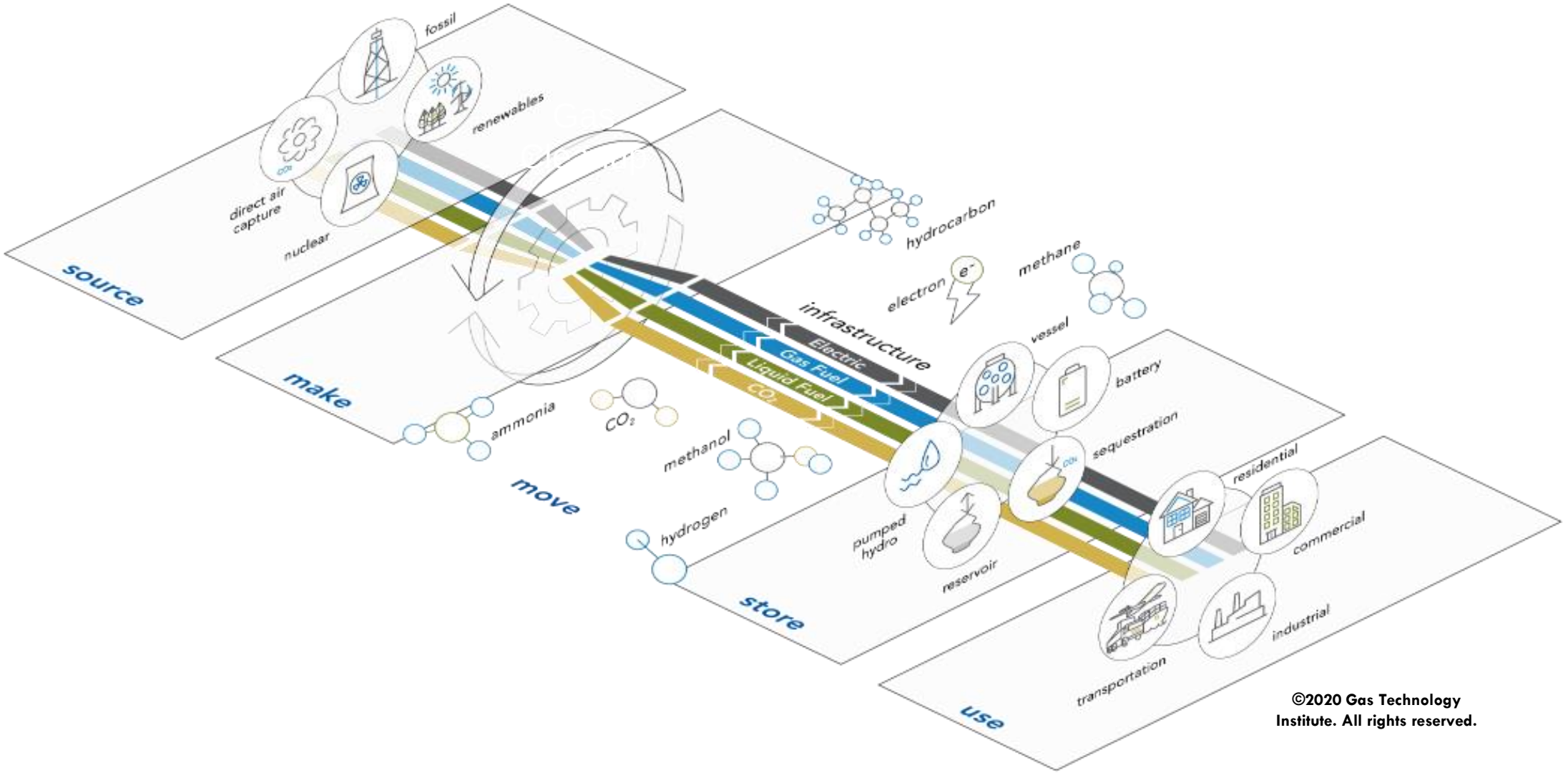
ADVANCING DECARBONIZATION FOR LDCs

Role of Hydrogen and Low Carbon Resources

September 14, 2021

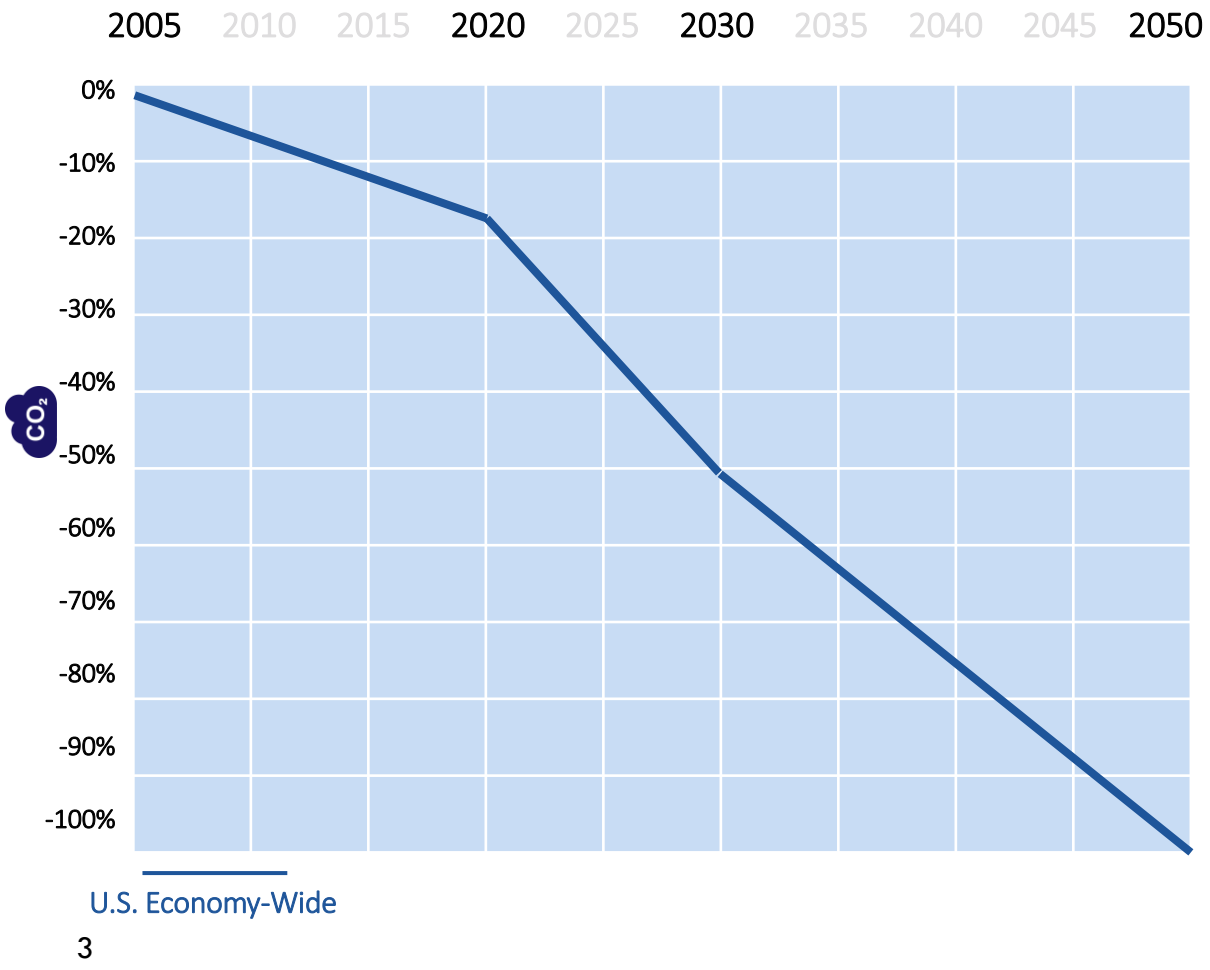
Kristine Wiley, VP Hydrogen Technology Center, GTI

INTEGRATED ENERGY SYSTEMS



THE ECONOMY WIDE NET ZERO CHALLENGE…

Gas Will Play a Critical Role

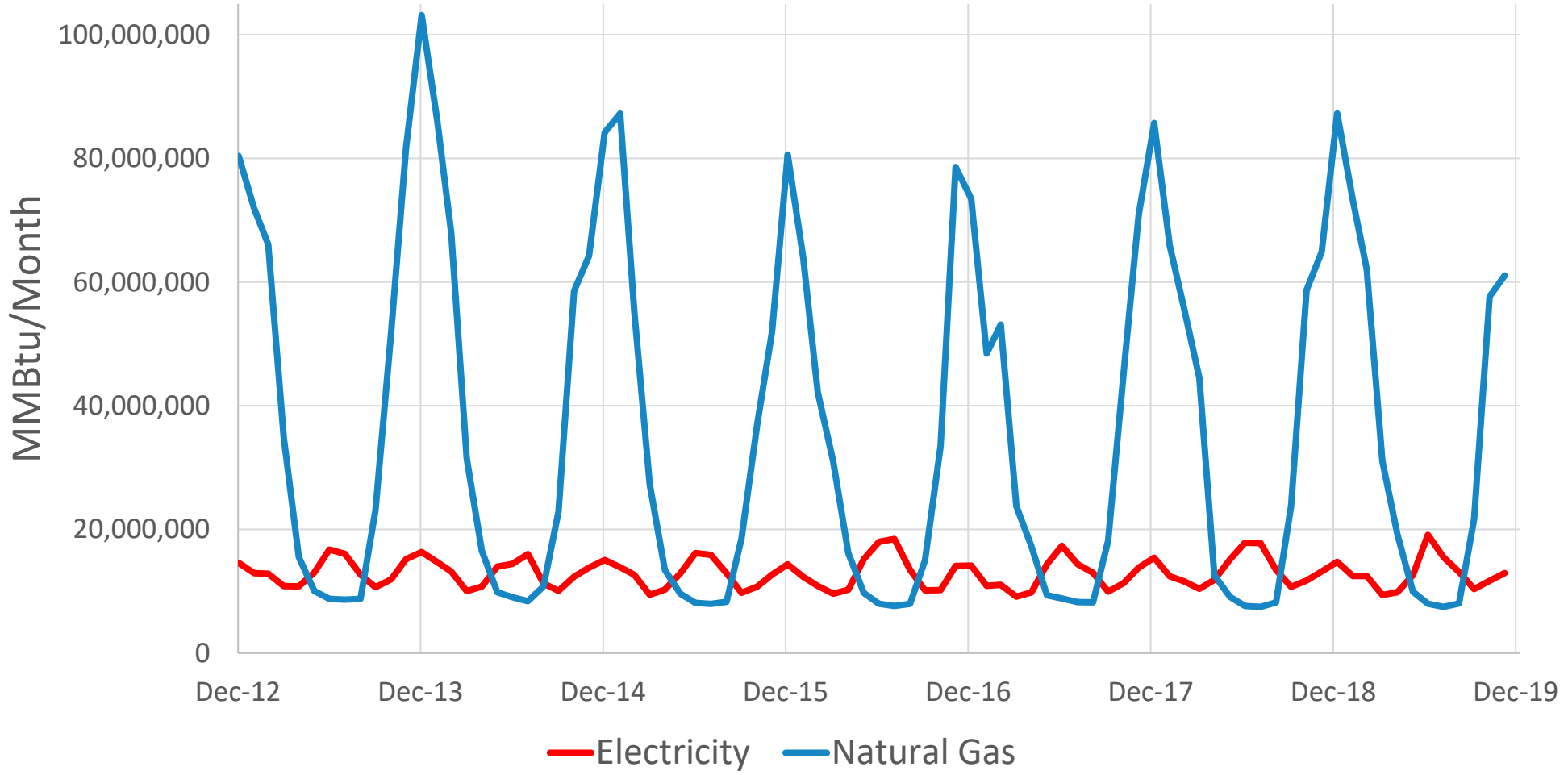


- Significant 2005-2020 reductions through EE, renewables, and switching to natural gas power generation
- Future gains will require addressing "hard to abate" applications
  - Long-haul heavy transportation
  - Heavy industry
  - Heating in cold climates
- Long duration, large scale energy storage will be key
- Increasing needs for resilient energy systems

PEAK ENERGY COMPARISON

Illinois Monthly Residential Energy Use

Role of Gas Molecules

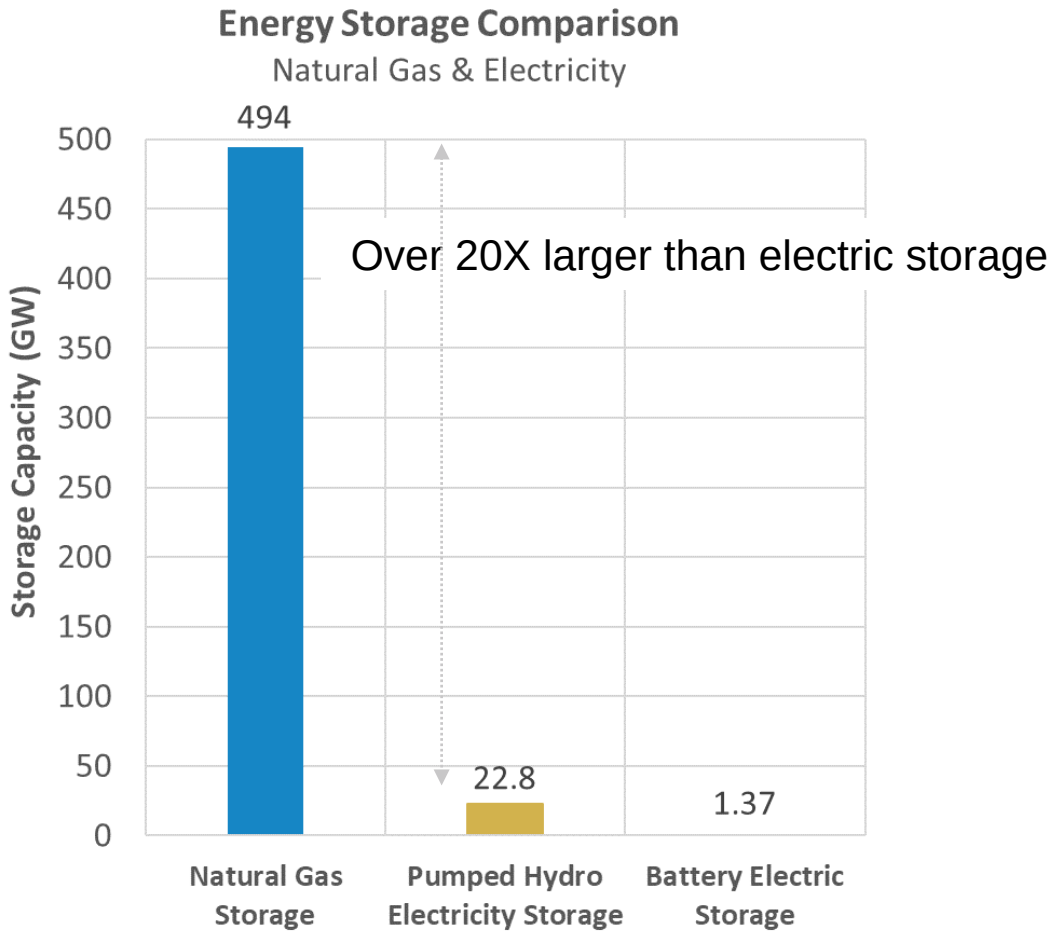


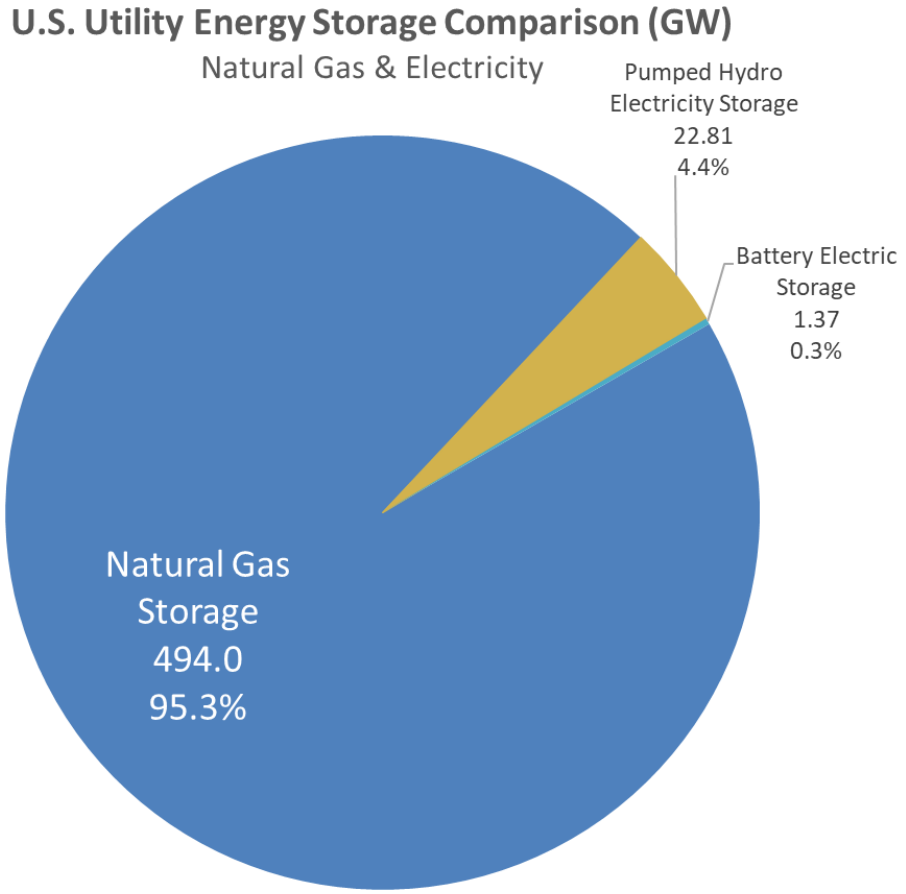
DOE-EIA

ENERGY STORAGE CAPABILITIES

Comparison of Natural Gas & Electricity

Role of Gas Molecules





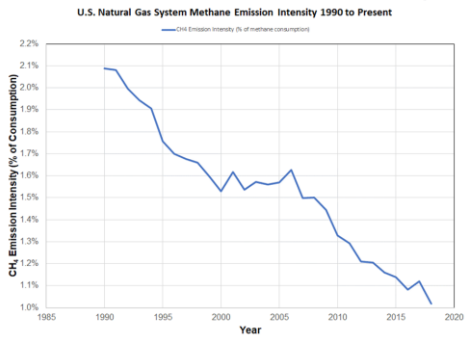
Natural gas underground storage comprises >95% of U.S. utility energy storage capacity. During peak cold spells, gas storage can flex up to 600 GW of sustained energy delivery capacity for a week or more.

Source: DOE-EIA

KEY ACTIONS FOR DECARBONIZATION IN NATURAL GAS SECTOR

Methane Leak Detection & Mitigation

Detection and mitigation to reduce full-cycle natural gas methane emissions



Lower Methane Emissions (5–10%)

Energy Efficiency

Expanded use of high-efficiency gas equipment

Hybrid natural gas furnace/boilers and electric heat pump systems

Building envelope improvement

Near Term (25–50+%)

Natural gas heat pumps for space & water heating

Micro CHP systems

Deep building retrofits

Next-Gen (40–60+%)

Renewables & Low Carbon Fuels

Bio-methane/RNG, Clean hydrogen

Solar thermal & geothermal / clean gas space & water heating

Renewables (Added 10–30%)

Hydrogen …

- is an energy carrier that can be used to **store energy** over long periods of time and to transport energy over large distances
- provides a zero-carbon emissions fuel
- offers a beneficial use of excess electricity produced by renewables

HYDROGEN MOMENTUM CONTINUING TO BUILD

R&D Collaboratives, Public-Private Partnerships, Industry Coalitions, Project Investments

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

LCRI LOW-CARBON RESOURCES INITIATIVE

THyGA

Department of Energy

DOE Announces $52.5 Million to Accelerate Progress in Clean Hydrogen

JULY 7, 2021

Home » DOE Announces $52.5 Million to Accelerate Progress in Clean Hydrogen

Projects Support DOE's Recently Announced Hydrogen Energy Earthshot to Lower Cost, Advance Breakthroughs for Clean Hydrogen Technology

WASHINGTON, D.C. — The U.S. Department of Energy (DOE) today announced $52.5 million to fund 31 projects to advance next-generation clean hydrogen technologies and support DOE's recently announced Hydrogen Energy Earthshot initiative to reduce the cost and accelerate breakthroughs in the clean hydrogen sector. Clean hydrogen is a form of renewable energy that—if made cheaper and easier to produce—can have a major role in supporting President Biden's commitment to tackling the climate crisis.

"Part of our path to a net-zero carbon future means investing in innovation to make clean energy sources like hydrogen more affordable and widely adopted so we can reach our goal of net-zero carbon emissions by 2050," said **Secretary of Energy Jennifer M. Granholm.** "These projects will put us one step closer to unlocking the scientific advancements needed to create a strong

Hydrogen Deployment Accelerating with More Than $300 Billion in Project Pipeline; Including $80 Billion in Mature Projects

Big money for hydrogen plans

€430B
Hydrogen investment needs to 2030

+

€145B
Hydrogen support needs to 2030

6 GW
EU 2024 green hydrogen electrolyzer target

→

40 GW
EU 2030 green hydrogen electrolyzer target

Data accessed July 2021.
Support needs include grants and subsidies. Investment and support needs cover hydrogen production, infrastructure and storage, and applications.
Source: Hydrogen Europe, European Commission

California FUEL CELL PARTNERSHIP
DRIVING FOR THE FUTURE

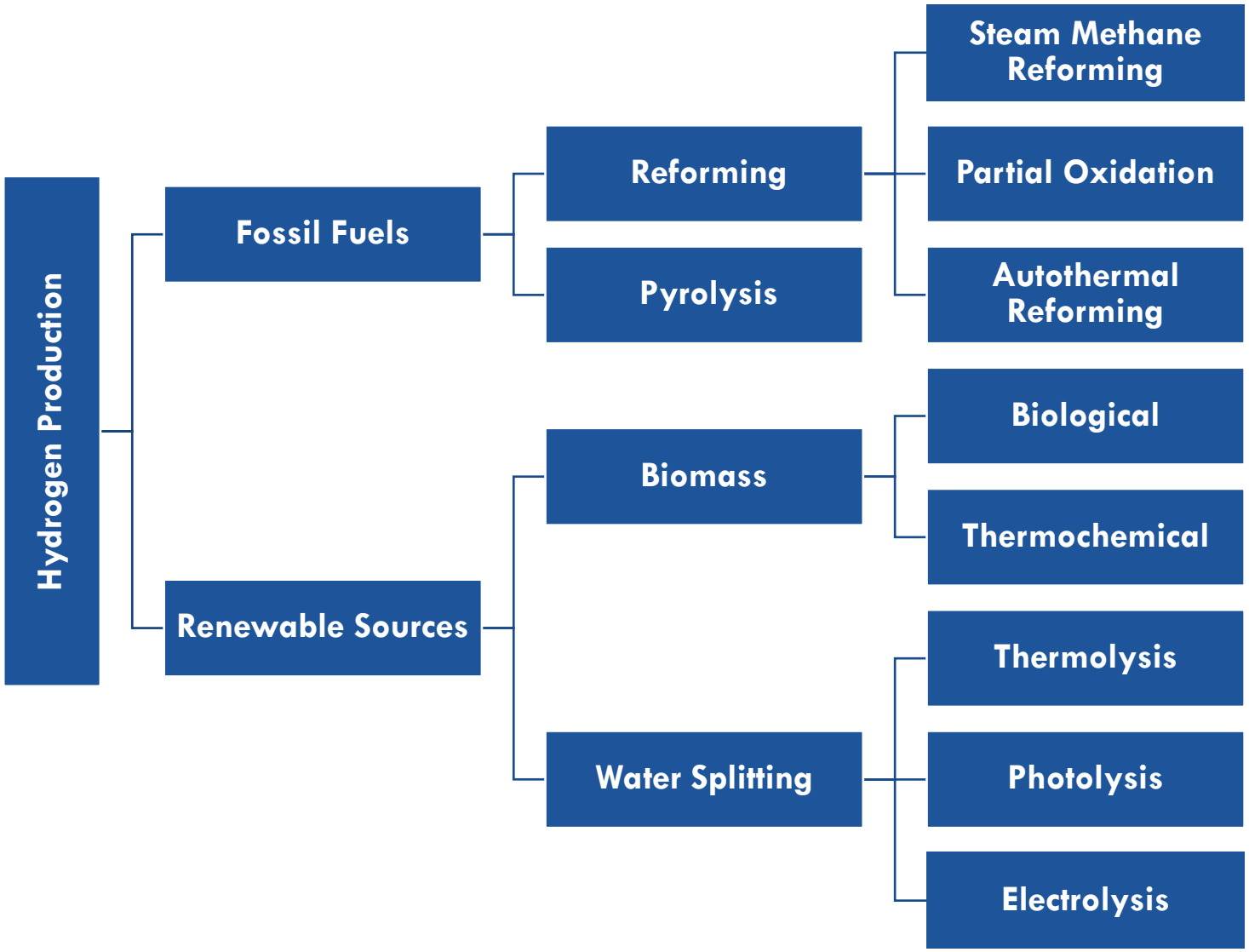
NREL Transforming ENERGY

HyBlend Project To Accelerate Potential for Blending Hydrogen in Natural Gas Pipelines

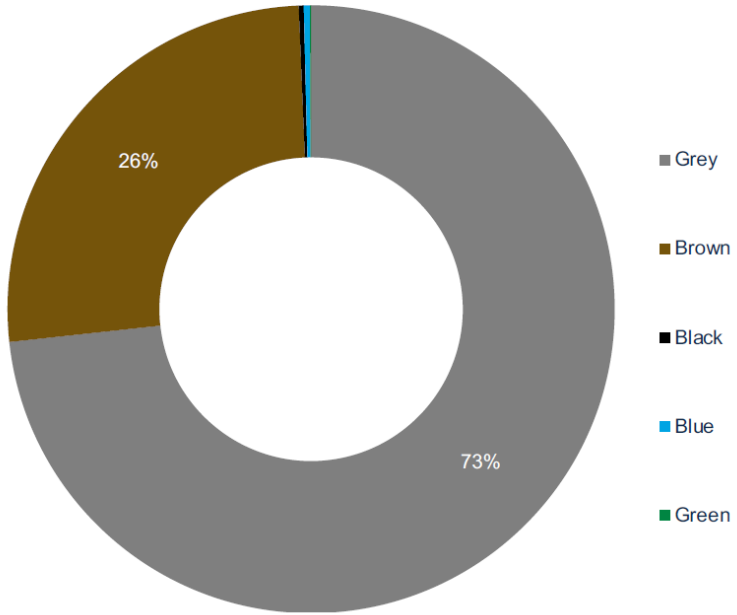
NREL Will Lead Multi-Lab, Multi-Industry R&D Effort To Overcome Technical Challenges

CH2FC Clean Hydrogen Future Coalition

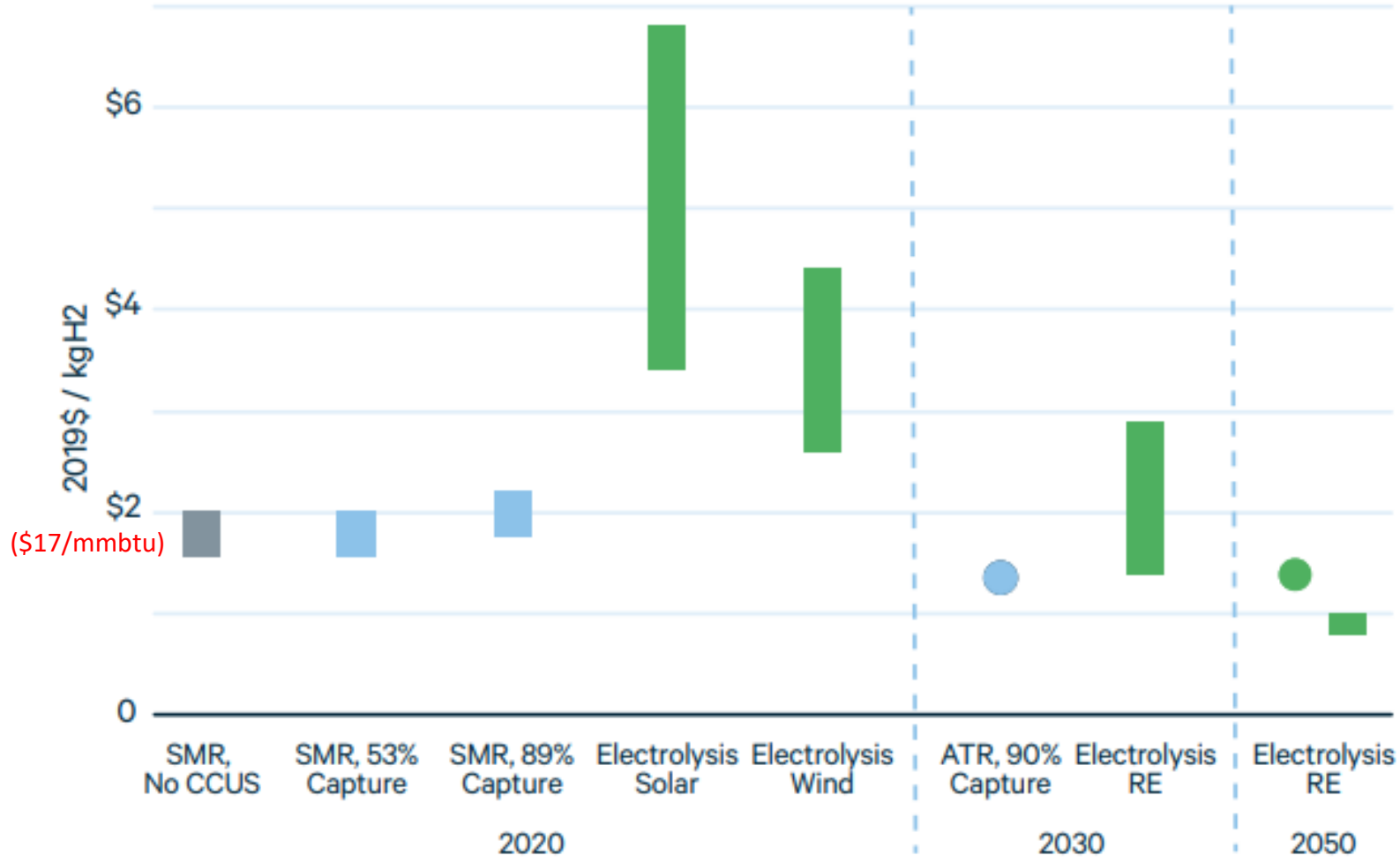
HYDROGEN PRODUCTION PATHWAYS



- Global hydrogen demand is about 70 million metric tons per year
- 98% of hydrogen is produced from fossil fuels



HYDROGEN PRODUCTION COSTS



Sources: Friedmann et al. 2019; IRENA 2019; Hydrogen Council 2020; Mathis and Thornhill 2019.

INFRASTRUCTURE PROVIDES UNPARALLELED DELIVERABILITY

Enabling Energy Transitions

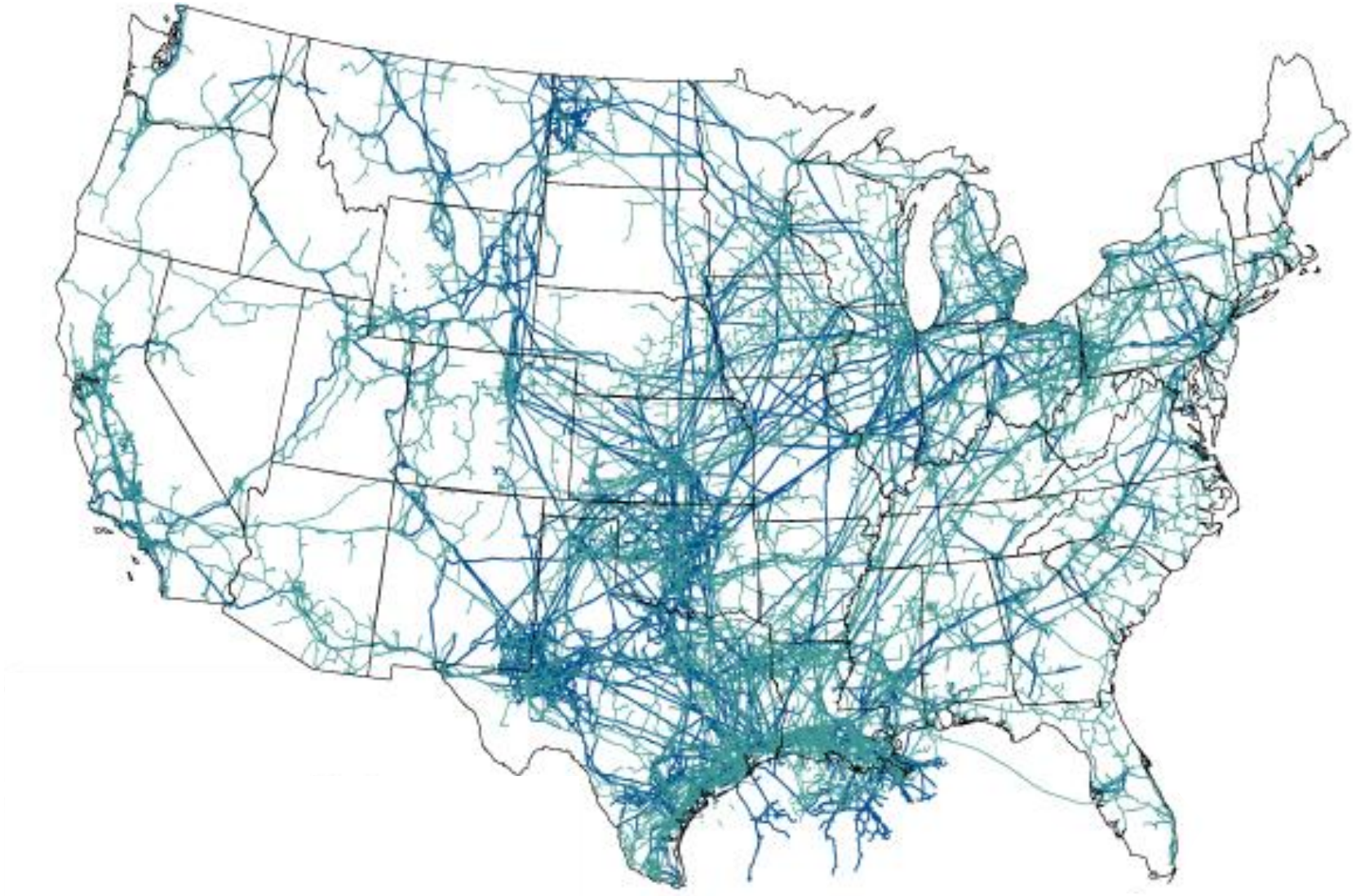
Production

Transmission

Storage

Conversion

End Use



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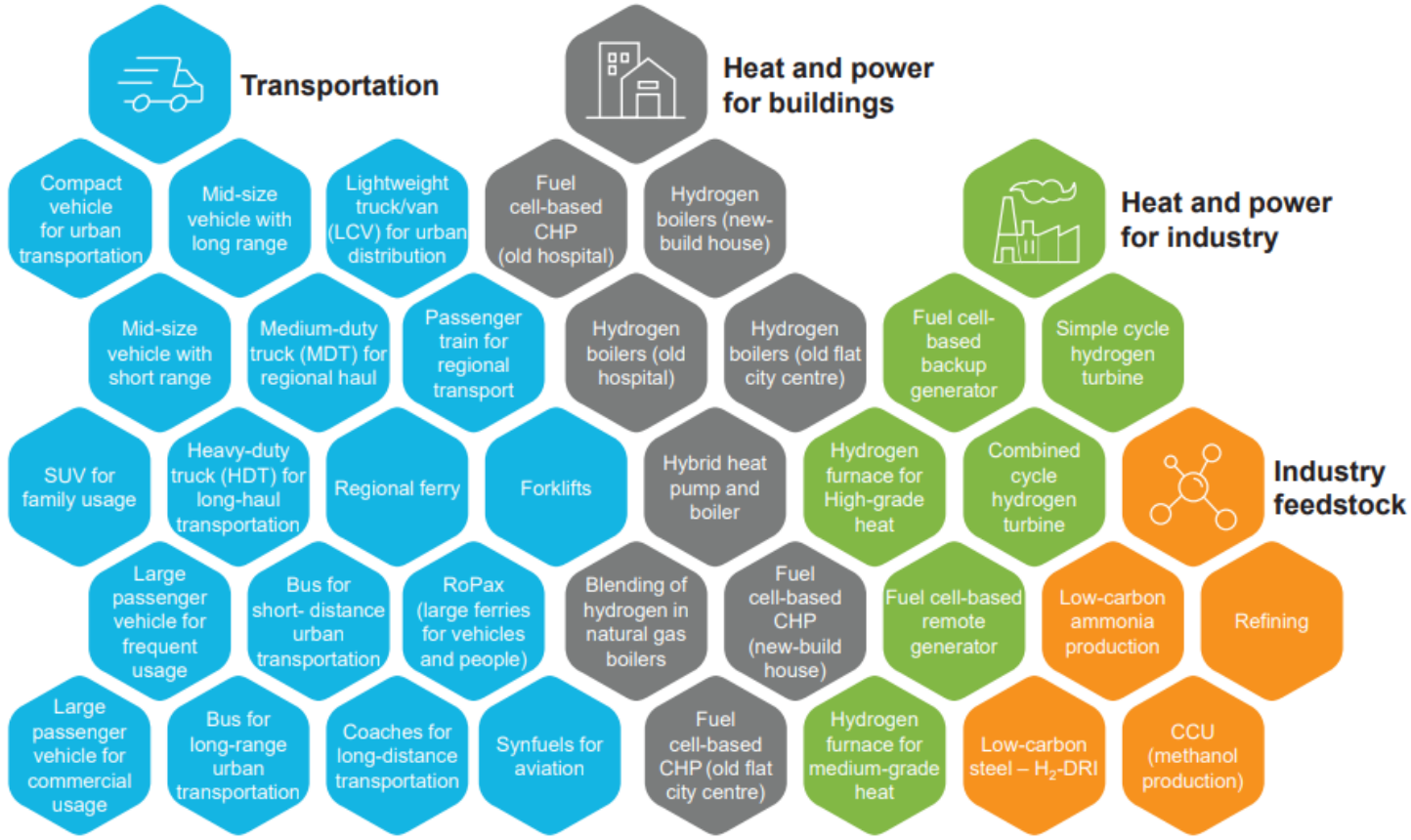
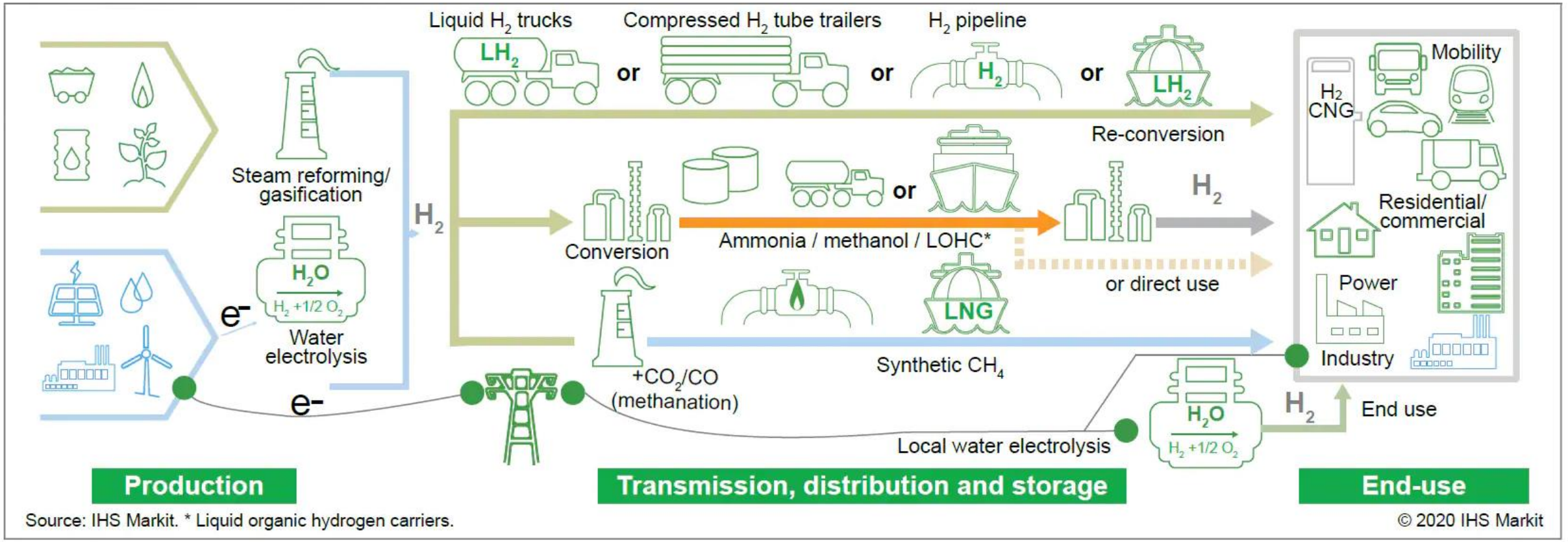
EXPANDING USES OF HYDROGEN

Challenges and R&D Needs

- Lower cost of low carbon hydrogen production
- Overcome technical barriers to using gas infrastructure for hydrogen transport and deliver
- Modify equipment, appliances, processes for the use of hydrogen as an energy source for power generation, buildings, industry, transportation



HYDROGEN SUPPLY CHAIN



HYDROGEN TECHNOLOGY CENTER

HYDROGEN TECHNOLOGY CENTER

SunGas RENEWABLES

HyPER

HyBlend

California FUEL CELL PARTNERSHIP DRIVING FOR THE FUTURE

Zero-Carbon Power & Hydrogen for Illinois' Energy Future
ZERO CARBON POWER • CLEAN HYDROGEN PRODUCTION • UTILIZING LOCAL GEOLOGY

LCRI LOW-CARBON RESOURCES INITIATIVE

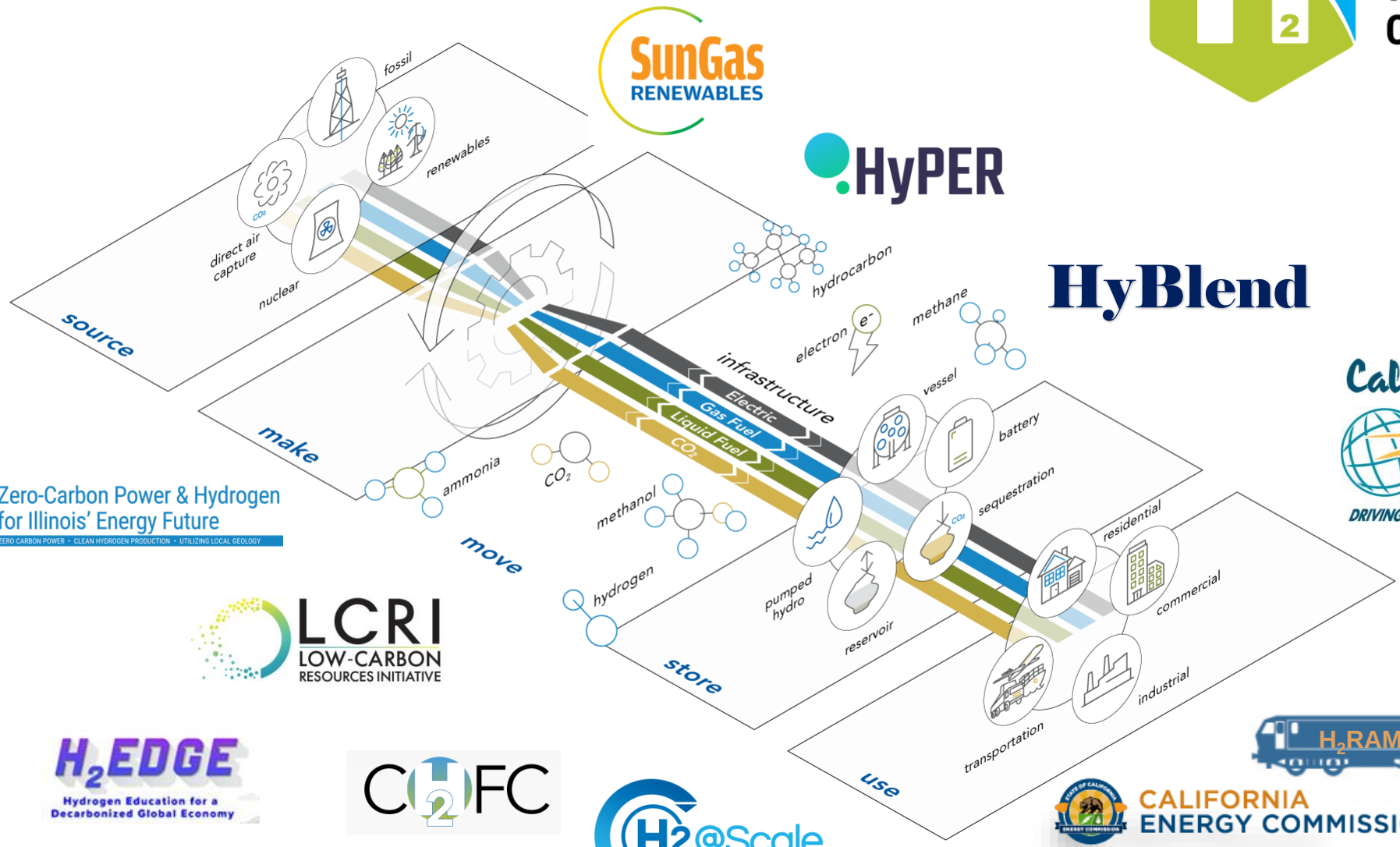
H2EDGE Hydrogen Education for a Decarbonized Global Economy

C2FC

H2@Scale U.S. Department of Energy

H2RAM

CALIFORNIA ENERGY COMMISSION



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ASSESSING COMPATIBILITY WITH NATURAL GAS DELIVERY INFRASTRUCTURE

Current GTI research

- Evaluated effects of a 5% hydrogen-natural gas blend on non-metallic material properties and operational safety
- Determine safety factors for hydrogen gas systems need to be established based on materials tests
- Develop **engineering tools** to allow an integrity assessment and a safety margin determination of hydrogen blended gas use
- Determine operational impacts of a hydrogen blend in pipelines, such as leak detection, surveys, emergency response

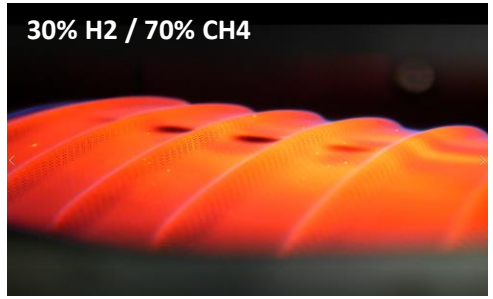
Factors on Hydrogen Embrittlement Susceptibility
Environmental Factors
Role of Microstructure
Hydrogen Traps
Inclusions and Precipitates
Texture and Grain Boundary
Effects of Alloying Elements

Material Properties most affected by HE
Toughness
Reduction in Area
Crack Growth Resistance

ENABLING HYDROGEN USE FOR RESIDENTIAL/COMMERCIAL APPLICATIONS

Current GTI Projects

- Demonstrate solutions to utilize high hydrogen blends in residential and commercial combustion equipment
- Performance testing of appliances with varying hydrogen blends
- Quantify the ability of appliances to retain normal operations (emissions, efficiency, cycling)
- Hydrogen sensor development for "behind the meter" applications and in-situ sensing



Engagement with Industry

WEIL-McLAIN
BRADFORD WHITE WATER HEATERS
A.O. Smith
Rheem
TRANE TECHNOLOGIES
DGC Danish Gas Technology Centre
gwi Gaswärme-Institut e.V. Essen
TOKYO GAS
ENGIE
DVGW
le gaz naturel

gti

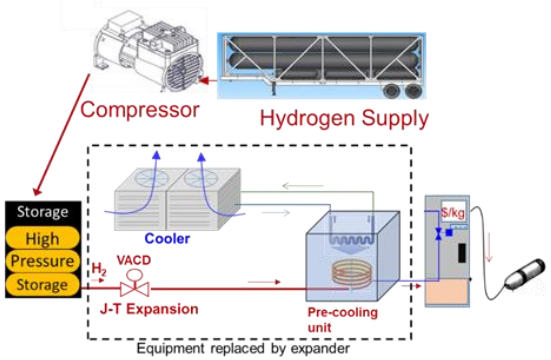
HYDROGEN USE IN TRANSPORTATION

Current GTI Projects

Reducing Air Pollution With FAST TRACK Fuel Cell Truck Project for Zero-Emission Heavy-Duty Vehicles

- Deploying heavy-duty fuel cell-electric hybrid trucks in Southern California near Ports of Los Angeles and San Diego
- Extensive performance data and analysis from real-world conditions to determine the impact of broadly deploying zero-emission Class 8 trucks on local air quality
- Training and local community outreach

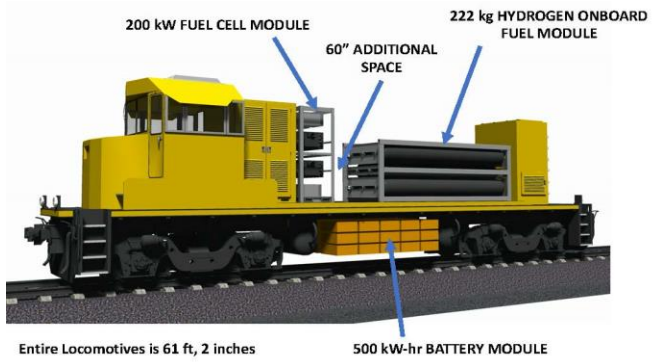
Improving Cost and Efficiency of Hydrogen Vehicle Fueling Infrastructure



- Free-piston linear drive expander for H_2 cooling counteracts heating effects that occur when fuel cell vehicles are fueled
- Substantial capital and operating cost savings anticipated

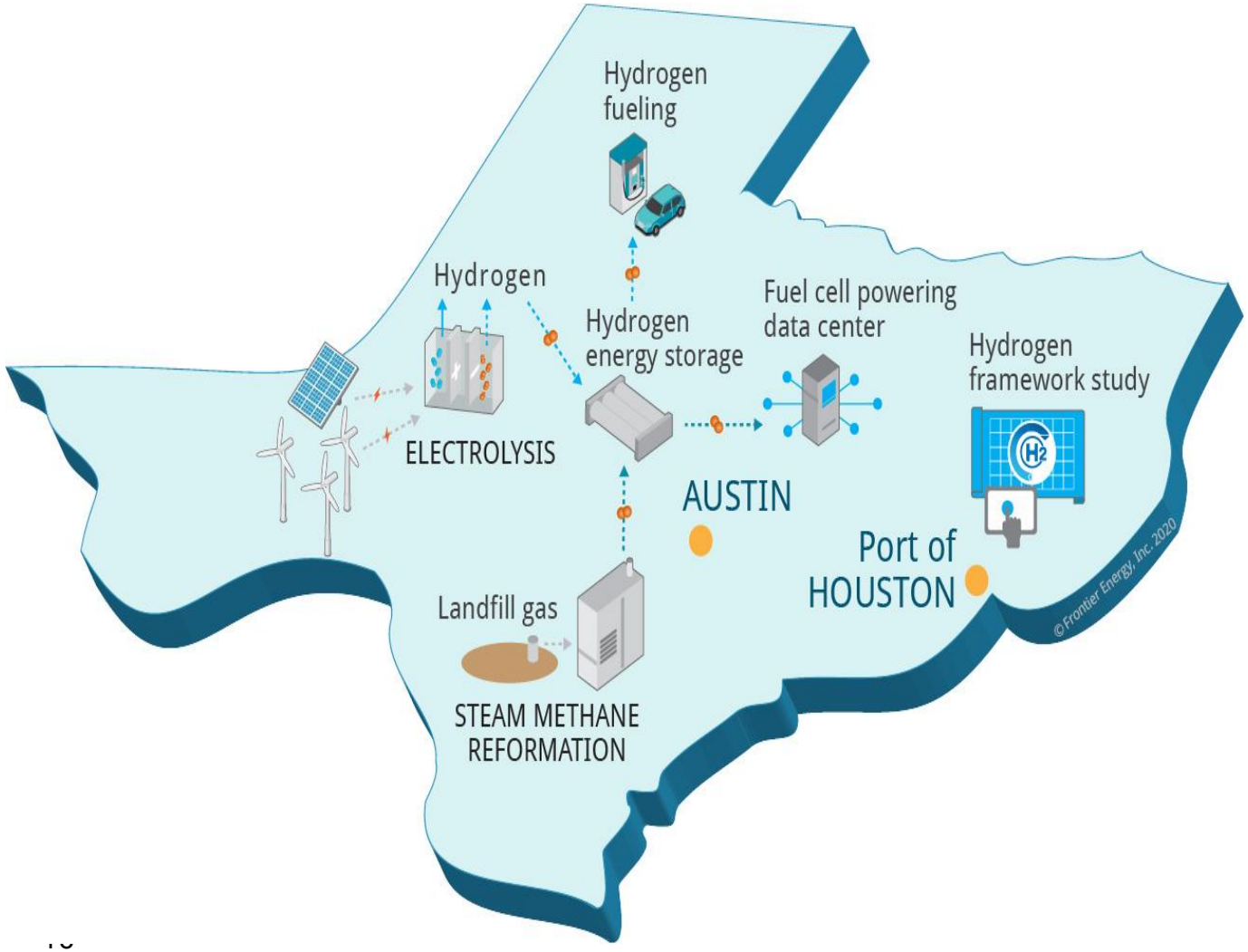
Hydrogen Fuel Cell Locomotive for Port Operations

- Design, build, and demonstrate a hydrogen-fueled, zero-emissions switcher locomotive at the Port of Sacramento.



H2@SCALE

Demonstration



~100% renewable H_2 generation

- 75 kg/day SMR: GTI, OneH2, ONE Gas, Waste Management
- 20 kg/day PEM electrolyzer in H70 SimpleFuel: MHI, SoCalGas, TACC
  - Emulated wind and solar power through UT CEM microgrid

Large scale, industry H_2 user

- 100kW fuel cell powering Texas Advanced Computing Center

Vehicle refueling

- Published SAE J2601-4 fueling of 7-10 Toyota Mirai's
- Drones included

Advancing a Clean Energy Future in Illinois

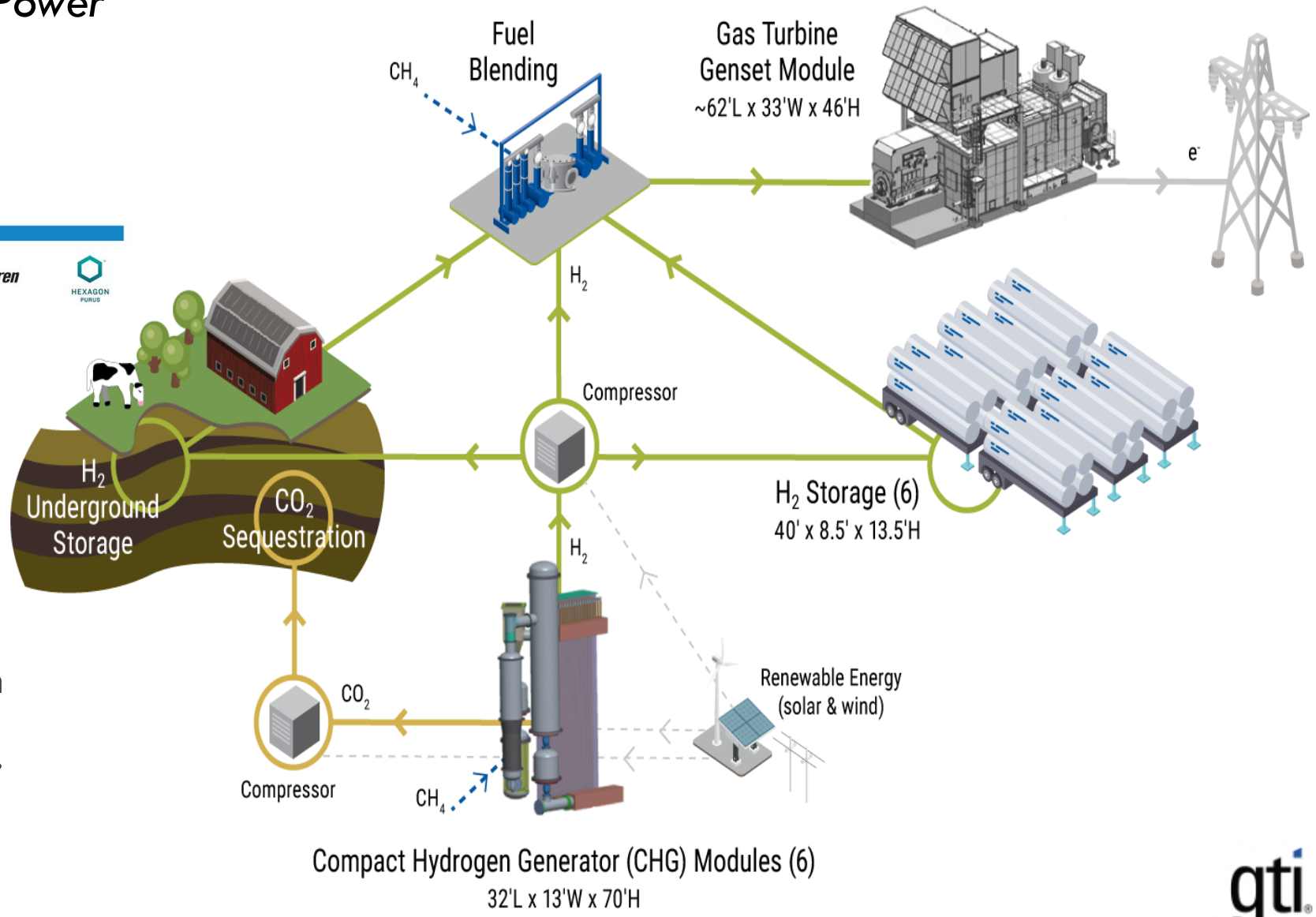
Hydrogen for Zero Carbon Power

Zero-Carbon Power & Hydrogen for Illinois' Energy Future

ZERO CARBON POWER • CLEAN HYDROGEN PRODUCTION • UTILIZING LOCAL GEOLOGY

gti · ILLINOIS Illinois State Geological Survey · MITSUBISHI HEAVY INDUSTRIES · Ameren ILLINOIS · HEXAGON PURUS

This **pilot and test facility** will support development of commercial zero-carbon power and hydrogen to help industry in Illinois lower its carbon footprint.



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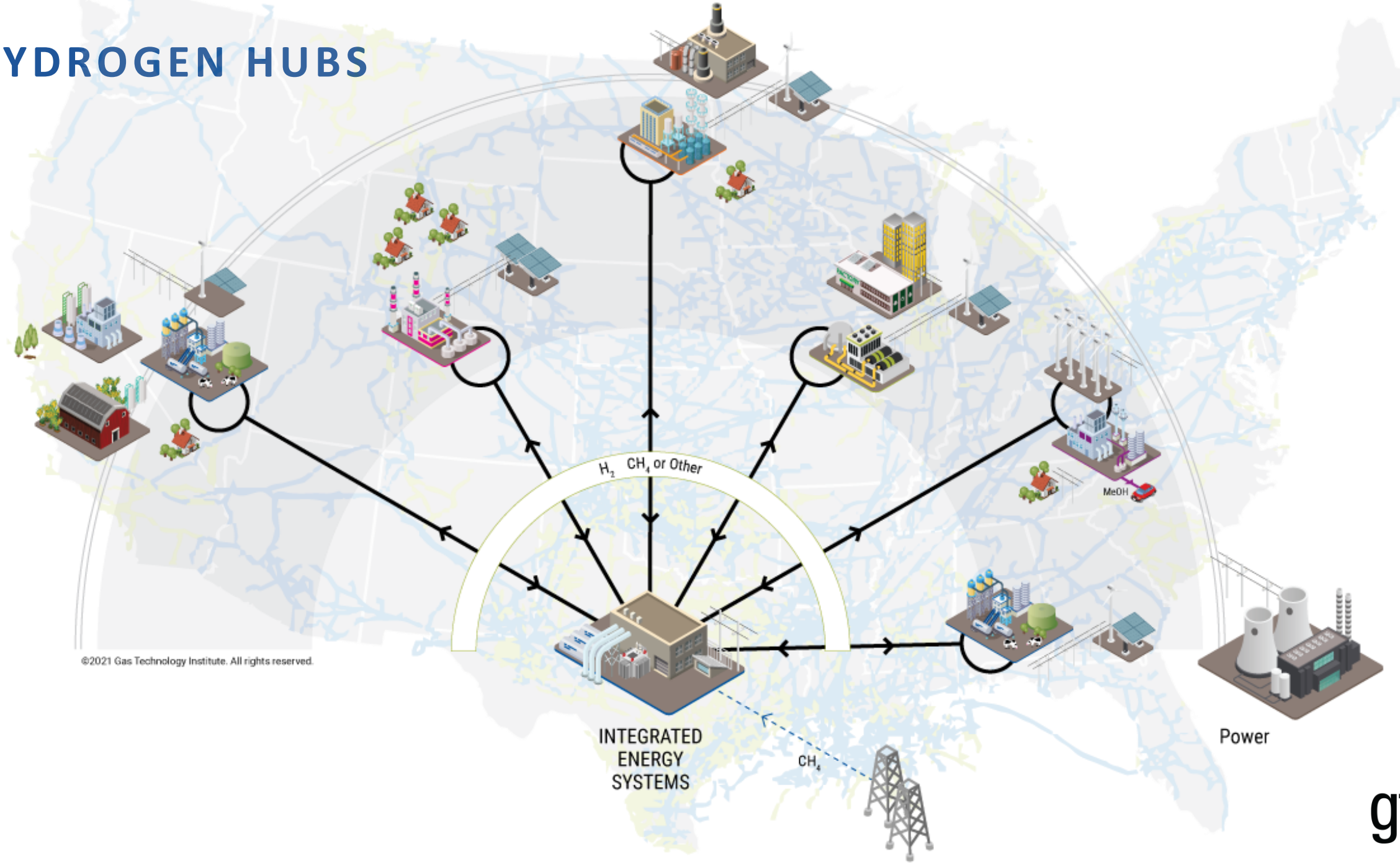
HYDROGEN HUBS



LOW CARBON, LOW COSTS ENERGY SYSTEMS – POST 2030

- Expand the supply of affordable energy,
- Ensure a safe and reliable energy delivery infrastructure, and
- Achieve deep decarbonization.

The **Low-Carbon Resources Initiative** (LCRI) is a five-year R&D commitment focused on the advancement of low-carbon technologies for large-scale deployment across the energy economy. This initiative is jointly led by **EPRI and GTI**.

FOCUS

Multiple options and solutions to establish viable low-carbon pathways

Technologies for hard-to-decarbonize areas of the energy economy

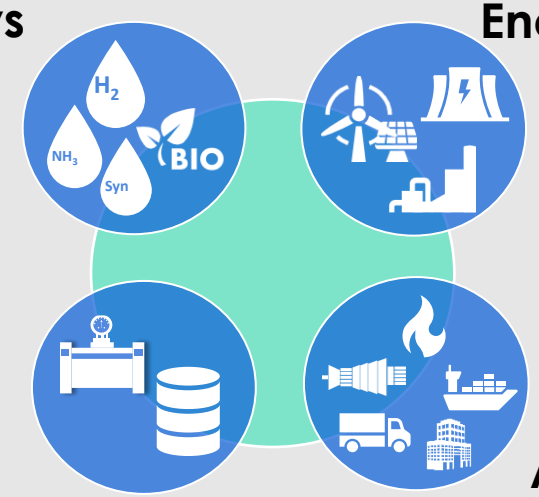
Affordable, reliable, and resilient integrated energy systems for the future

RESEARCH AREAS

Hydrogen **Ammonia** **Synthetic/ Derivative Fuels** **Biofuels**

Production Pathways

Integrated Energy Systems



Storage & Delivery

End Use Applications

VALUE

Independent, objective research leveraged by global engagement and collaboration

Comprehensive value chain approach across adjacent sectors

High-impact results that accelerate technology time to market

LCRI Sponsorship | By Fuel Type

LCRI LOW-CARBON RESOURCES INITIATIVE

Electric

- aeci Associated Electric Cooperative Inc.
- American Electric Power
- aps
- East Kentucky Power Cooperative
- FirstEnergy
- Hawaiian Electric
- LES
- LA DWP Los Angeles Department of Water & Power
- Missouri River Energy Services
- Nebraska Public Power District
- New York State of Opportunity. NY Power Authority
- NOMAC
- OglethorpePower
- OPPD Omaha Public Power District
- Portland General Electric
- PowerSouth Energy Cooperative
- SRP
- Southern California Edison
- TVA Tennessee Valley Authority
- TEPCO
- Tri-State

Gas

- Atmos Energy
- Intermountain Gas Company
- National Fuel
- NW Natural
- SoCalGas A Sempra Energy utility

Dual Fuel

- Alliant Energy
- Ameren
- CenterPoint Energy
- conEdison
- Consumers Energy Count on Us
- cps Energy
- Dominion Energy
- DTE
- Duke Energy
- Exelon
- Fortis Inc.
- nationalgrid
- NiSource
- ppl
- Southern Company
- WEC Energy Group
- Xcel Energy

OEMs

- GE
- Mitsubishi Power

EPC

- B&W Babcock & Wilcox
- Black & Veatch

2020 | 2030 | 2050+

Beyond 2030

LCRI Focus:

How might value chains incorporate low-carbon energy carriers?

H_2 Hydrogen | Ammonia | Synfuels | Biofuels | CCS

- Renewable Fuels
- Hydrocarbon-Based Processes
- Electrolytic Processes
- Delivery & Storage
- Power Generation
- Transportation, Industry, & Buildings
- Safety and Environmental Aspects
- Integrated Energy System Analysis

Current Priority Research Areas

PRODUCTION

Electrolytic Processes

- Power-to-X technologies
- Technology integration with renewable and nuclear energy systems

Hydrocarbon-Based Processes

- Hydrogen production from steam-methane reformation, gasification
- Hydrogen production from methane cracking
- Fischer Tropsch and Haber-Bosch low-carbon alternatives
- Carbon capture and utilization, DAC

Renewable Fuels

- Biochemical processes
- Renewable natural gas
- Biofuel feedstocks and conversion
- Methane capture, Green Hydrogen

DELIVERY & END USE

Storage & Delivery

- Gas and liquid fuel infrastructure, storage and distribution (e.g., pipeline blending)
- Metal hydrides, liquid organic hydrogen carriers
- Safety and codes/standards
- Underground & aboveground storage

Power Generation

- Low-carbon fuels (pure or blended forms)
- Gas turbines, boilers, RICE, fuel cells
- Integrated plant impacts

Transportation, Industrial & Buildings

- Light duty, medium/heavy duty, off-road, aviation, maritime, rail
- Combustion and heating applications
- Feedstocks for chemicals and processing

CROSS-CUTTING

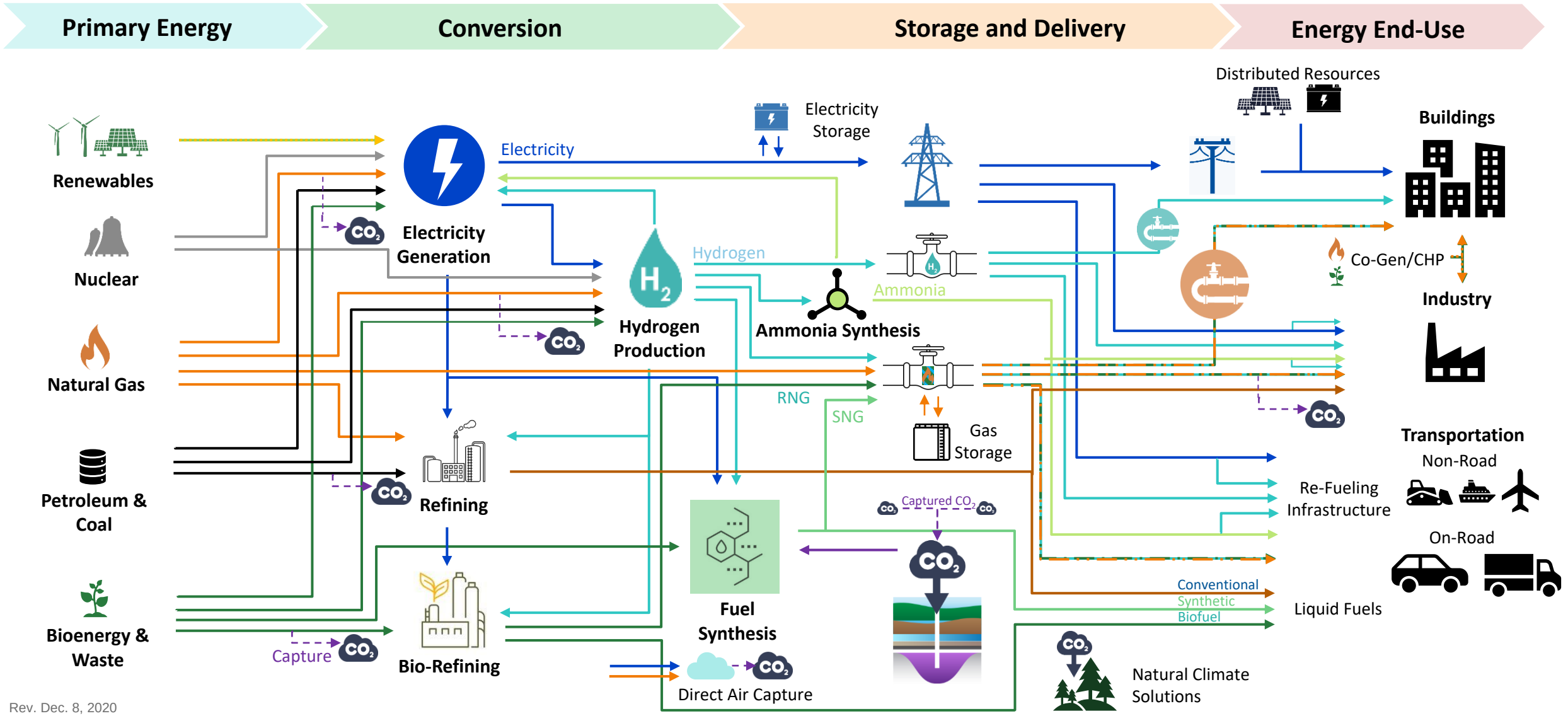
Safety and Environmental Aspects

- Lifecycle environmental impact assessments
- Safety standards and protocols
- Decision support tools

Integrated Energy Systems Analysis

- Economic model to understand decarbonization pathways across the energy ecosystem
- Impact assessment of low-carbon energy on reliability
- Scenarios and sensitivities covering energy usage, economic considerations, environmental aspects, and consumer preferences

LCRI Integrated Energy System Modeling



Rev. Dec. 8, 2020

LCRI Resources

www.lowcarbonlcri.com

- LCRI Overview and Current Sponsors
- Publicly-released documents
- Subscribe to LCRI Newsletter
- Research Vision Launch Recordings

WHAT'S NEXT

The Future – an Integrated Energy Systems Approach

HYDROGEN TECHNOLOGY CENTER

Planning, investment, and R&D must consider:

- **the whole energy SYSTEM**

  not just a particular energy product, sector, or source

- **gas and liquid fuels will evolve and play a vital role**

  grid-scale, long-duration storage, long-distance energy transport, resilience, and difficult-to-decarbonize sectors

- **INFRASTRUCTURE is fundamental and near-term decisions have long-term impact**

  enable energy systems integration to deliver energy where we need it, when we need it

- **storage must balance both demand and supply**

  address seasonal variations, reliability, resiliency, and price volatility

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GTI envisions low-carbon, low-cost integrated energy systems which leverage gases, liquids and infrastructure.

Ambition. Innovation. Scale. Collaboration.

All Required.