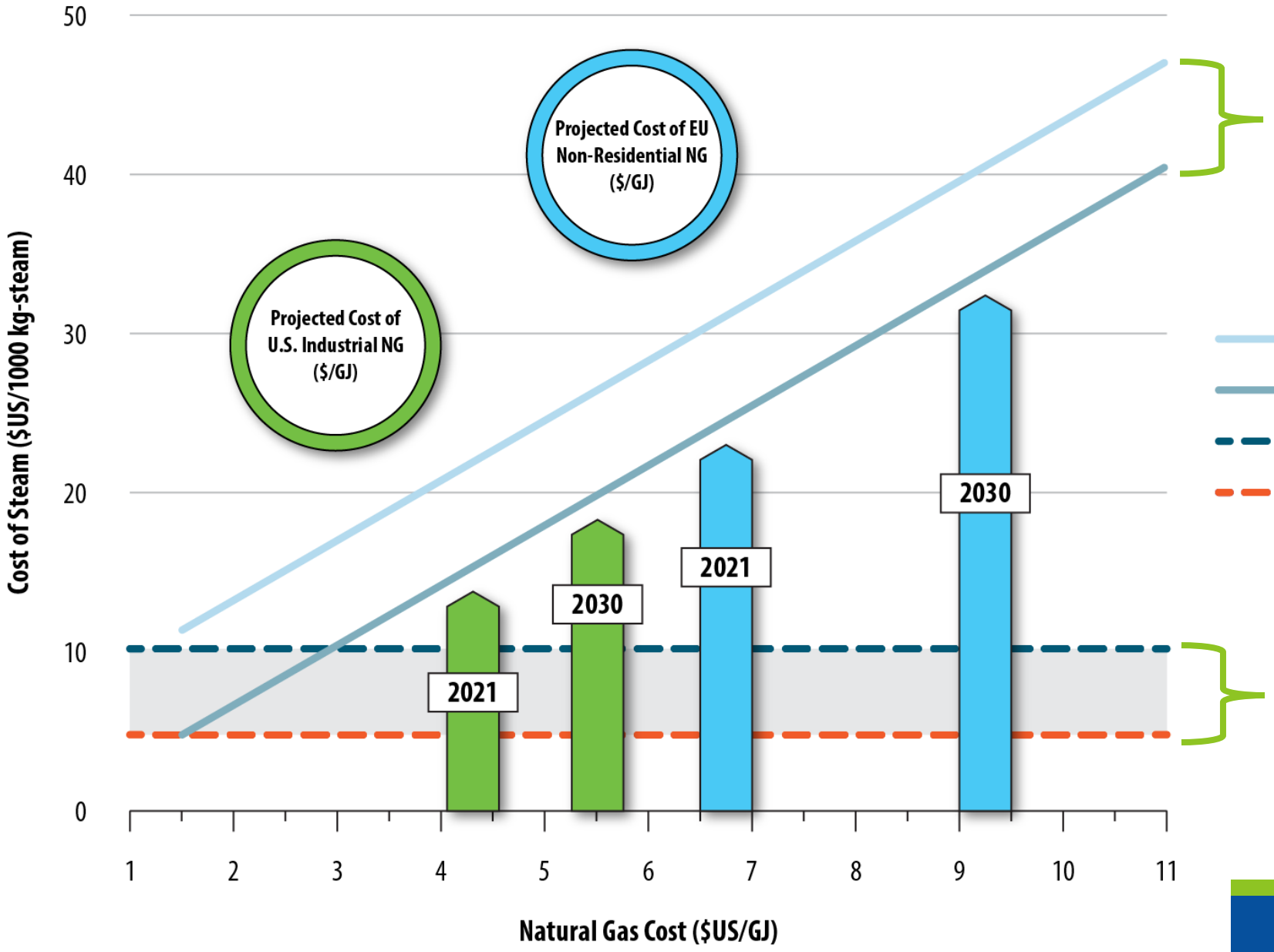
- Clean energy markets based on Wyoming resources
- Cartridge and microreactors fabrication
- Skilled crafts and operator education and training
- Engineering education
- Research, development, and testing

❑ **Manufacturing of Supply Chain Reactors and Components**


Idaho National Laboratory

- ❑ Production of Net-Zero Energy Services & Products
- ❑ Manufacturing of Supply Chain Reactors and Components

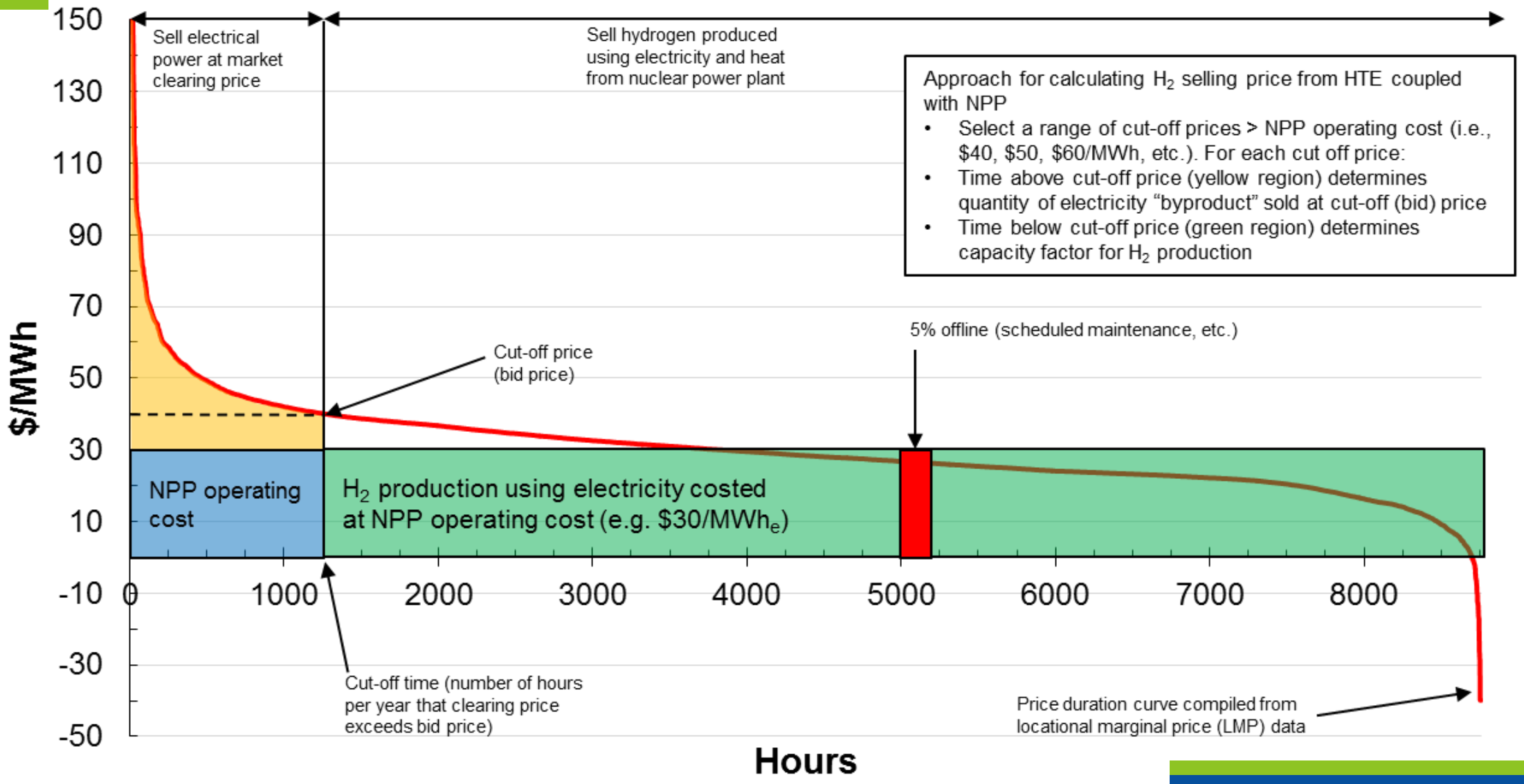
# Can Nuclear Compete? Natural Gas vs Nuclear LWR



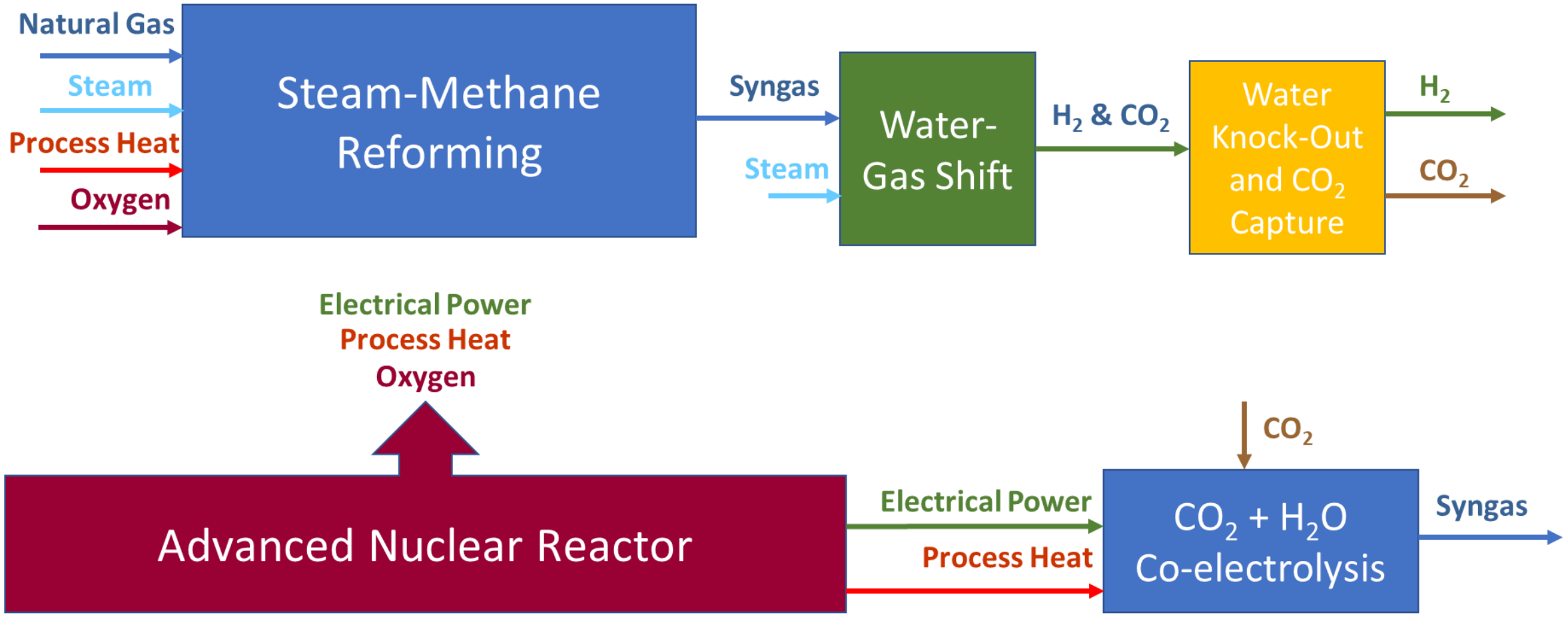

**Cost of carbon capture, transport, sequestration and life-time monitoring is $50-100/tonne $CO_2$ (best estimate)**

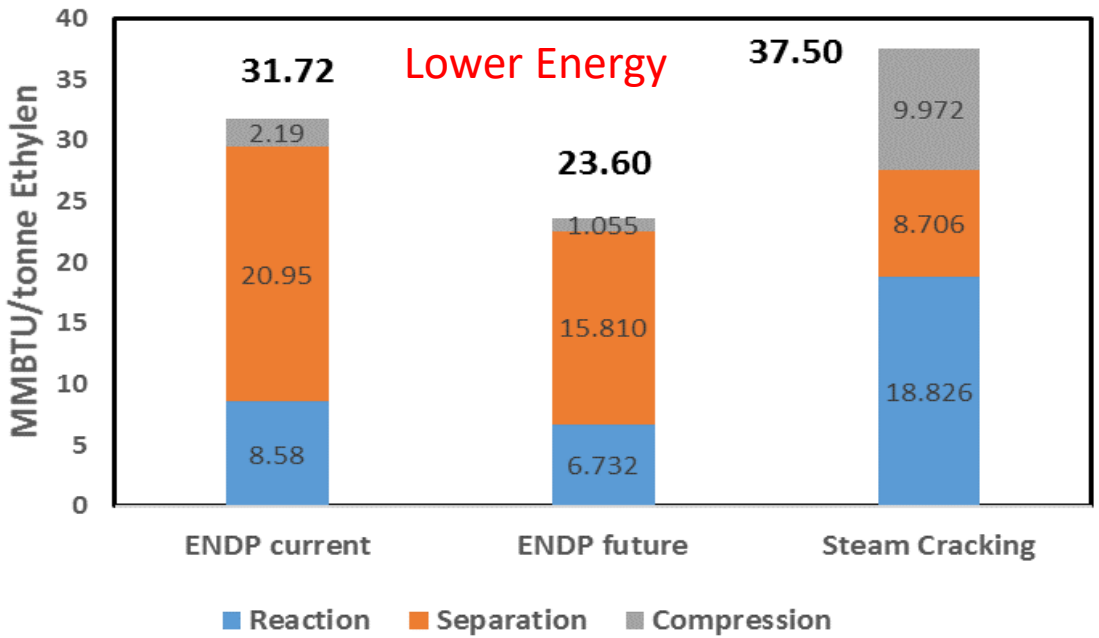
**LWR steam is less expensive than natural gas boilers**

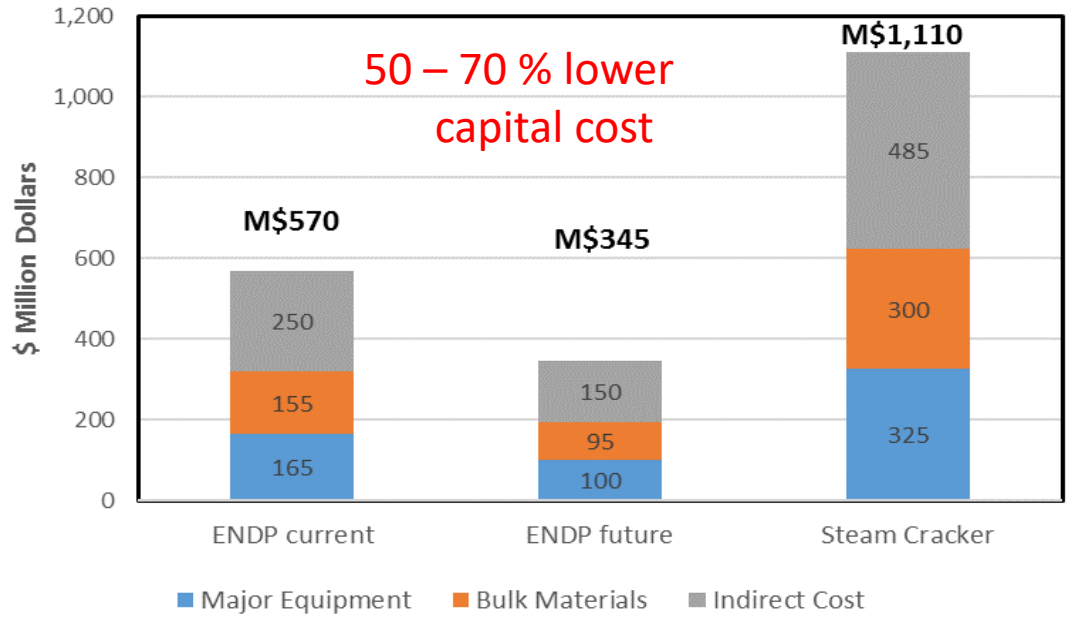
# Switching between electricity and hydrogen markets

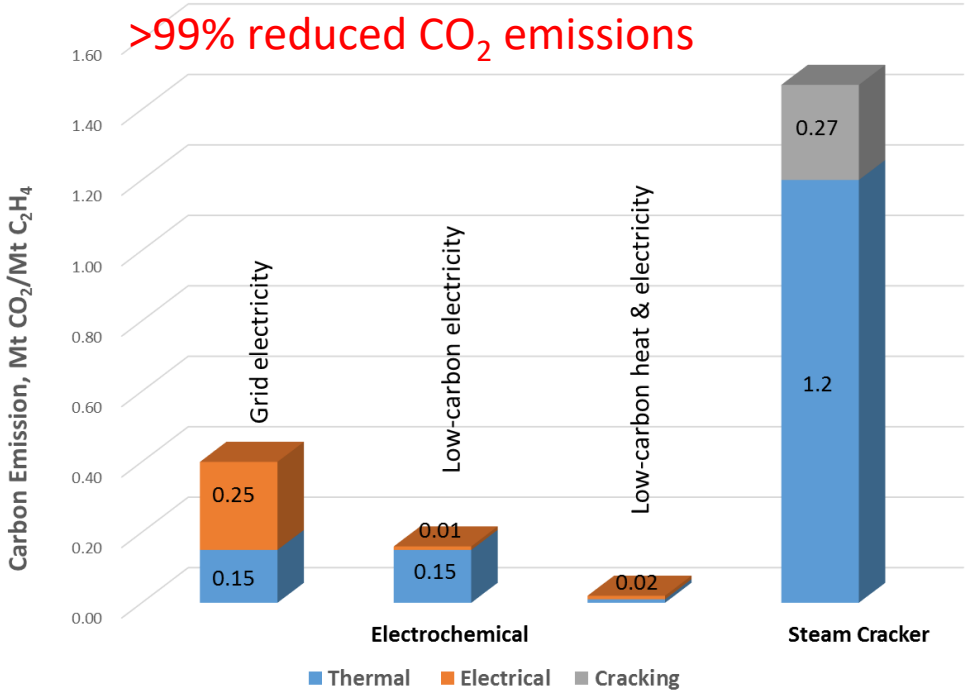


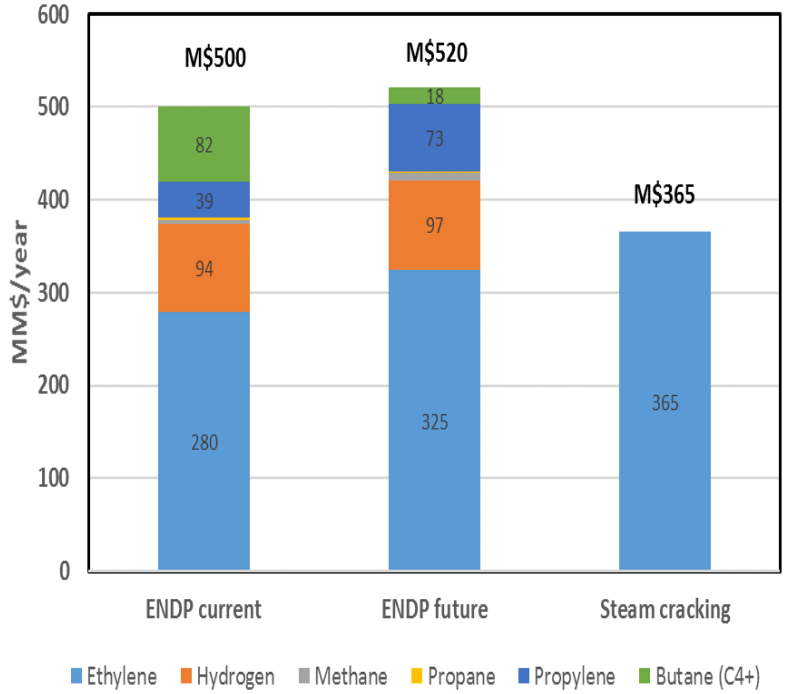
# How nuclear can enhance conventional steam methane reforming production of hydrogen






Higher Revenue

# Joint EERE-NE $H_2$ Production Demonstration Projects

## Three projects have been announced for demonstration of hydrogen production at nuclear power plants

- Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant
- Develop monitoring and controls procedures for scaleup to large commercial-scale hydrogen plants
- Evaluate power offtake dynamics on NPP power transmission stations to avoid NPP flexible operations
- Produce hydrogen for captive use by NPPs and first movers of clean hydrogen

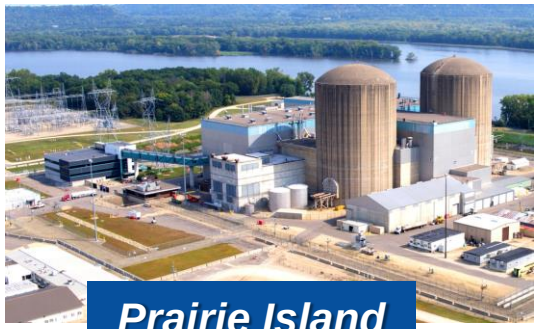
## Schedule:

- Exelon: Nine-Mile Point NPP; LTE/PEM Vendor 1; using “house load” power; PEM skid testing is underway at NREL; H2 production beginning ~Jan. 2022
- Energy Harbor; LTE/PEM Vendor 2; power provided by completing plant upgrade with new switch gear at the plant transmission station; installation to be made at next plant outage; contract start anticipate by Oct. 2022
- Xcel Energy:  HTE/SOEC Vendor 1; Project negotiations are being finalized. Tie into plant thermal line engineering is being planned; Official project start anticipated around Jan. 2022.

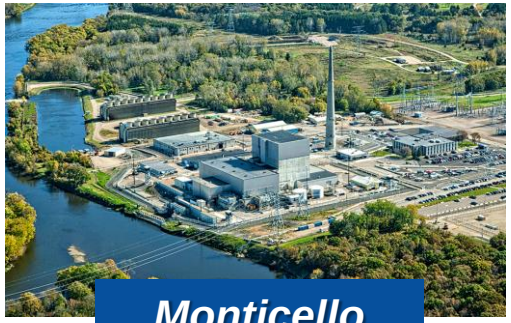
***Davis-Besse Nuclear Power Plant LTE-PEM Vendor 1***

***Nine Mile Point Nuclear Power Plant LTE/PEM Vendor 2***

***Thermal & Electrical Integration at an Xcel Energy Nuclear Plant HTE/Vendor 1***

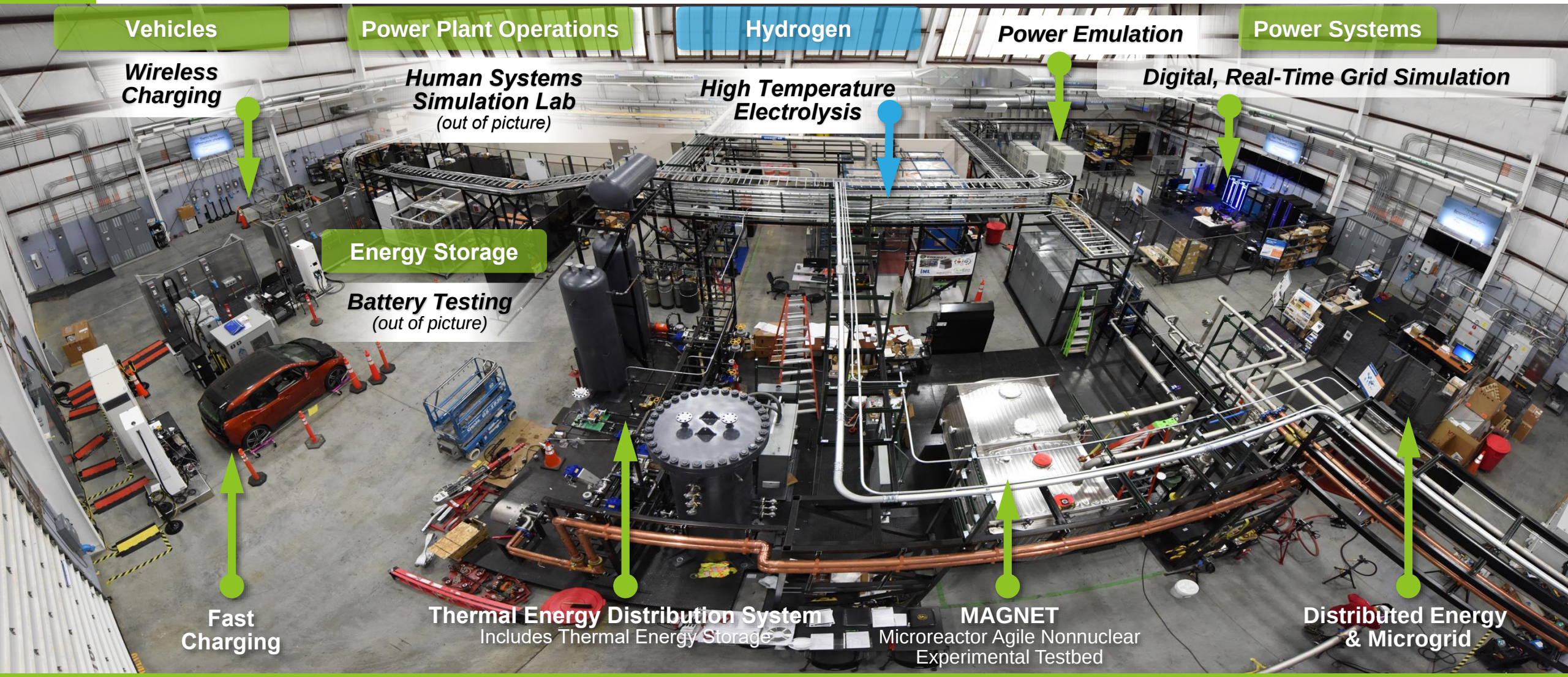


***Prairie Island***



***Monticello***

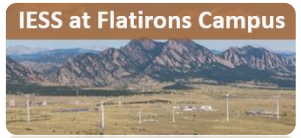
# Integrating systems for the nation's net-zero future



# Tri-Lab Demonstration of Integrated Energy Systems

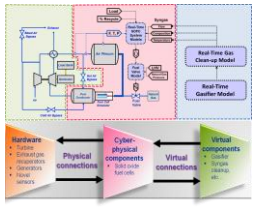
ARIES

IESS at Flatirons Campus



NREL
Transforming ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY




Power Hardware and Grid-in-the-Loop

Human-in-the-Loop


Hydrogen and other Flexible Industrial Processes

Thermal Energy Generation and Transport

# Electrical-to-Thermal Energy Storage