InnovationXLab CarbonX Summit

Hydrogen-Carbon Economy

Wednesday, October 21, 2020

Moderator
Dr. Briggs White

Technology Manager for Crosscutting Research – High Performance Materials, Water Management, and Energy Storage
National Energy Technology Laboratory

Panelist
Eric Guter

Vice President and General Manager of Americas Growth Platforms
Air Products and Chemicals Inc.

Panelist
Danny Deffenbaugh

Vice President, Mechanical Engineering Division
Southwest Research Institute

Panelist
Guy DeLeonardo

General Manager, Application Engineering & Technology, Gas Power Systems
GE

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Dr. Jennifer Kurtz

Director for the Energy Conversion and Storage Systems Center
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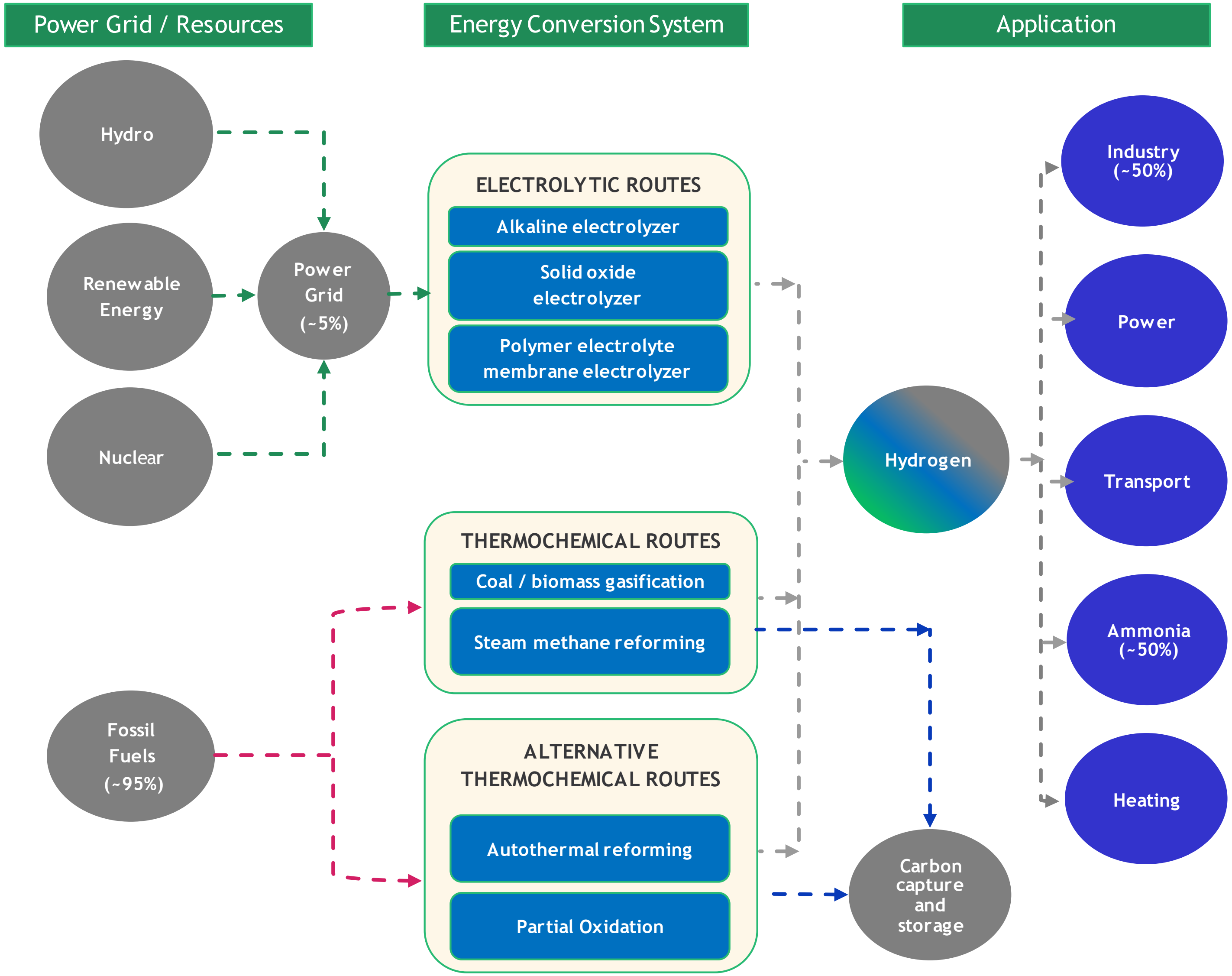
Hydrogen Production Overview

Hydrogen Explained

How is hydrogen produced?

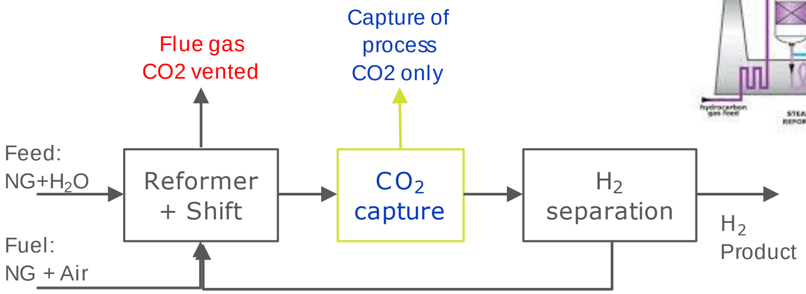
- To produce hydrogen, it must be separated from the other elements in the molecules where it occurs.
- Hydrogen atoms can be separated from water; from hydrocarbons in coal, petroleum, and natural gas; and from biomass.

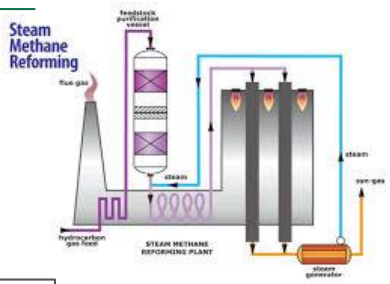


Source: The Royal Society, Options for producing low-carbon hydrogen at sale (public domain)

Hydrogen via fossil fuels

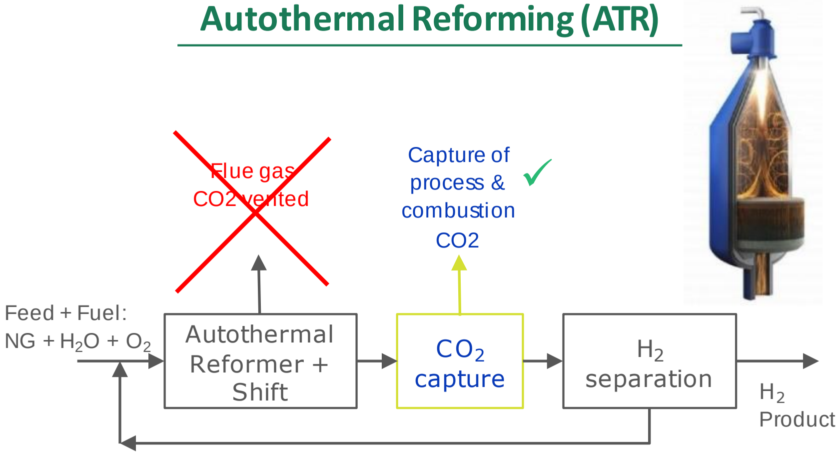
Steam Methane Reforming (SMR)





- Most common production method globally due to inexpensive feedstock; typically natural gas
- All CO_2 is emitted into atmosphere unless capture equipment is installed
- Due to design, only about 50% of CO_2 can be economically removed using current technologies
- DOE / Air Products successfully demonstrated CO_2 removal at scale in Port Arthur, TX

Autothermal Reforming (ATR)



- Less common production method but gaining interest due to deeper levels of CO_2 removal
- When combined with CO_2 removal system, approximately 95% of CO_2 can be removed
- Attractive option where CO_2 sequestration infrastructure / geology exists

Hydrogen via electrolysis

Alkaline

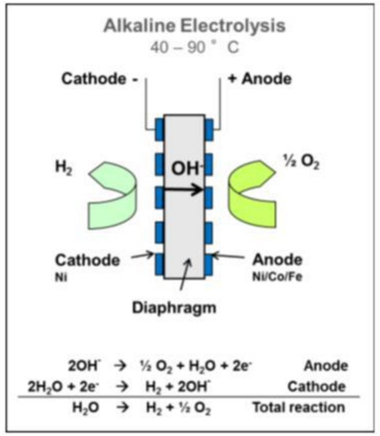
- Oldest electrolyzer technology
- Uses a cell with a cathode, an anode and an electrolyte based on a solution of caustic salts.
- When voltage is applied, water decomposes in the alkaline solution.
- Hydrogen is formed at the cathode and oxygen at the anode characterized by two electrodes operating in a liquid alkaline electrolyte solution of potassium hydroxide or sodium hydroxide.

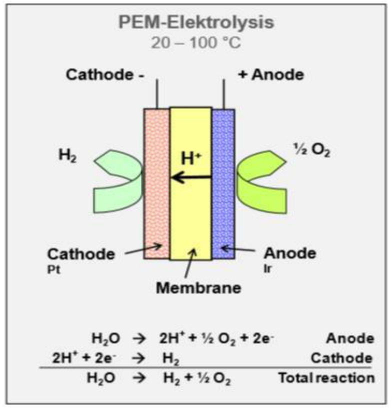
Polymer Electrolyte Membrane (PEM)

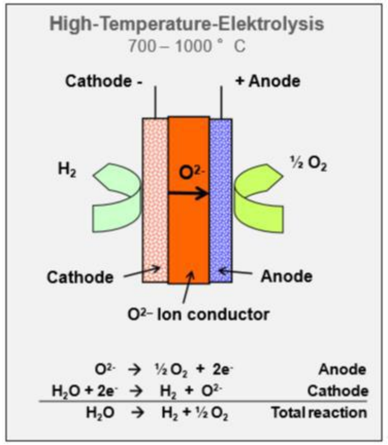
- Cell equipped with a solid polymer electrolyte responsible for the conduction of protons, separation of product gases and electrical insulation of the electrodes.
- Introduced in the 1960's by GE to overcome the issues of partial load, low current density, and low-pressure operation currently plaguing alkaline electrolyzer
- Can operate at high current densities which is useful in dynamic energy sources such as wind and solar.

Solid State

- Solid ionic conductor electrolyte (typical in a solid-state battery)
- Main advantages are the increased safety, no issues of leakages of toxic organic liquids , low flammability, non-volatility, mechanical and thermal stability, easy processability, low self-discharge, higher achievable power density and cyclability
- Considered encouraging technology to long-range EVs







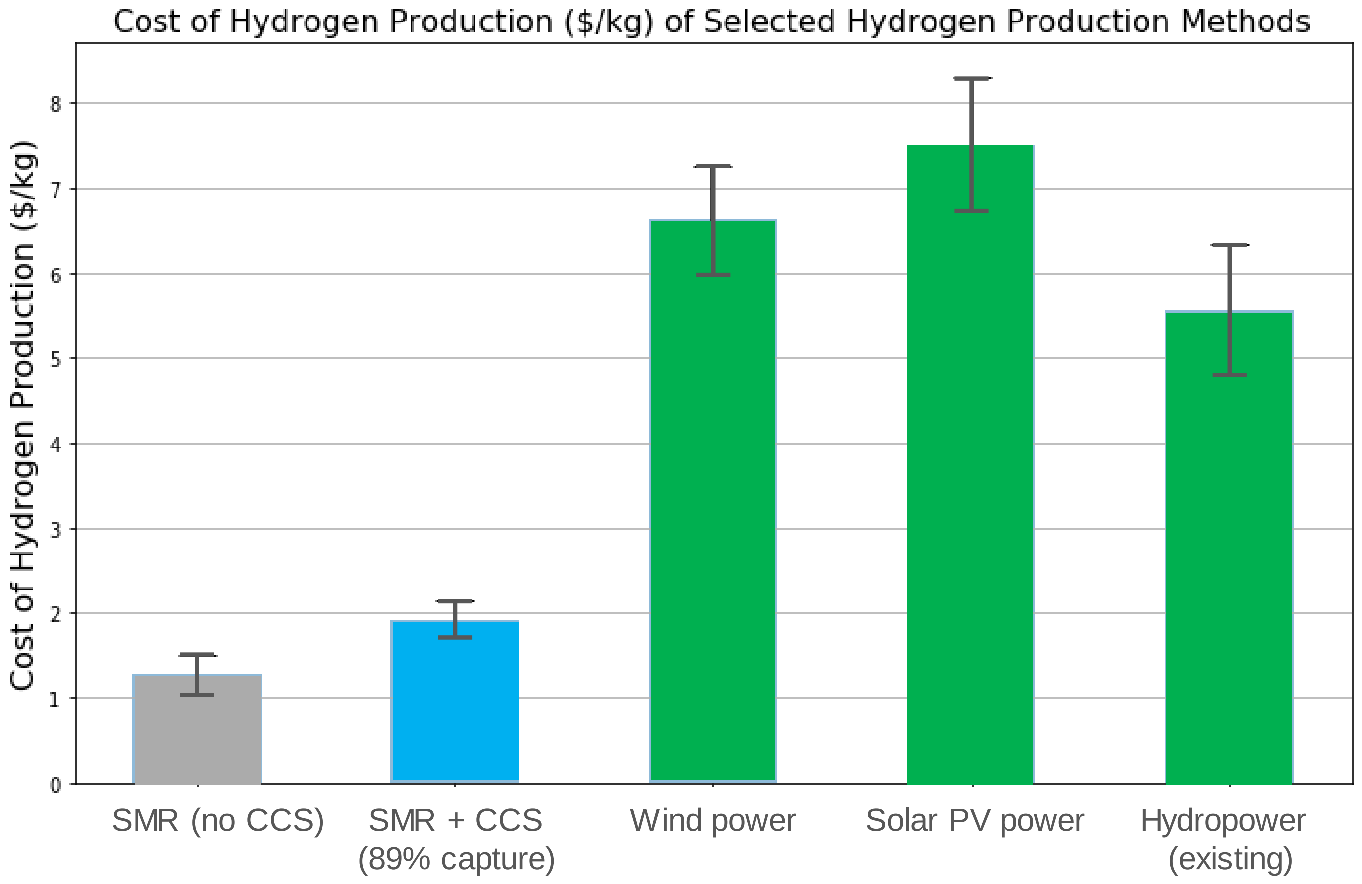
Hydrogen cost of production versus carbon content

C footprint: Grey, blue & green H_2

- Gas reformation with no CCS
- Gas reformation with CCS (50-90% C reductions)
- Water + zero-C electricity (near-zero C reduction)

Incentives supporting blue & green H_2

- Federal 45Q tax credit
- California Low Carbon Fuel Standard



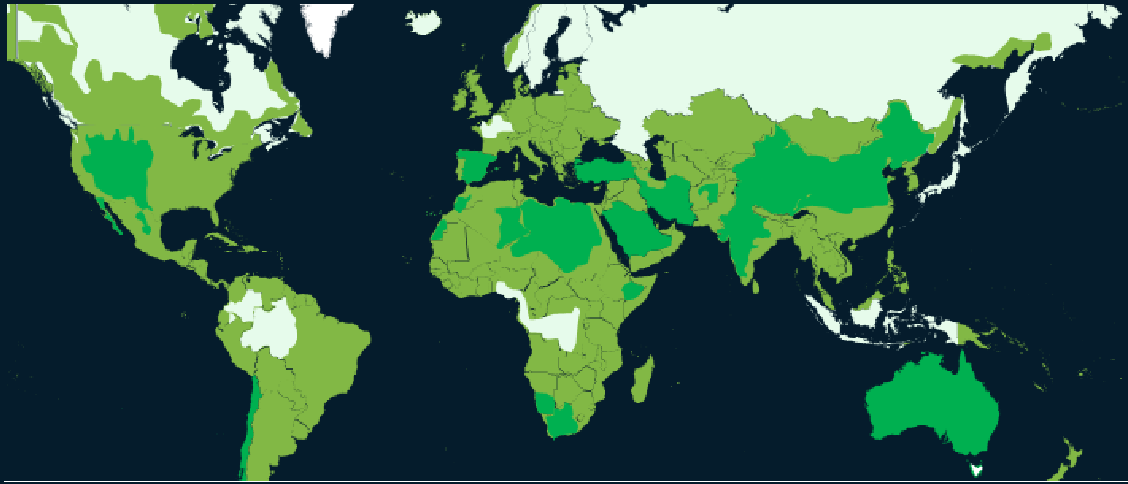
https://energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

Green and blue hydrogen are geographically complementary

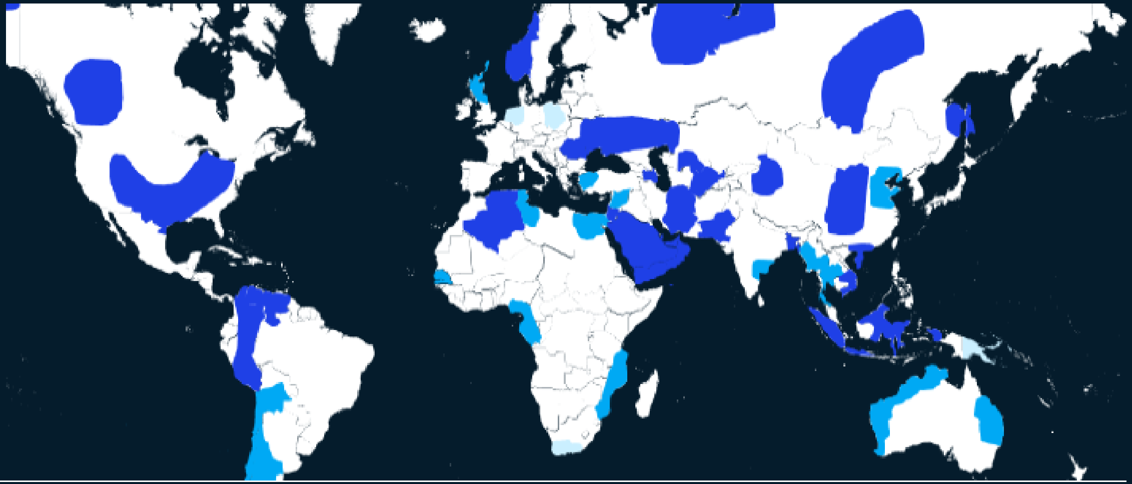
Optimal Resources:

Least Most

PV/wind resources for green hydrogen production



Natural gas resources for blue hydrogen production



U.S.

- Good availability of natural gas and CCS for low-carbon hydrogen production
- Favorable PV and wind conditions

Chile

- Favorable PV/wind hybrid conditions, good access to natural gas

EU

- Likely to be a high-demand location
- Renewables-constraints due to varying load curves and limited space availability

Middle East, North Africa

- High PV/wind hybrid potential and low-cost natural gas for low-carbon hydrogen

China

- Large investments in hydrogen economy with potential to become self-sufficient

Korea, Japan

- Strategy to scale up hydrogen consumption; resource constraints on RES; necessity to import hydrogen

Australia

- Potential for large-scale PV with favorable load profiles

Source: McKinsey

Drivers and indicators of hydrogen's momentum

Drivers of renewed interest in hydrogen

Stronger push to limit carbon emissions

10

Years remaining in the global carbon budget to achieve the 1.5°C goal

66

Countries that have announced net-zero emissions as a target by 2050

Falling costs of renewables and hydrogen technologies

80%

Decrease in global average renewable energy prices since 2010

55x

Growth in electrolysis capacity by 2025 vs. 2015

Indicators of hydrogen's growing momentum

Strategic push in national roadmaps

70%

Share of global GDP linked to hydrogen country roadmaps to date[1]

10 m

2030 target deployment of FCEVs announced at the Energy Ministerial in Japan

Industry alliances and momentum growing

60

Members of the Hydrogen Council today, up from 13 members in 2017

30+

Major investments announced[2] globally since 2017, in new segments, e.g. heavy duty and rail

1. Based on 18 country roadmaps announced as of publication
2. Not exhaustive

Image: The Hydrogen Council – Path to Hydrogen Competitiveness report

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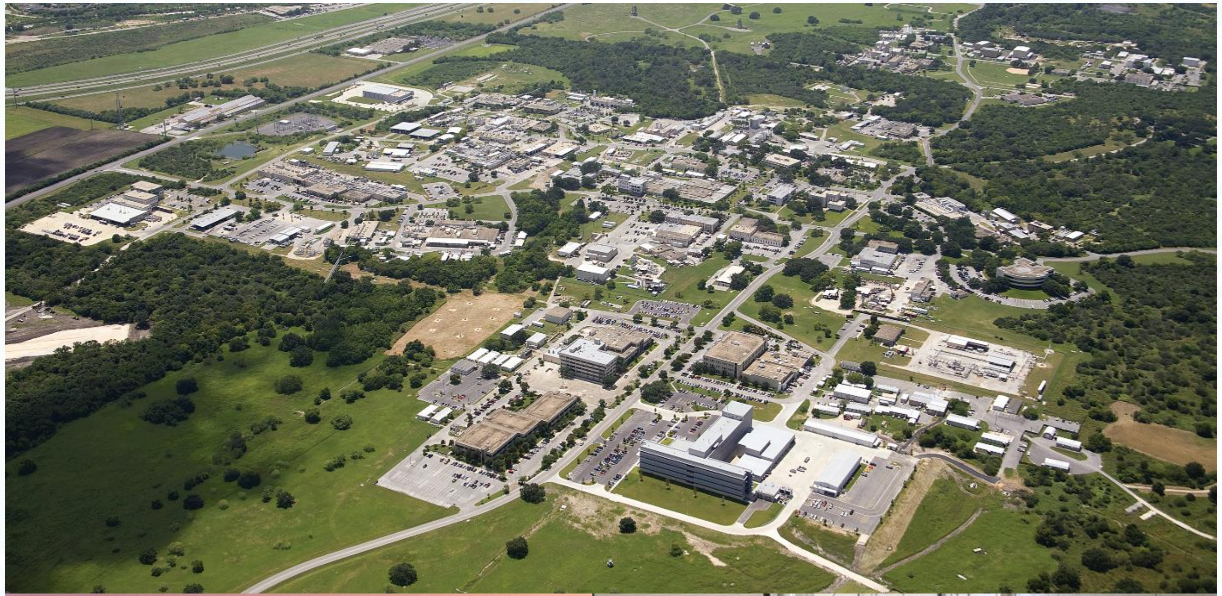
Hydrogen Infrastructure and Gas Pipelines

SOUTHWEST RESEARCH INSTITUTE®

Danny Deffenbaugh, VP Mechanical Engineering
2020 Department of Energy InnovationXLab CarbonX Summit

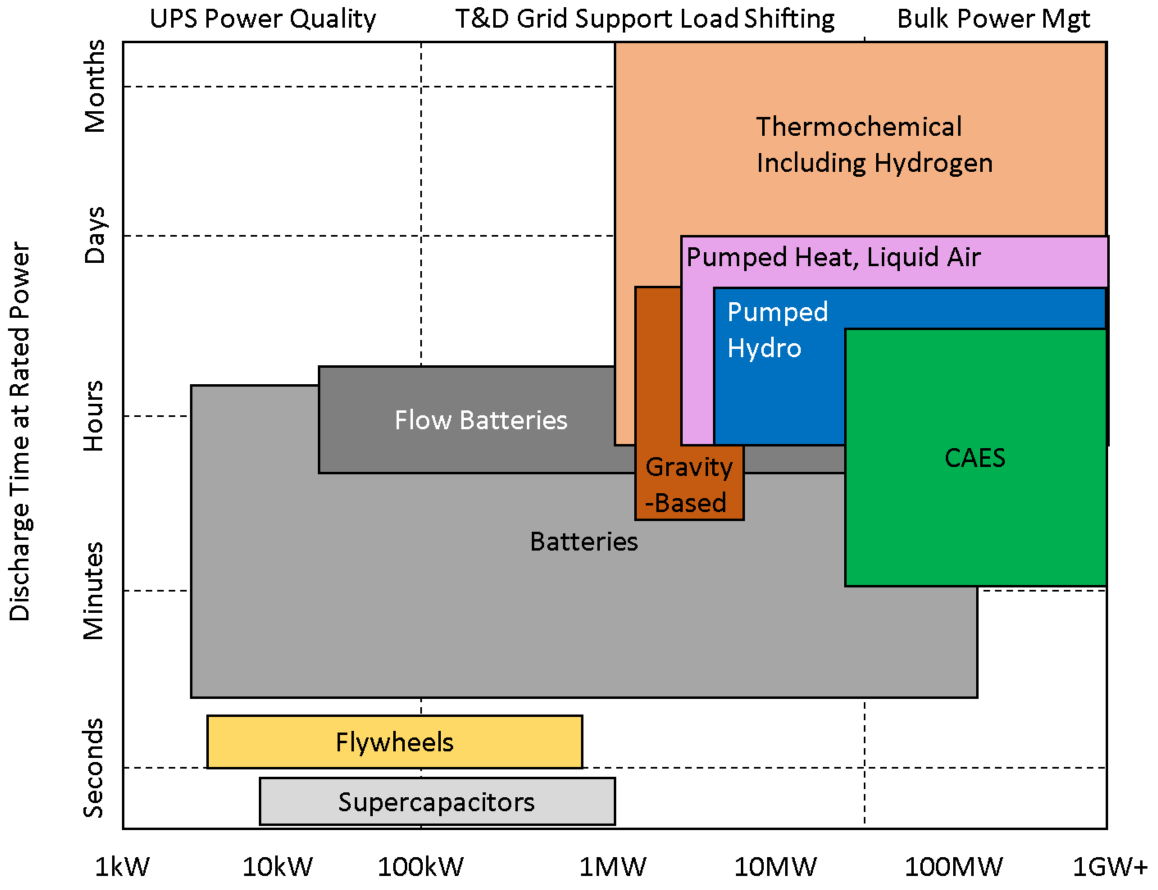
SwRI: 70 Years' Research in Pipeline and Machinery Systems

- 501(c)(3) Nonprofit corporation performing contract RDT&E
  - Founded in 1947 in San Antonio, Texas
  - 2600 Employees; 300 Laboratories on 1500 acres; $690M Revenue
  - Applied research with flexible IP policies
- Multidisciplinary technology development from deep sea to deep space
- Research partnerships with domestic and international gas pipelines since 1953
- First involvement with hydrogen was fuel sloshing in the 1960's for power and propulsion for the Apollo moon missions and later the Shuttle main engine development program.



Hydrogen Storage

- Hydrogen shows potential to be a game-changer for significantly decarbonizing the energy landscape.
  - including transportation, power generation, and industrial heating sectors.
- Hydrogen produced with renewable power can be stored and used as fuel to help compensate for solar and wind variability in the grid.
  - GW-scalable and
  - the only ones capable time-shift renewable power at seasonal durations



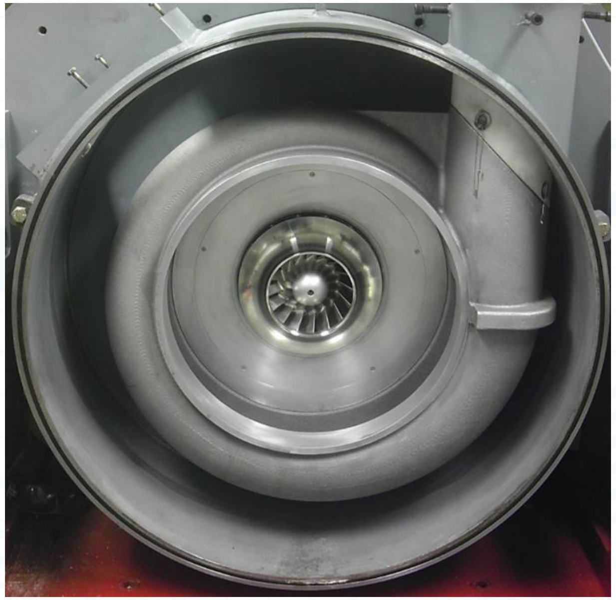
Hydrogen in Pipelines

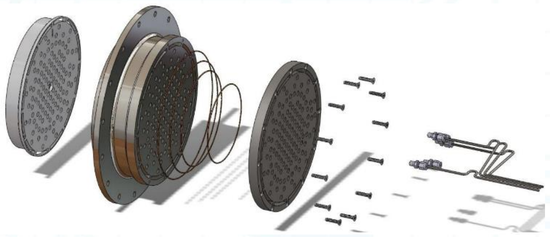
- Large-scale hydrogen infrastructure for production, transport, storage, and utilization is already proven to some extent in the refinery and petrochemical industries.
- Research in blending natural gas with 15 – 20% H2 to leverage the current pipeline infrastructure.
  - Challenges are reduced energy density, higher compression ratio, materials compatibility, leakage, and safety.

Images Courtesy Air Liquide

Compression Research

- Pipeline hydrogen compressor development is required to increase reliability and pressure ratio capabilities at high flow rates
  - Advanced compressor technologies for higher tip speeds and low or zero leakage
  - Due to gas property differences, a compressor that produces a 1.7 pressure ratio on natural gas will only produce a 1.07 ratio on 100% hydrogen.
  - Additional stages and/or faster impeller tip speeds are required to improve the pressure ratio.
- Developed a Linear motor reciprocating compressor prototype for vehicle refueling .





Combustion Research

- Pipeline gas turbines must be able to operate and meet emissions requirements with elevated hydrogen fuel mixtures
  - These smaller gas turbines used for mechanical drive of pipeline compressors may not meet these requirements
  - Advanced injector designs, combustion testing with hydrogen will be required
- Additional work is needed to apply these components, potentially along with high-performance materials, to develop compressor designs suitable for H2 pipeline applications.

Emissions Monitoring and Detection

Machine Learning Applied to Emissions Detection

Fugitive Emissions Testing

Advanced Sensors for Detection and Quantification

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General Manager,
Application Engineering &
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GE

Hydrogen Carbon Economy

DOE 2020 InnovationXLab CarbonX Summit

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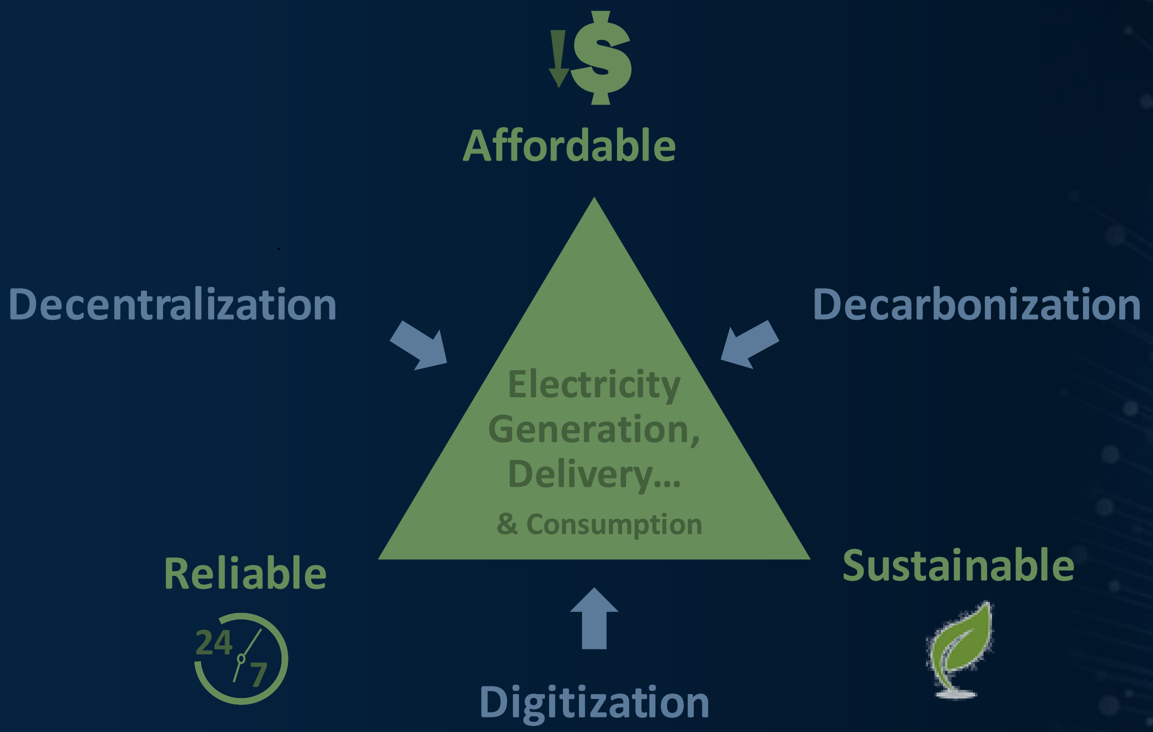
GE Gas Power Systems

Hydrogen’s Role in Decarbonizing Energy



Gas turbines … ~¼ electricity growing 15% next decade

$12B/yr … US exports & high quality engr & adv mfg jobs

Successful public-private programs

What are the obstacles to achieving the benefits of hydrogen?

What must we do to realize benefits of hydrogen for the US?

What are the obstacles to achieving the benefits of hydrogen?

Hydrogen benefits

- ✓ **Avoids CO2**
- ✓ **Gray ➔ Blue ➔ Green pathway** enables progressive transition
- ✓ **Scales well** … blend to available H2
- ✓ **Cross-sector benefits** … Power & Heat as well as Transportation
- ✓ **Minimal plant capex add**

Challenges to solve

- **Availability & Production**
- **Transportation**
- **10 times the operating cost** … ~$40/mmbtu
- **Added nitrous oxide emissions** … NOx doubles at 100% H2
- **3 times the volume** of natural gas
- **4.5 times the flame speed** of natural gas
- **Material embrittlement**

20% H2 … 7% less CO2/kwh ➔ **50% H2 …** 22% less CO2/kwh ➔ **75% H2 …** 45% less CO2/kwh ➔ **100% H2** Carbon Free

What must we do to realize benefits of hydrogen for the US?

Recognize value to the US

- **Pathway** to **net zero carbon power & heat**
- **US exports** with high quality **engineering & manufacturing jobs**
- **Energy security**

Public-Private collaboration

- **Government** role & leadership
- **Legislation & Policy**
- **Science & market based … supply chain & generation**

Step change in R&D

- **Across H2 value chain**
- Gas turbine capability to **100% H2** new build & retrofit
- **Focused $250M/ year R&D** on high risk/ high reward

Advance hydrogen capability across the value chain for US leadership to deliver affordable, reliable & net zero carbon power

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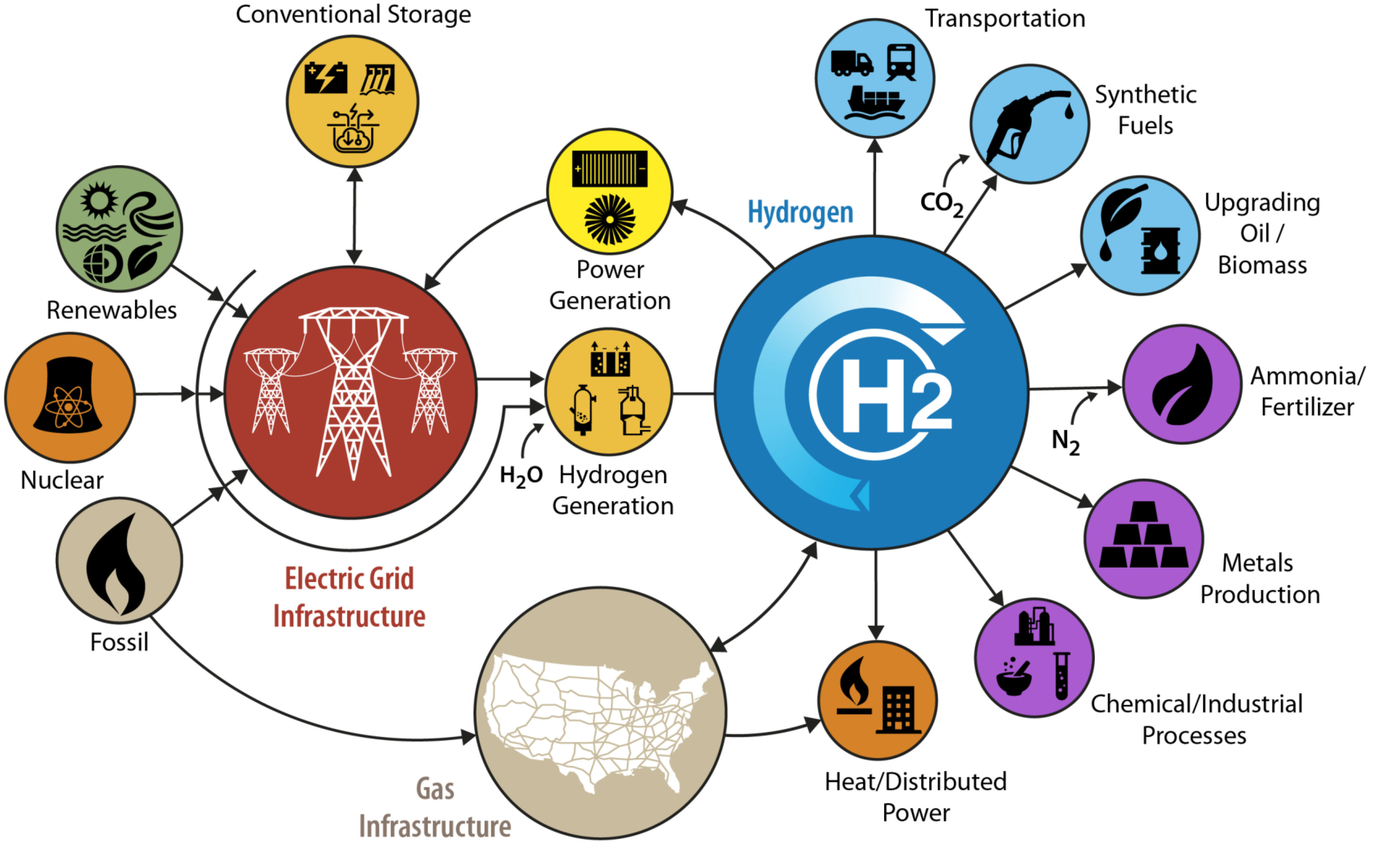
Exploring Hydrogen Utilization Options for Transportation

Jennifer Kurtz

Supported by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office within Office of Energy Efficiency and Renewable Energy

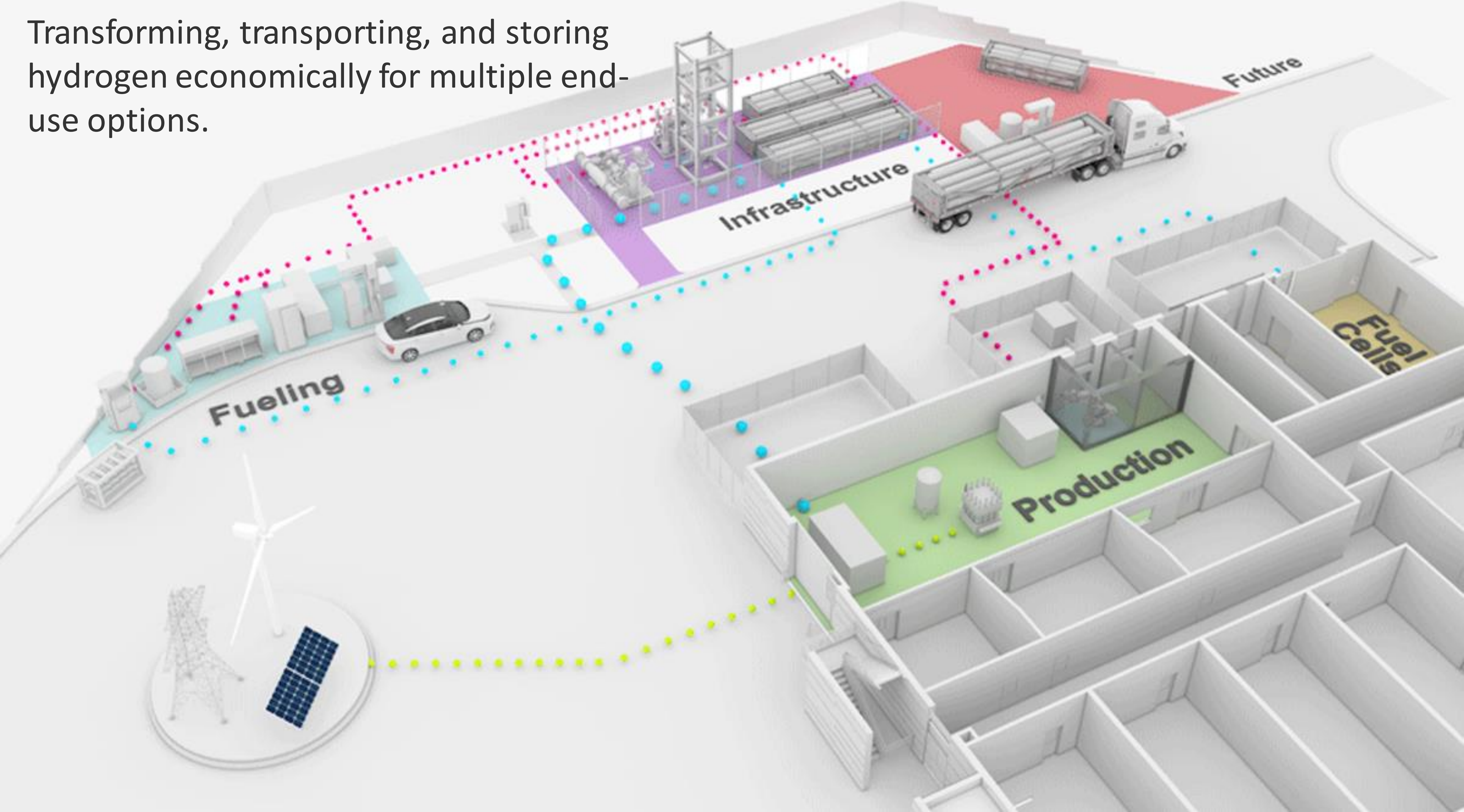
Hydrogen at Scale (**H2@Scale**)

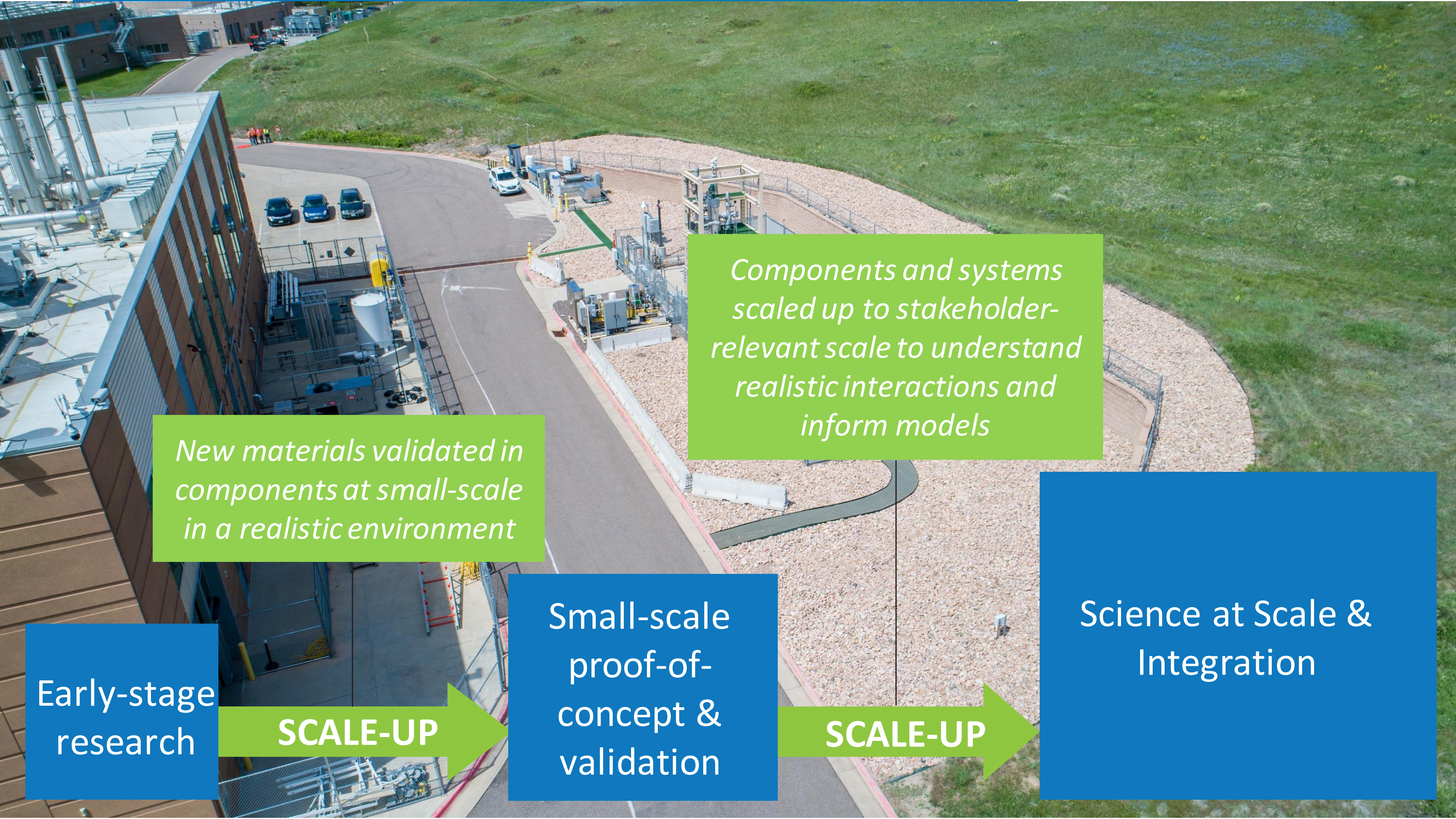
Exploring innovations and opportunities for widespread hydrogen utilization



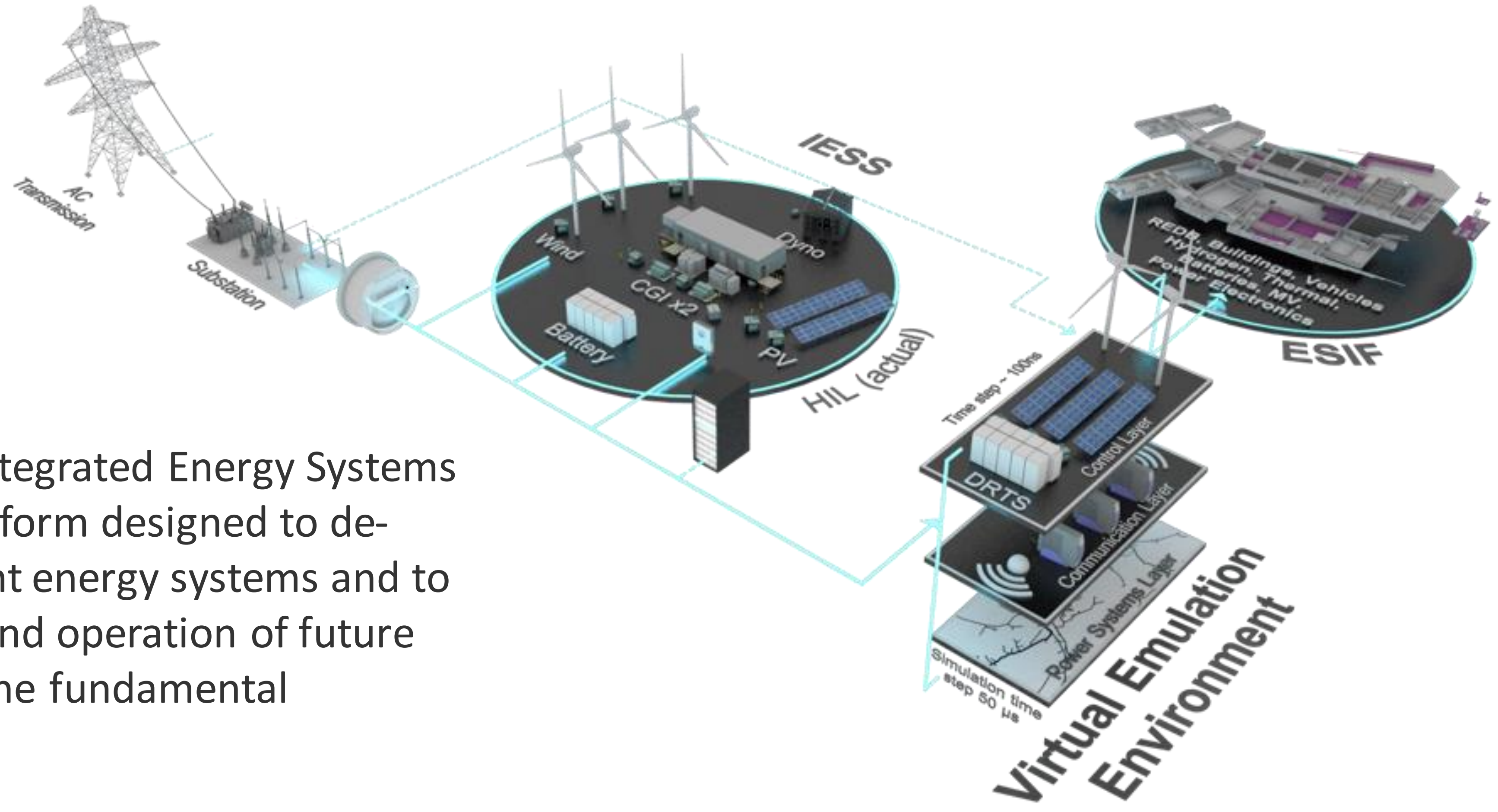
https://www.energy.gov/eere/fuelcells/h2scale

Transforming, transporting, and storing hydrogen economically for multiple end-use options.




Components and systems scaled up to stakeholder-relevant scale to understand realistic interactions and inform models
New materials validated in components at small-scale in a realistic environment
Early-stage research
SCALE-UP
Small-scale proof-of-concept & validation
SCALE-UP
Science at Scale & Integration

ARIES

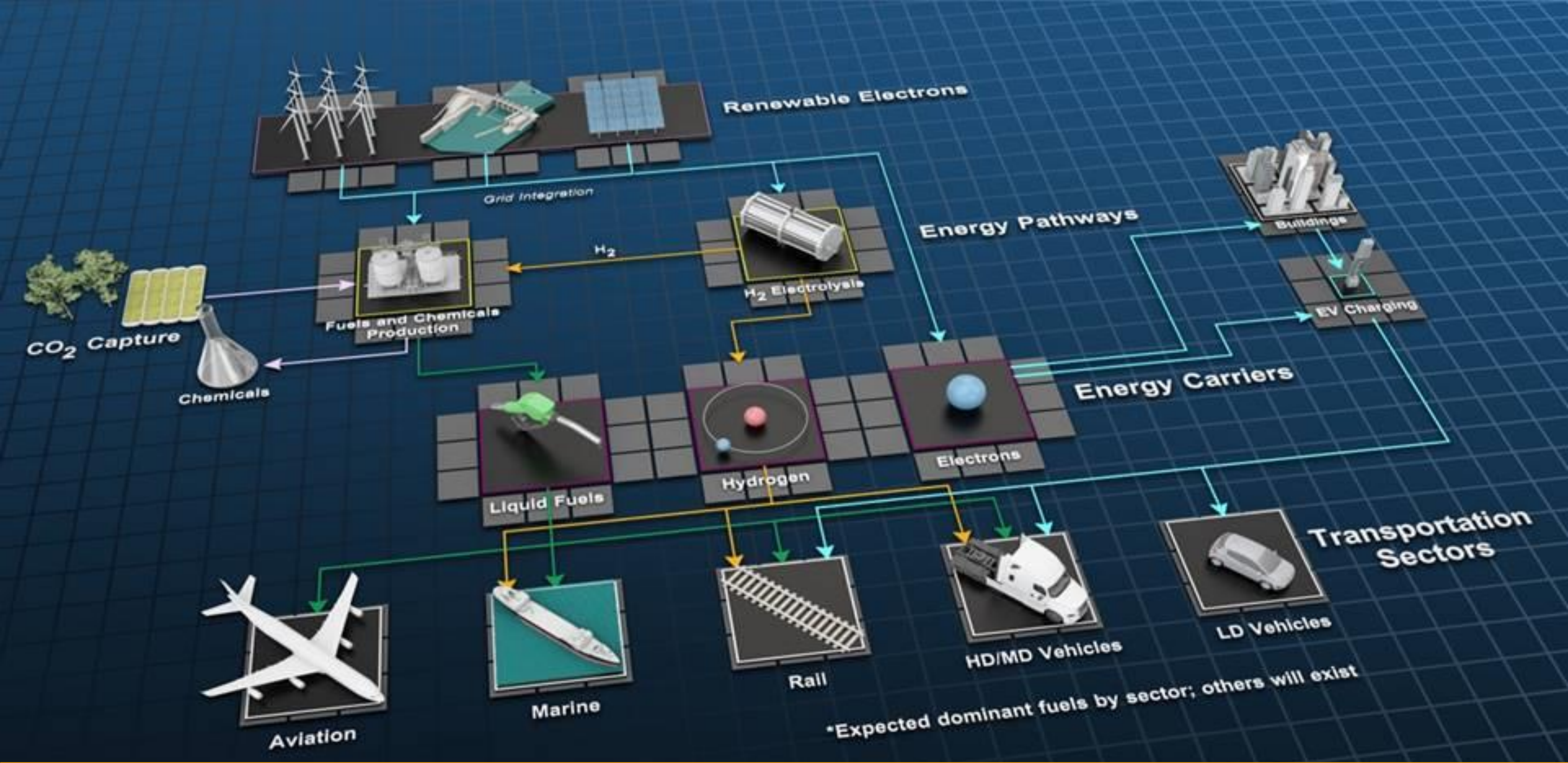


NREL's Advanced Research on Integrated Energy Systems (ARIES) is a unique research platform designed to de-risk, optimize, and secure current energy systems and to provide insight into the design and operation of future energy systems. It will address the fundamental challenges of:

- Variability in the **physical size** of new energy technologies being added to energy systems
- Controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together

One Research Platform
Developing and Using Assets at ESIF, IESS, and Virtual Emulation Environment and Remote Connections

www.nrel.gov/aries



In transportation: Hydrogen can be used directly as a fuel,
reacted with CO2 to create synthetic fuels or used to upgrade crude oil or biomass.

NREL Transforming ENERGY

九州大学 KYUSHU UNIVERSITY

Partners: Frontier Energy Inc., Kyushu University, Ford Motor Company, General Motors LLC, Honda R&D Americas, Hyundai-Kia America Technical Center, Ivys Energy Solutions Inc., Shell, Toyota, Argonne National Laboratory, Saga University, Sandia National Laboratories, and Zero Carbon Energy Solutions Inc.

H2FillS

Hydrogen Filling Simulation

Learn more at www.nrel.gov/hydrogen/h2fills.html

Developed for those who seek to fill knowledge gaps of the interaction between a hydrogen station and a fuel cell electric vehicle, this software simulates the process of filling a hydrogen fuel cell electric vehicle.

Thank you

www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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THANK YOU!

Please submit your questions in the Zoom Q&A function!

Looking for additional conversation and networking?

Join us in the Peer Connections Lounge after the live Q&A!