FuelCell Energy

The Future of Energy

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About Me

@MarkFeasel   MarkFeasel   mfeasel@fce.com

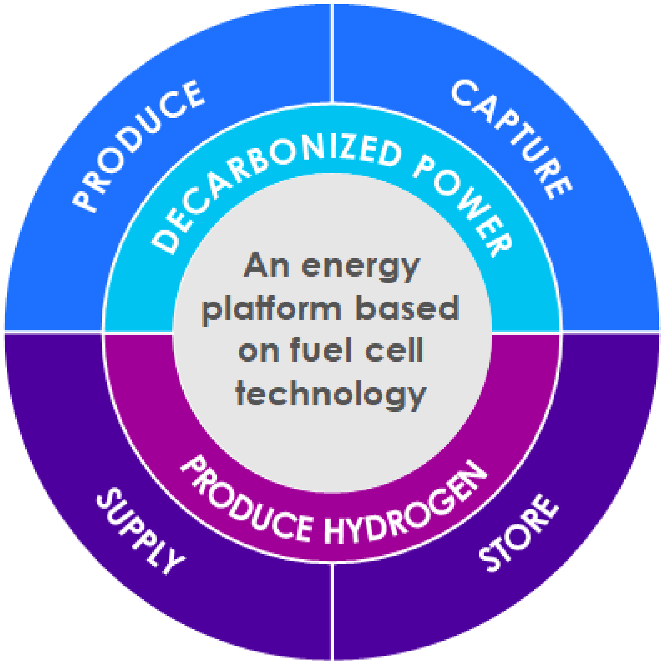
- I’ve been in energy for a LONG time! (picture circa 1990 aboard a nuclear submarine. I was responsible the electrical systems associated with the reactor plant)
- I lead commercial activities for FuelCell Energy
- I am an Adjunct Professor at Northwestern’s Institute for Energy and Sustainability
- I spent 20+ years at Schneider Electric building businesses around power management, electric utilities, and microgrid

FuelCell Energy

Enabling a World Empowered by Clean Energy

A global leader in manufacturing stationary energy platforms for decarbonizing power and producing hydrogen through our proprietary fuel cell technologies

- Founded in 1969
- NASDAC Listed: FCEL
- ~450 Employees
- Manufacturing sites in US, Canada, and Germany
- 95 Platforms in commercial operation
- Awarded >600 Patents



EXPANDING GLOBAL COLLABORATIONS / SOLUTIONS DELIVERED / PARTNERS / RELATIONSHIPS

Global Track Record of Reliability and Performance

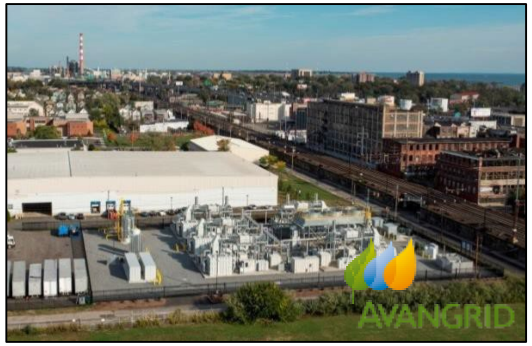
Grid Support with CHP

- 6-month construction
- 20 MW KOSPO site built in 2018
- Power sold to grid
- **Heat provided to district heating system**
- Easily scalable

Resiliency for Pharma

- 5.6 MW with steam for company campus
- **Reliable power solving local grid quality issues**
- Immediate savings vs. grid
- Complements ESG goals

Grid Support / Urban Redevelopment



- Power sold to grid
- Enhances resiliency
- **Brownfield revitalization**
- 15 MW on 1.5 acres
- 12 mo. installation

Fuel Cell / Solar Integration

- Utility-owned, rate-based
- **Enhances resiliency**
- **2.8 MW** fuel cell on **¼ acre**
  - ~23,000 MWh/yr.
- **2.2 MW** solar on ~**9 acres**
  - ~3,000 MWh/yr.

More than 12 Million MWh generated[1]

[1] As of the October 31, 2020.

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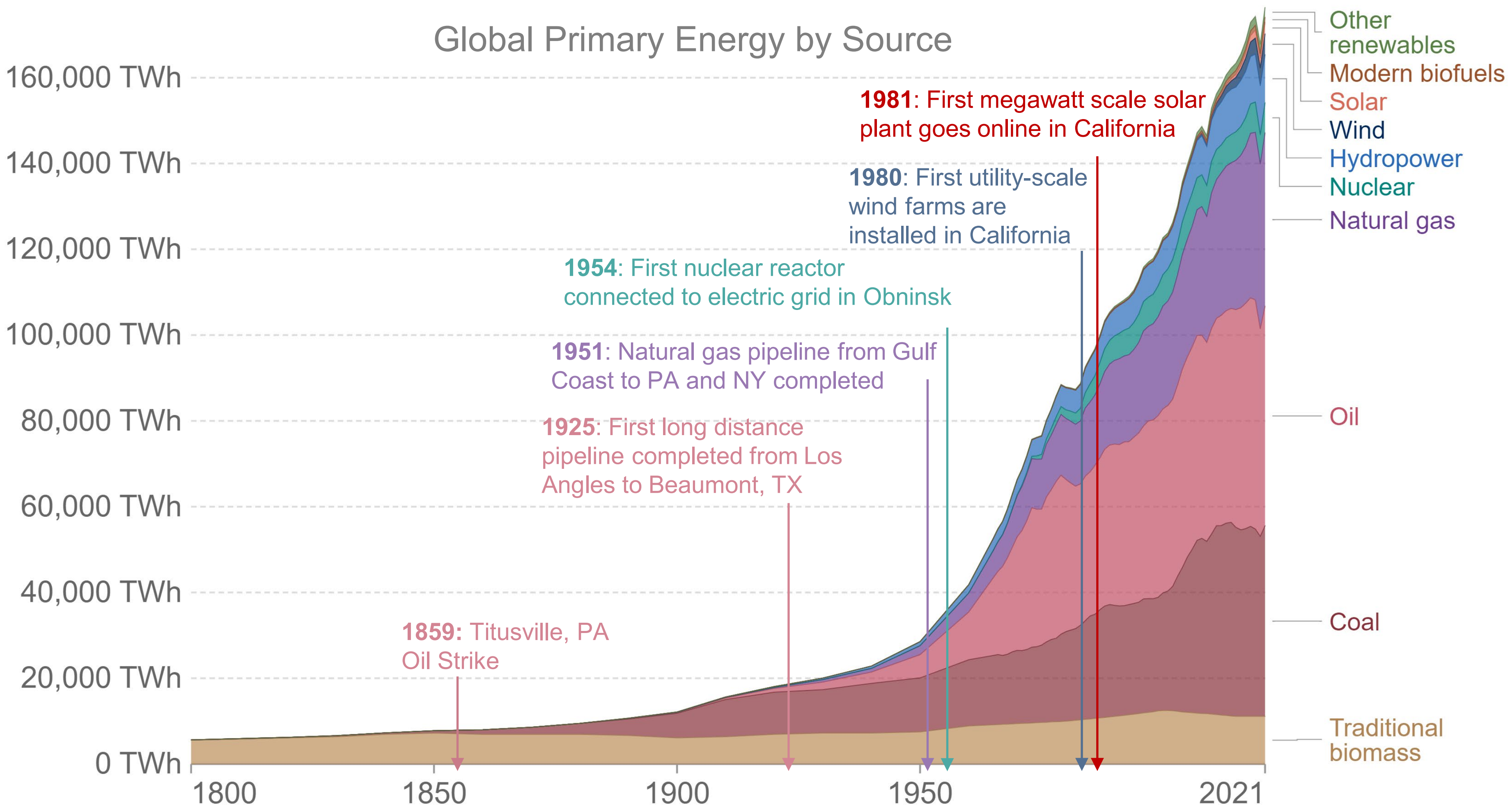
The History of Energy



Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy

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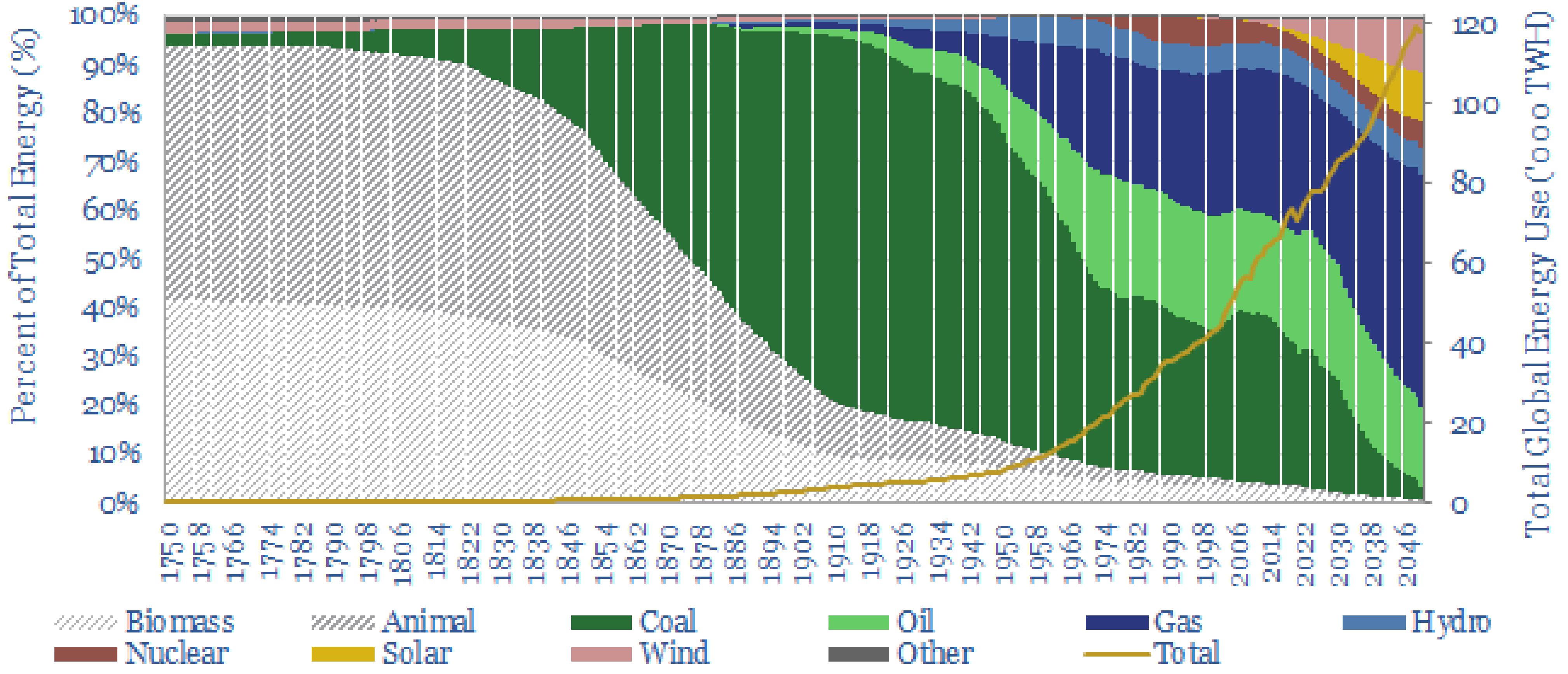
Energy Transition



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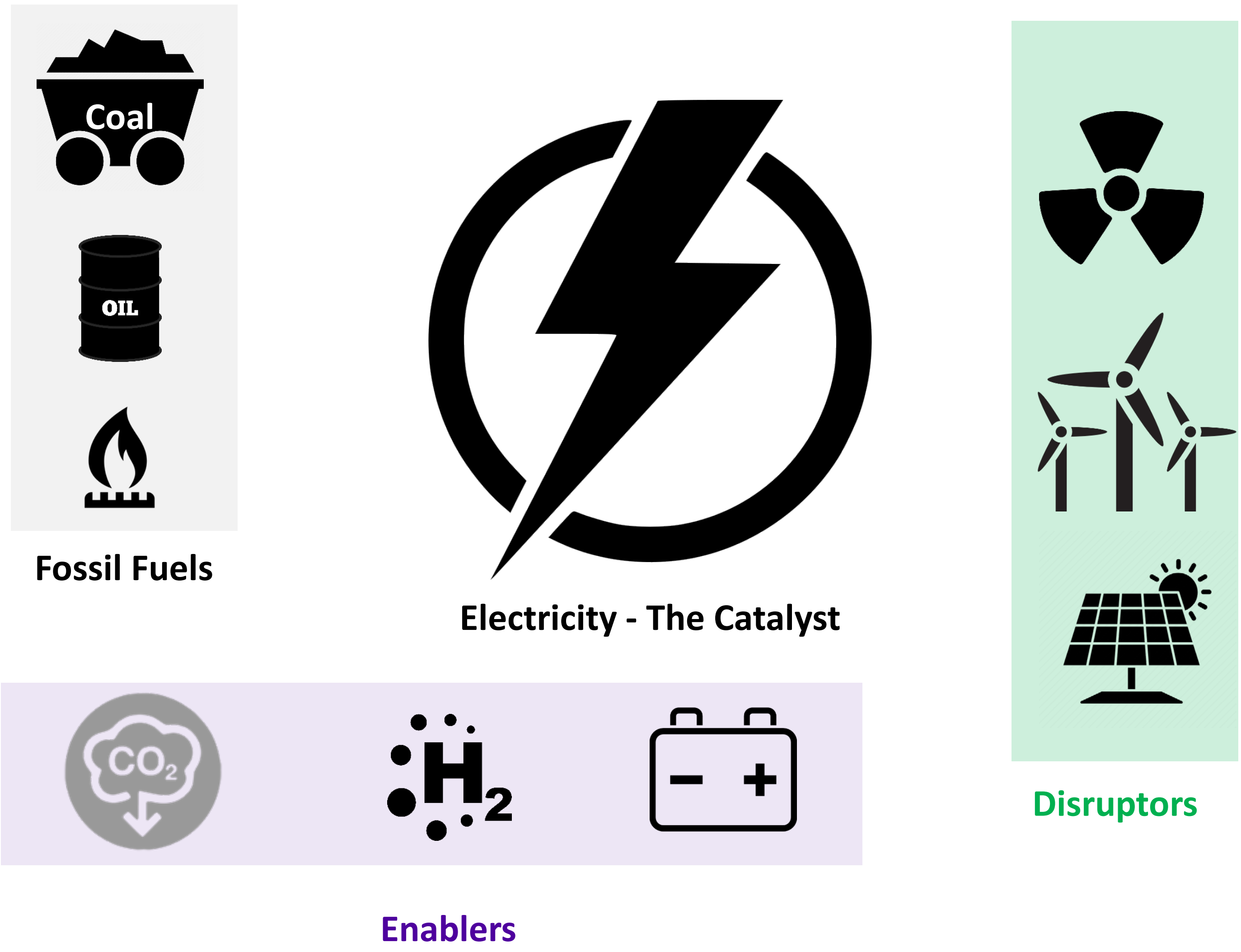
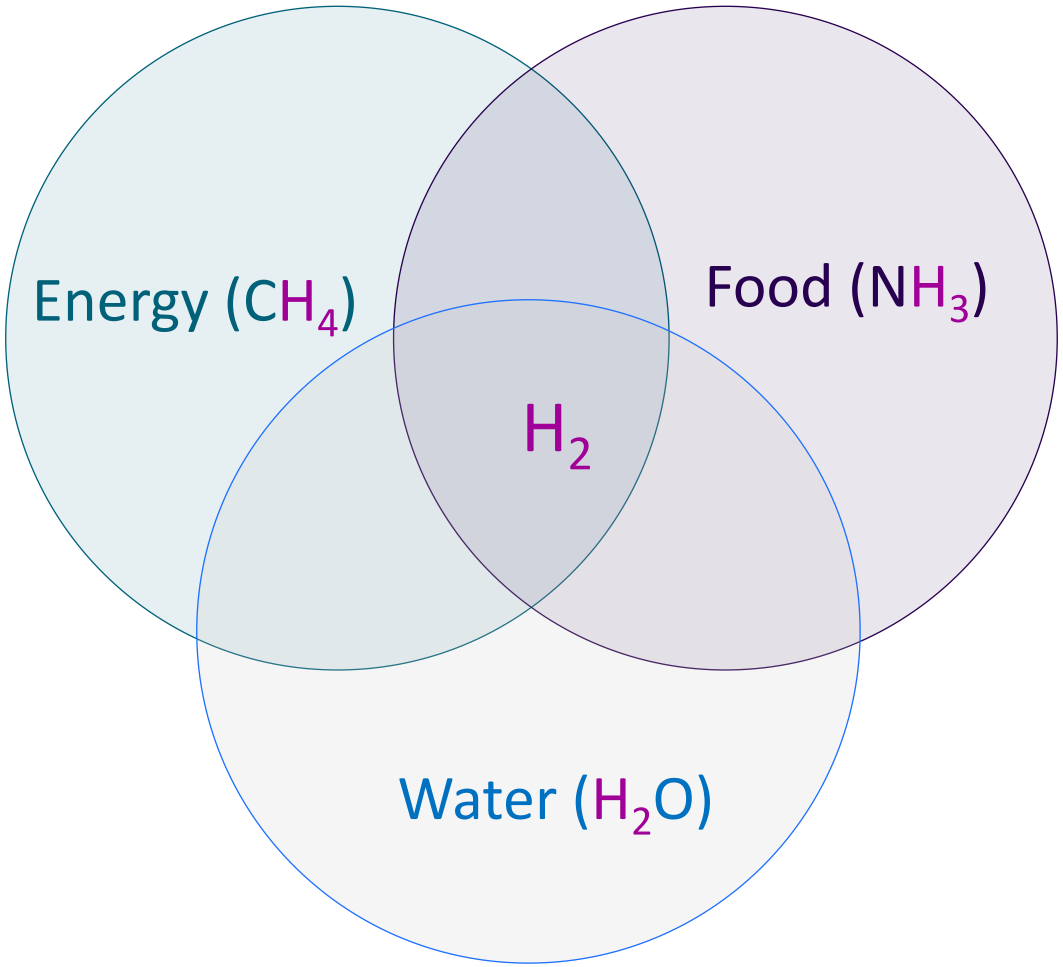
The New Energy Landscape

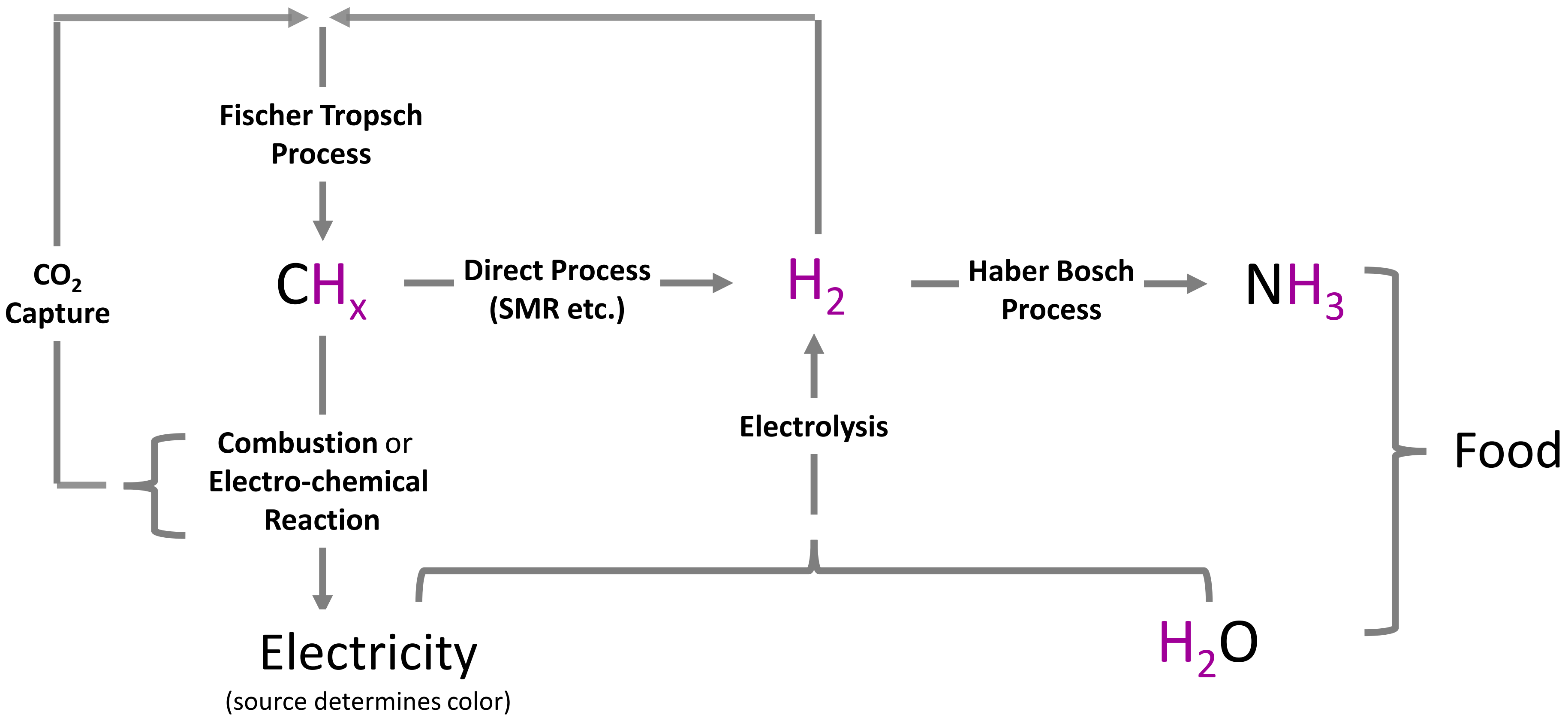


Why is Hydrogen Important?

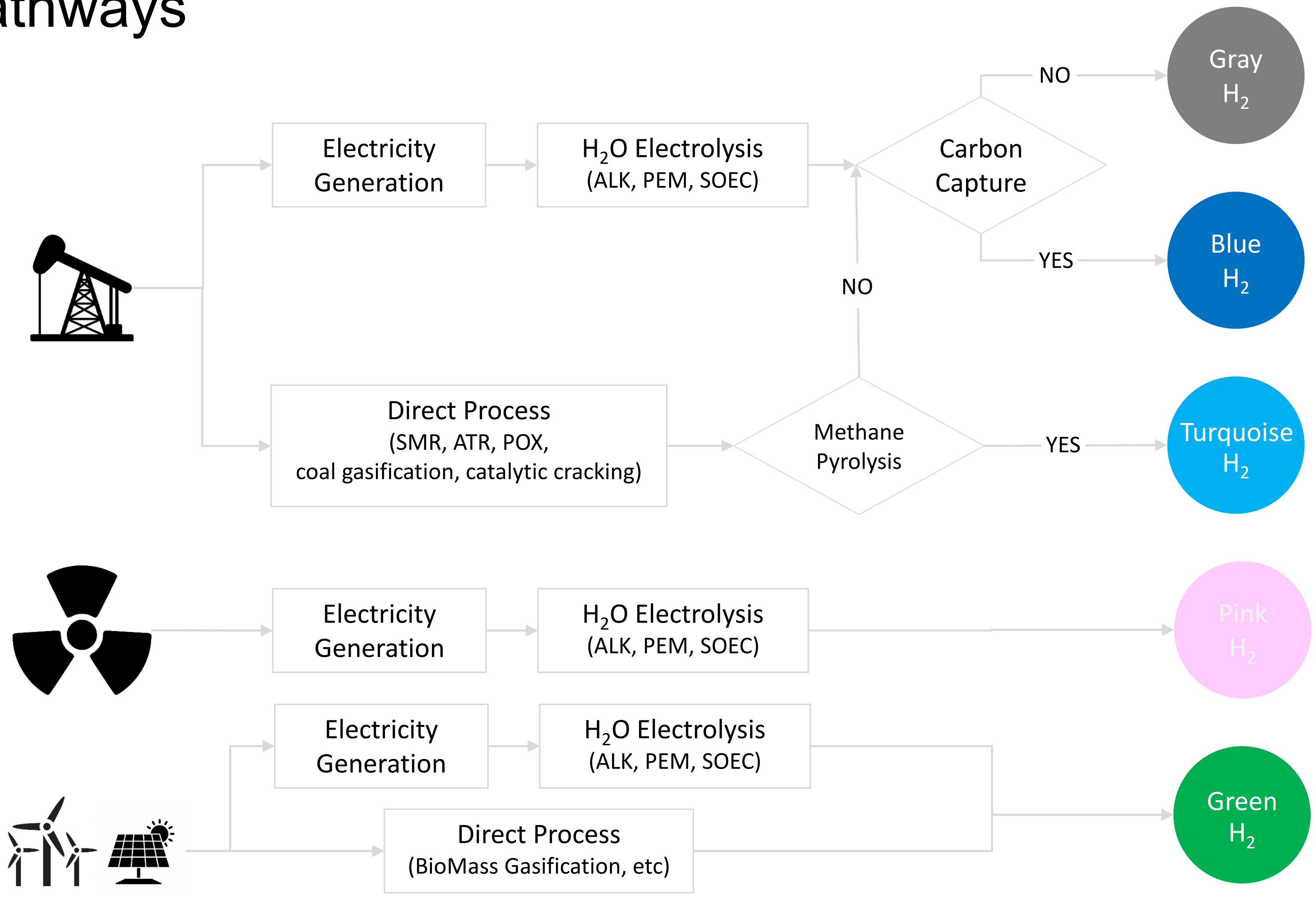


- Fossil fuels are made up of hydrocarbons
- Ammonia (NH_3) is a fertilizer that is a precursor to 45% of the world's food
- Water – the basis of the fluids of all living organisms
- H_2 is at the center of the Energy – Food – Water Nexus

Hydrogen is a Vital Energy Carrier

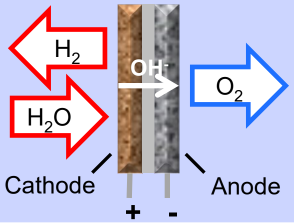
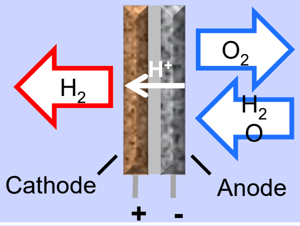
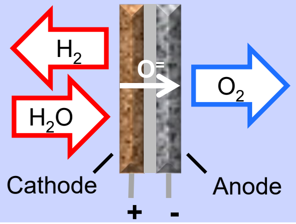


H_2 Pathways



Electricity Generation
H2O Electrolysis
(ALK, PEM, SOEC)
Carbon Capture
NO
YES
Gray H2
Blue H2
NO
Direct Process
(SMR, ATR, POX,
coal gasification, catalytic cracking)
Methane Pyrolysis
YES
Turquoise H2
Electricity Generation
H2O Electrolysis
(ALK, PEM, SOEC)
Pink H2
Electricity Generation
H2O Electrolysis
(ALK, PEM, SOEC)
Direct Process
(BioMass Gasification, etc)
Green H2

H_2 Electrolysis Technologies

	Alkaline Electrolysis	PEM Electrolysis	Solid Oxide Electrolysis
			
Electrolyte	KOH	Polymer membrane	Ceramic membrane
Circulating medium	KOH	Water	Steam
Materials	Nickel, steel alloys	Uses platinum group metals for electrodes	Nickel, ceramics
Operating temperature	60 – 90°C	RT – 80°C	650 – 900°C
Ability to use waste heat	N	N	Y
Efficiency (%)	70	80	90-100
Technical maturity	Industrially mature	Developing	Developing
Reverse (fuel cell) mode	N	N	Y

FuelCell Energy Solid Oxide Platform

Solid Oxide Fuel Cell Power Generation Platform

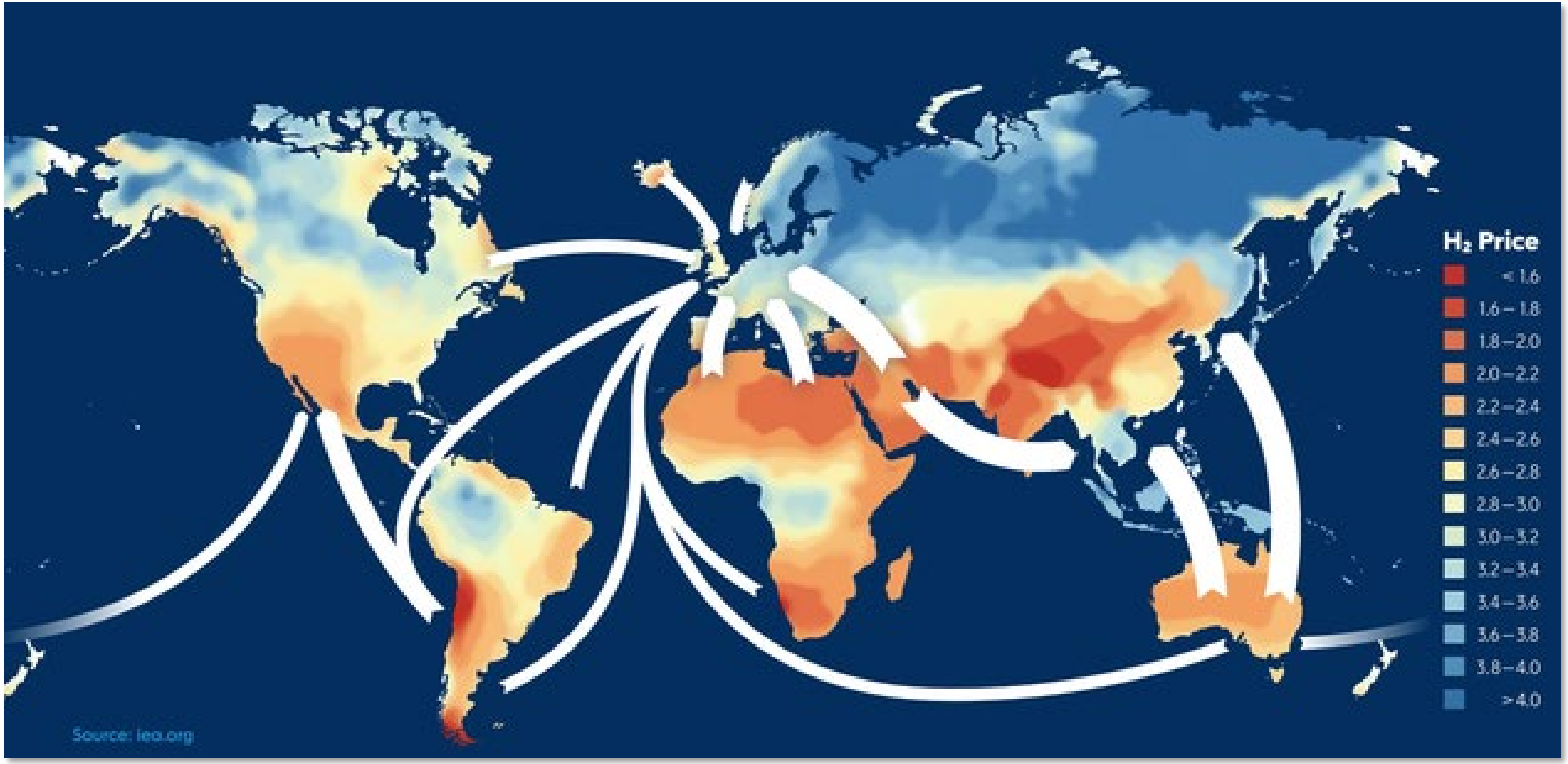
- 250kW Rated Output
- Hydrogen (Also Natural Gas and Biogas)
- High electrical efficiency
- Higher total efficiency in combined heat and power applications

Solid Oxide Electrolysis Platform

- 600 kg/day hydrogen production
- 100% electrical efficiency if waste heat is available (1MW Power Input), 92% (1.1MW Power Input) if not.
- Two modules – stack/mechanical BOP and electrical BOP

Global Green Hydrogen Value Chain potential

By 2030, global hydrogen energy demand will increase by about 76 million tons



Global Green Hydrogen Value Chain Components

Production

- Large, centralized projects
- 100s MW to 1GW++

- Australia
- Middle East (Oman, Saudi Arabia, etc)
- North Africa (Tunisia, etc)
- Chile

Transportation

- Ammonia
- Liquid Organic Molecule
- Liquid H2
- Synthetic Methane

- Ammonia tanker
- Custom molecule tanker
- H2 tanker
- LNG tanker

Usage

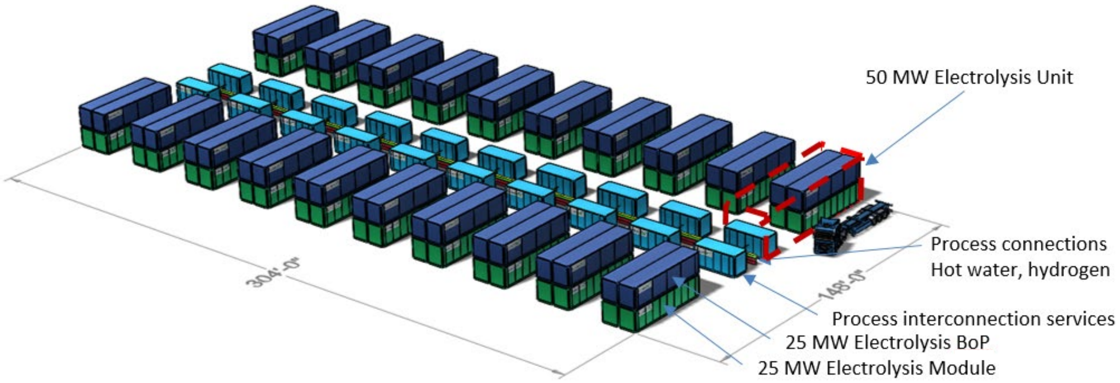
- Power Production
- Gas pipeline
- Steel
- Fertilizer
- etc

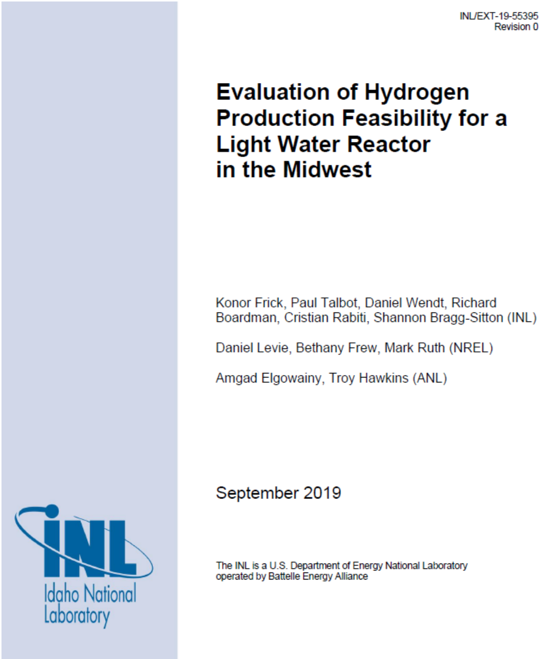
- Europe
- Japan
- Korea
- Taiwan
- Singapore

February 16, 2023:

FuelCell Energy to collaborate with Malaysia Marine and Heavy Engineering to deliver Solid Oxide Electrolyzers for Large Scale Green Hydrogen Production

Nuclear + Electrolysis




INL/EXT-19-55395
Revision 0

Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest

Konor Frick, Paul Talbot, Daniel Wendt, Richard Boardman, Cristian Rabiti, Shannon Bragg-Sitton (INL)

Daniel Levie, Bethany Frew, Mark Ruth (NREL)

Amgad Elgowainy, Troy Hawkins (ANL)

September 2019

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance

Idaho National Laboratory

Distributed Electrolysis
600 kg/day H_2 from 1.1MW

GW-scale electrolysis system for converting off peak nuclear power to hydrogen

ELECTROLYSIS WILL BE DEPLOYED IN DISTRIBUTED AND LARGE-SCALE APPLICATIONS

Energy Storage

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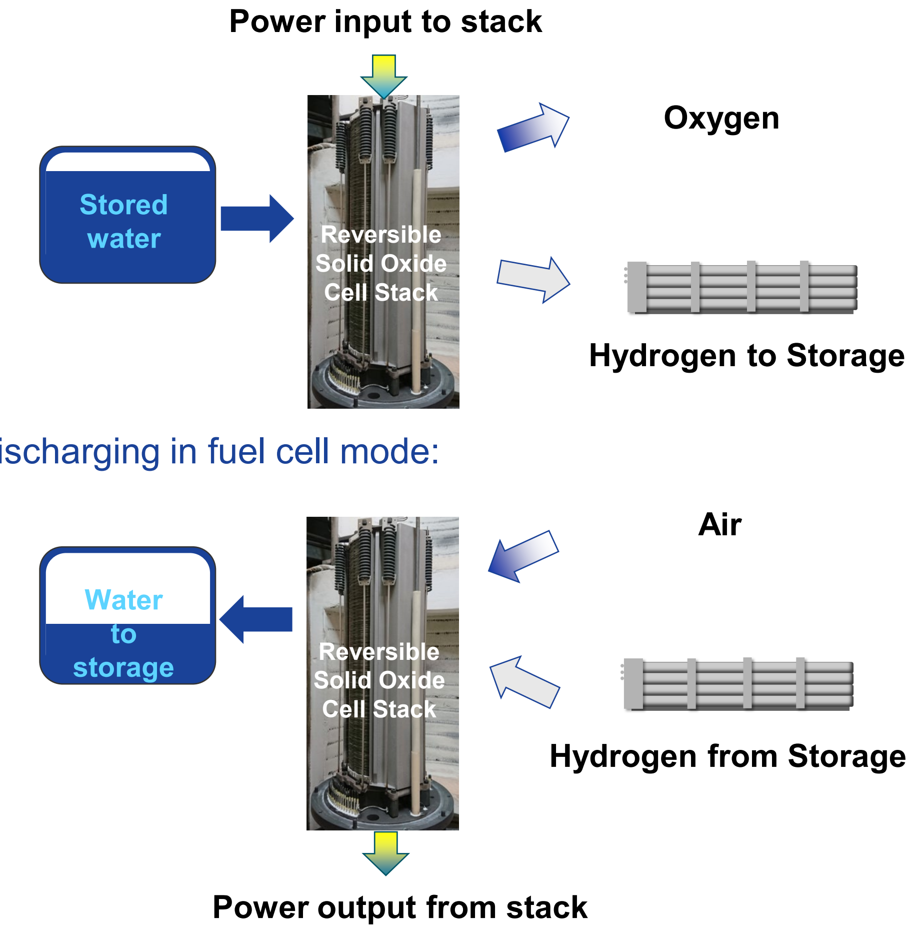
Solid Oxide Hydrogen Based Energy Storage

- In addition to operation in **electrolysis mode** Solid Oxide Fuel Cells (SOFC) can run in **fuel cell mode**, and can switch between modes, called Reversible Solid Oxide Fuel Cell **(RSOFC)**.
- High efficiency in electrolysis and fuel cell mode enable high round trip efficiency
- RSOFC stacks with hydrogen and water storage are an advanced energy storage approach:
  - High round trip efficiency
  - Long duration achieved by adding low-cost hydrogen and water storage capacity, without the need to add more stacks
  - Inexpensive water is the only reactant – added as an initial fill and regenerated with each discharge cycle

Charging in electrolysis mode:

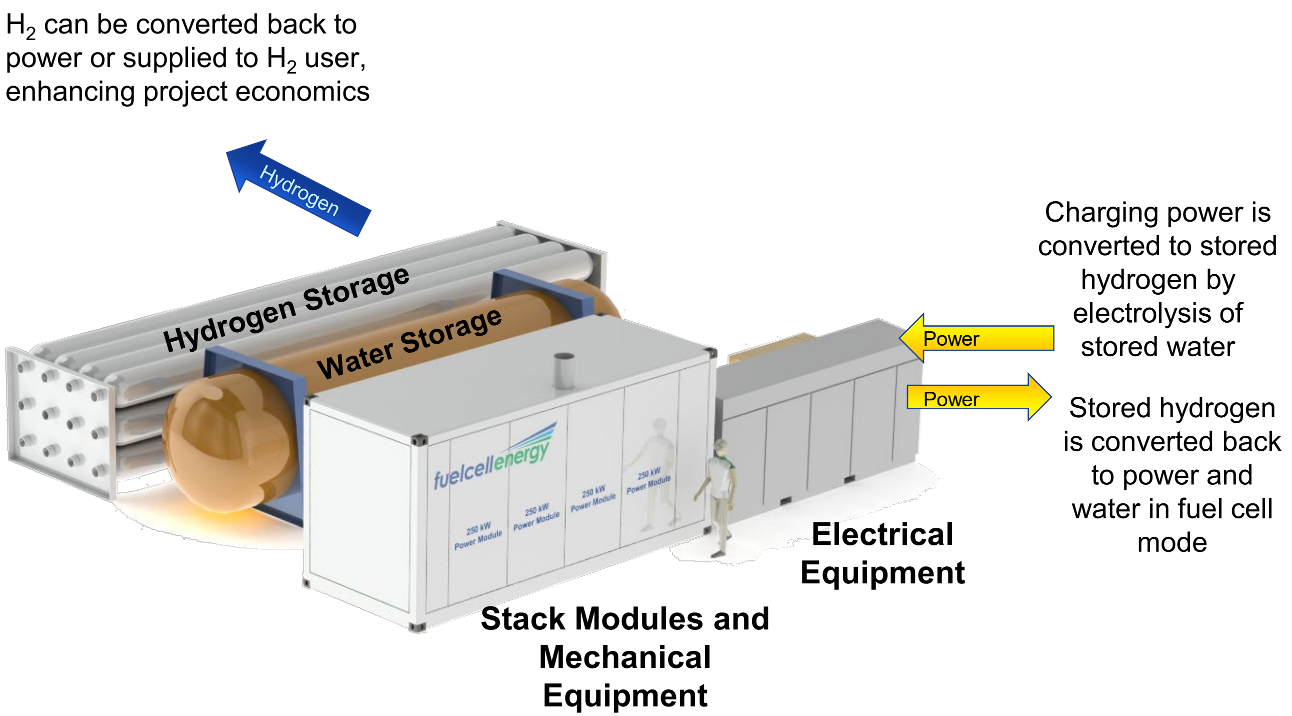
Discharging in fuel cell mode:



WITH WATER AS THE ONLY STORED REACTANT, HYDROGEN-BASED STORAGE HAS SIGNIFICANT ADVANTAGES FOR LONG DURATION STORAGE

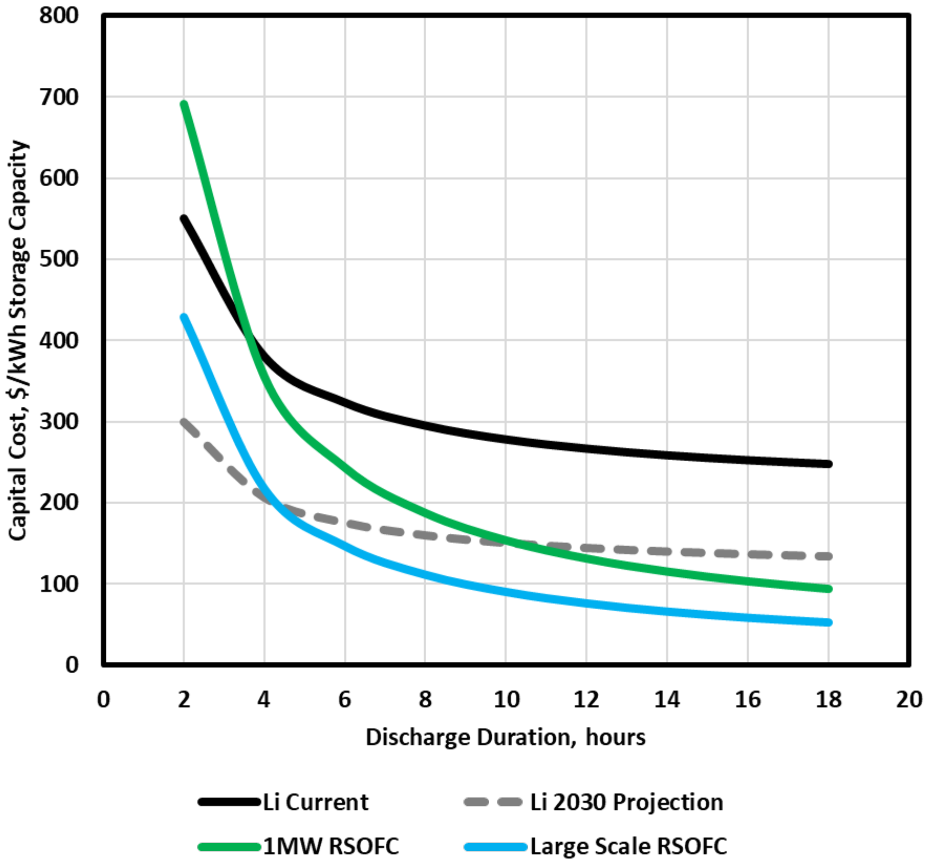
Solid Oxide - Hydrogen Based Long Duration Energy Storage System

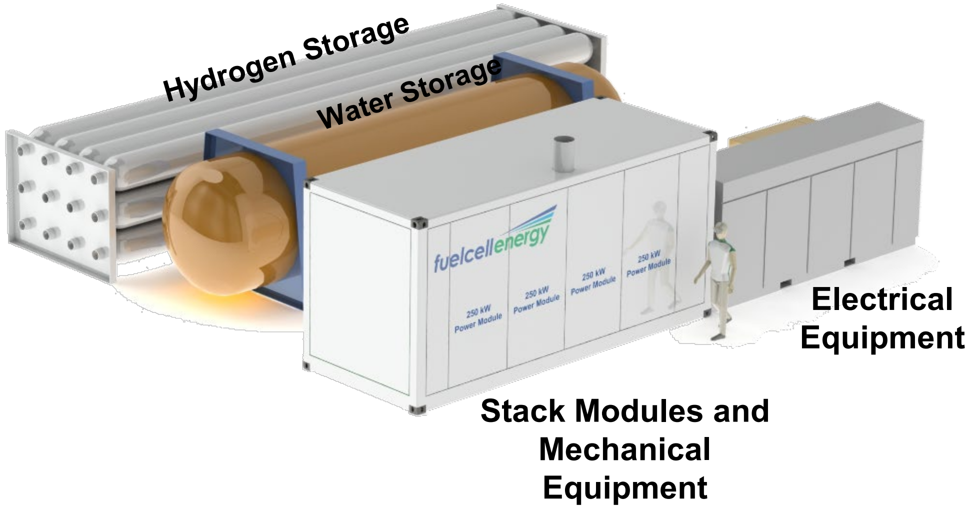
- Hydrogen during charge cycle can be used to provide power during discharge cycle or can be exported to hydrogen user
- Geological storage of hydrogen can provide weekly or seasonal storage
- The storage reactant is water, which is regenerated during power generation discharge – does not depend on limited quantities of lithium or cobalt
- Discharge duration is added by adding inexpensive hydrogen and water storage – so cost of storage capacity reduces significantly with longer duration



1MW SOFC/SOEC System

Lithium and Reversible Solid Oxide Cost vs Discharge Duration





RSOFC Energy Storage System

Discharge duration is increased by adding Hydrogen and water storage – very low $/kWh cost components

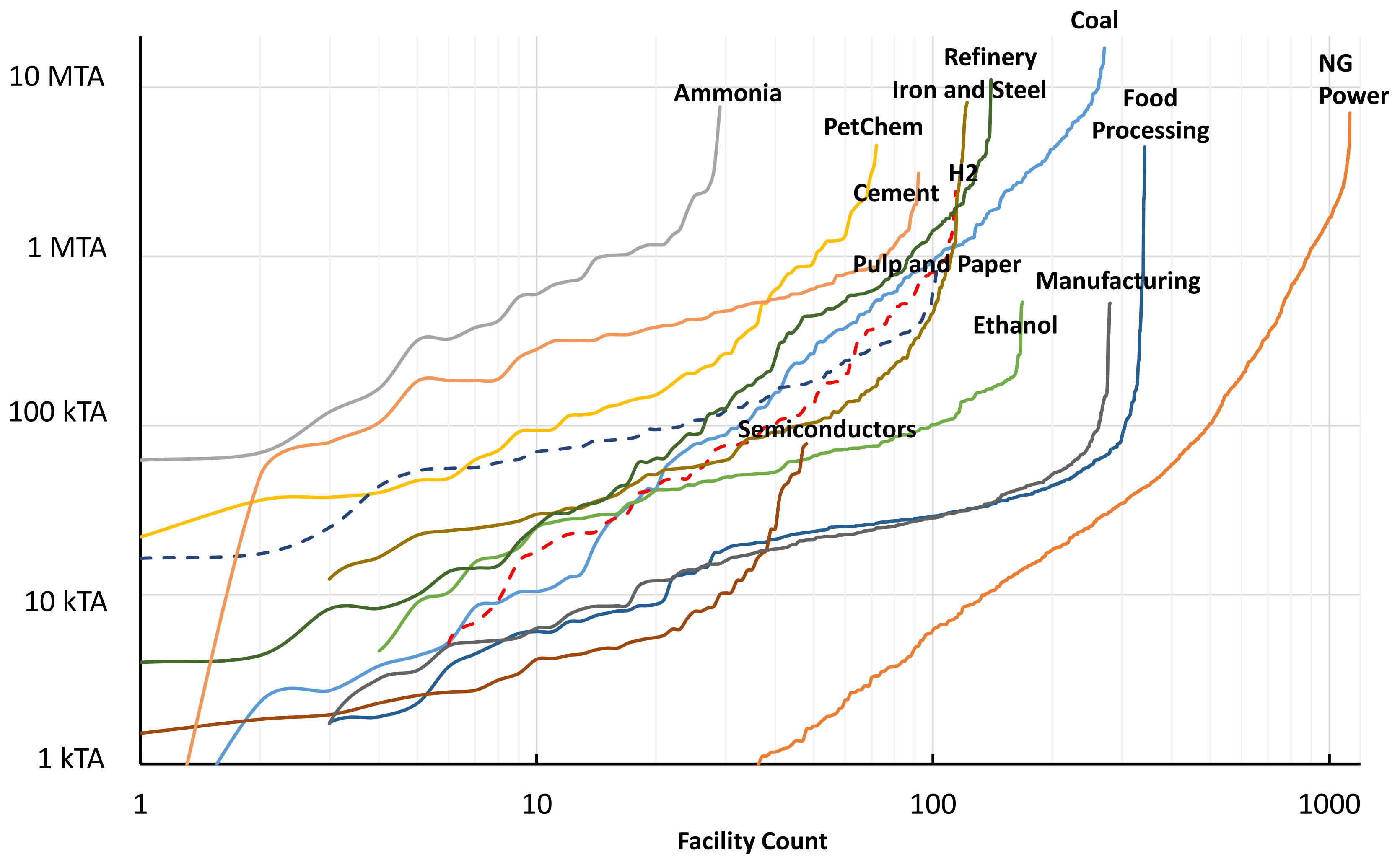
Li projections based on NREL estimates from
Cole, Wesley, and A. Will Frazier. 2019. Cost Projections for Utility-Scale Battery Storage. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73222. https://www.nrel.gov/docs/fy19osti/73222.pdf

RSOFC based on company estimates
1MW projected costs of $1345/kW plus $19/kWh
Large scale applies 80% scaling power factor to $/kW cost and assumes geologic H_2 storage, reducing energy cost factor to $5/kWh

LOW $/kWh COMPONENT OF HYDROGEN-BASED STORAGE REDUCES COST OF LONG DURATION SYSTEMS

Carbon Capture

US Point-Source Emissions by Sector



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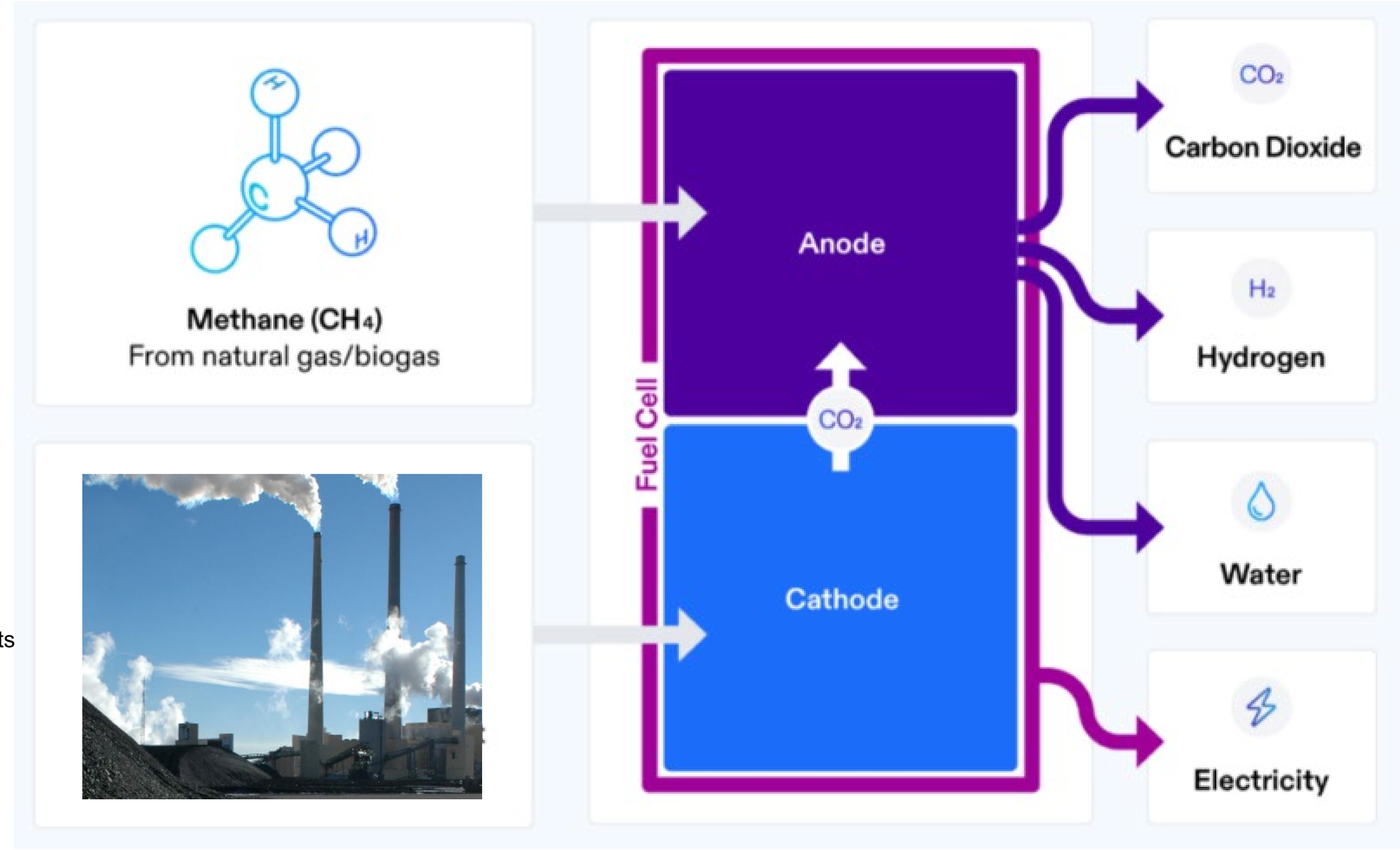
Clean Power + Carbon Capture

Fossil Emissions:

- Coal Power Plants
- Natural Gas Power Plants
- Industrial Boilers
- Steam Generators



Concentrated and Captured

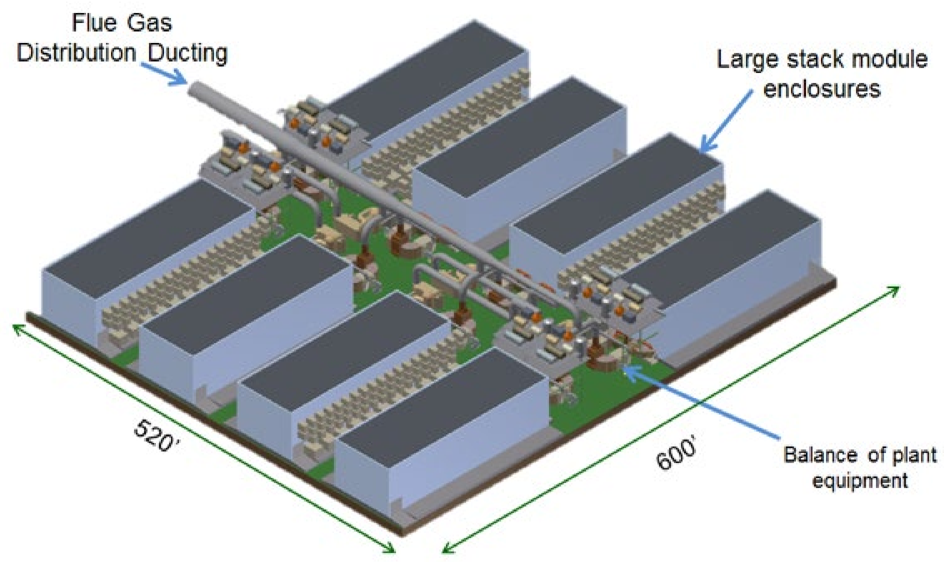
Created

Created

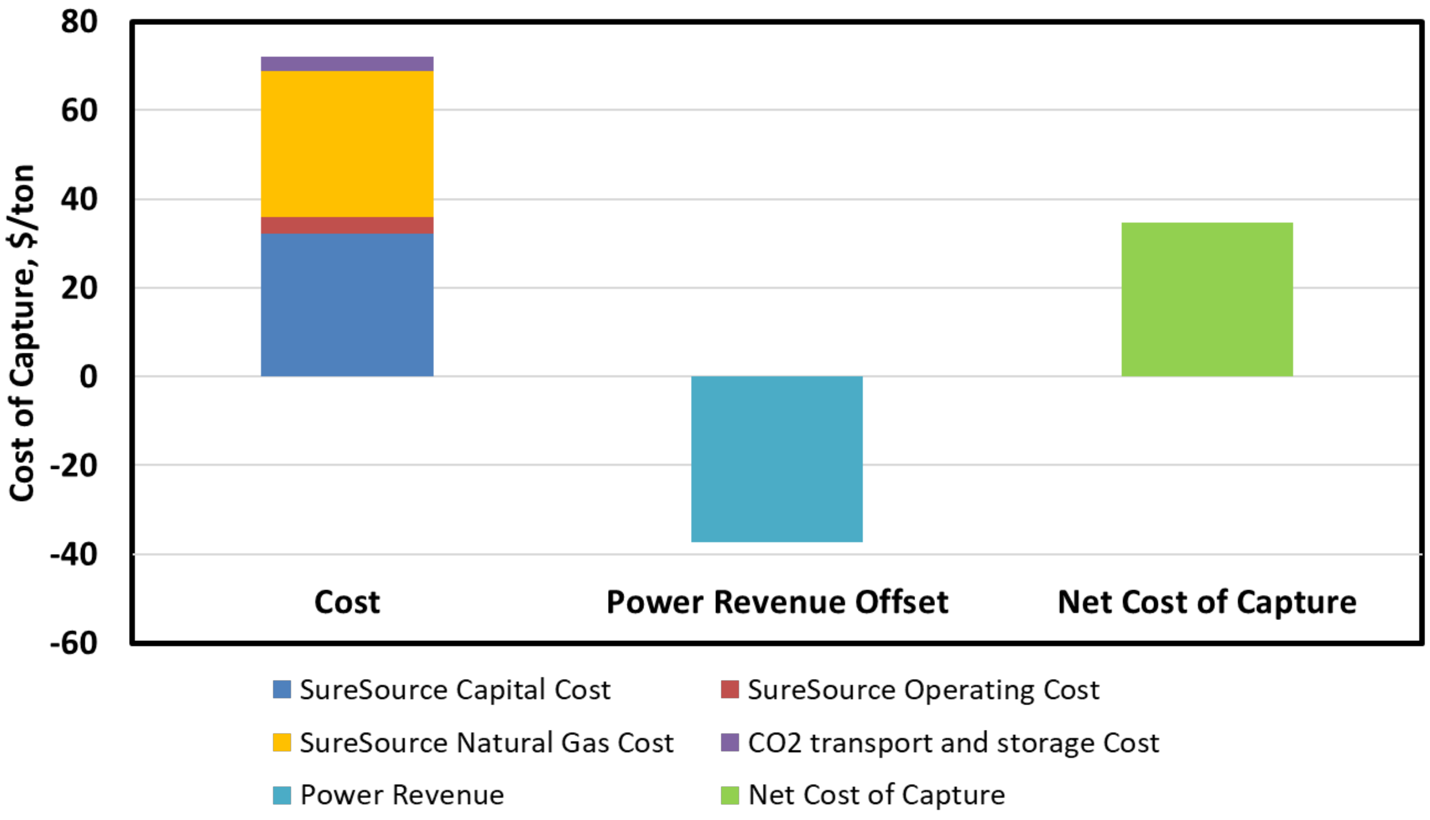
Created

FuelCell Energy's Carbon Separation & Unique Carbon Capture

Only Platform In The World That Can Capture Carbon From An External Source And Produce Power At The Same Time



319 MW SureSource plant for capture from coal systems – 90% capture from 550 MW coal plant



Cost analysis of fuel cell carbon capture applied to 550 MW Reference Supercritical PC Plant under DOE DE-FE0026580

Hydrogen co-production could reduce net cost of capture further

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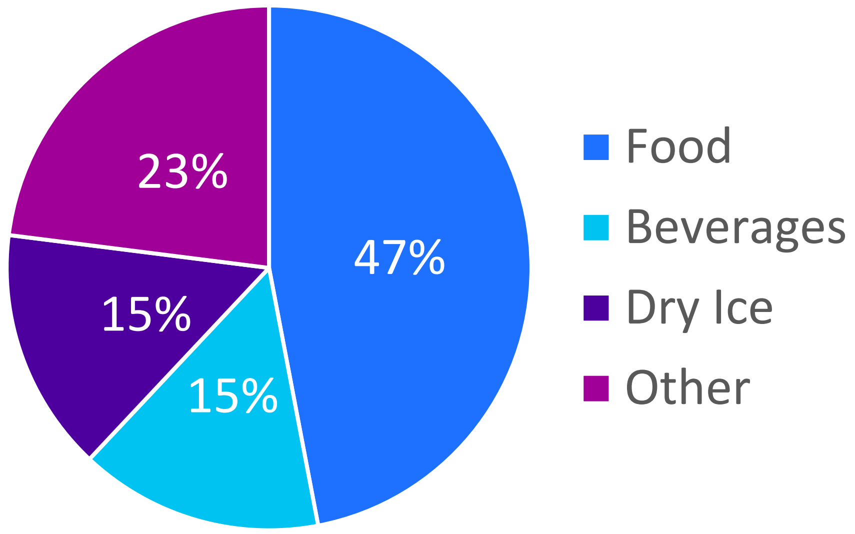
Source and for more information:
https://www.netl.doe.gov/projects/files/H-Ghezel-Ayagh-FCE-Electrochemical-Membrane-System.pdf
Pilot Test of Novel Electrochemical Membrane System for Carbon Dioxide Capture and Power Generation (DE-FE0026580)
2018 NETL CO2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 13-16, 2018

Case Study - CO_2 and the Food Processing Industry

The three major applications for commercial CO_2 are:

- Food
- Beverages
- Dry ice



The Meat Processing industry uses CO_2 to:

- Stun animals
- Keep products cold during transportation
- Cool meat products and equipment during processing

There are few viable alternatives that can easily replace CO_2 for these purposes

The Cost of CO_2 is on the Rise

1. **COVID-19**
   - One-third of the North American supply of CO_2 is derived from the fermentation step of creating ethanol.
   - Ethanol production was significantly reduced as demand for fuel dropped when people drove less. In the long term, the rise of hybrid work arrangements and electric vehicle adoption are working against growth of ethanol.
   - Vaccine storage and transportation has created a significant new demand for commercial CO_2
2. **Price of Natural Gas**
   - Another major source of CO_2 is derived from the creation of synthetic NH_3 for fertilizer.
   - Natural gas is a key competent of the process and some fertilizer plants have shut down due to the high cost creating scarcity in CO_2 markets.
3. **Natural Source Contamination**
   - Contaminants ,such as benzine, have been found in some of the largest natural reserves of CO_2 increasing scarcity.
4. **Regulation / Policy**
   - IRA establishes $85 / ton for sequestration of CO_2, practically creating a market floor.

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Case Study – Benefits to Food Processor

$2.7M / year savings

$34M NPV over 20 years

84% capture of CO_2

from on-site boilers

70% reduction in Boiler NO_X

monetized via Arizona Emissions Bank

54 TPD of beverage grade CO_2

securitizing supply

1.3MW of baseload power

for increased resilience

96MMBTU / day of Heat

reducing boiler load

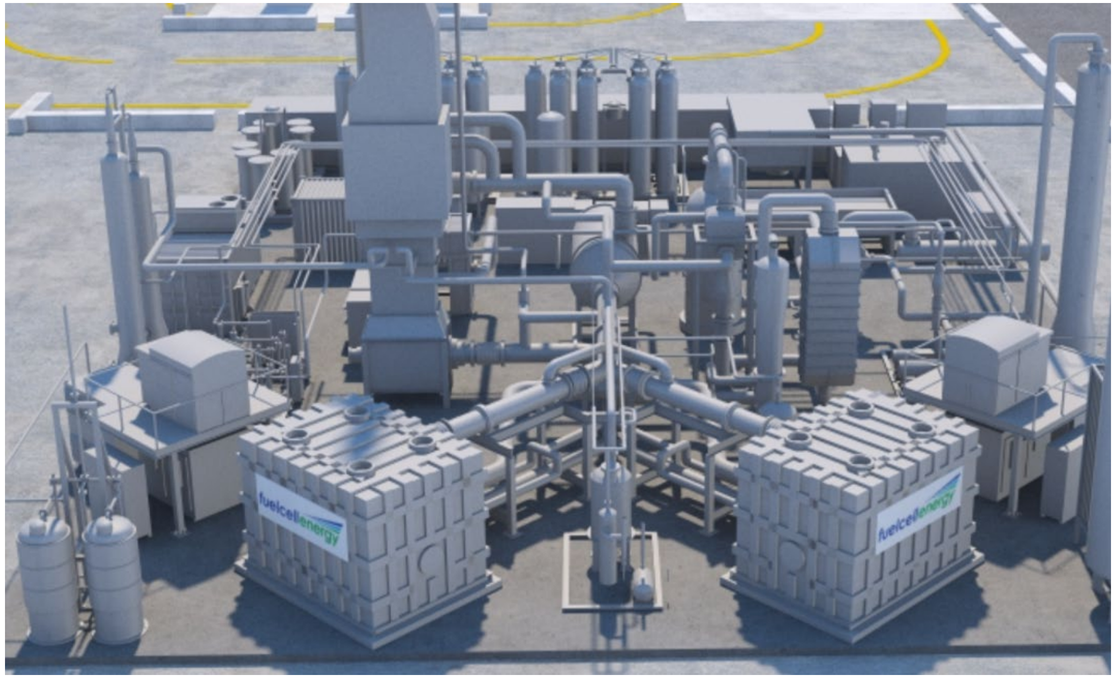
1440 gal/day of H_2O created

supporting ESG goal

Case Study – Port of Long Beach

Carbonate Trigeneration System

Natural gas or renewable biogas fuel



2.35 MW Clean and green power – 18 GWh/year

- 1200 tons per year avoided grid CO_2 emissions with natural gas fuel
- 10,000 tons per year avoided grid CO_2 emissions with biogas fuel
- 5 tons per year avoided NOX

0.5 MMBtu/h thermal energy

- 290 tons per year avoided boiler CO_2 emissions
- 200 lbs per year avoided NOX

1270 kg/day hydrogen

- 1700 tons per year CO_2 reduction vs SMR
- 4200 tons per year CO_2 reduction vs SMR with biogas fuel
- 700 lbs per year NOX reduction vs SMR
- 2 million gallons less water used per year vs SMR

1400 gallons / day water

Thank You! / Q&A