Low-Carbon Resources Initiative

Enabling the Pathway to Economy-wide Decarbonization

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Decarbonization Briefing
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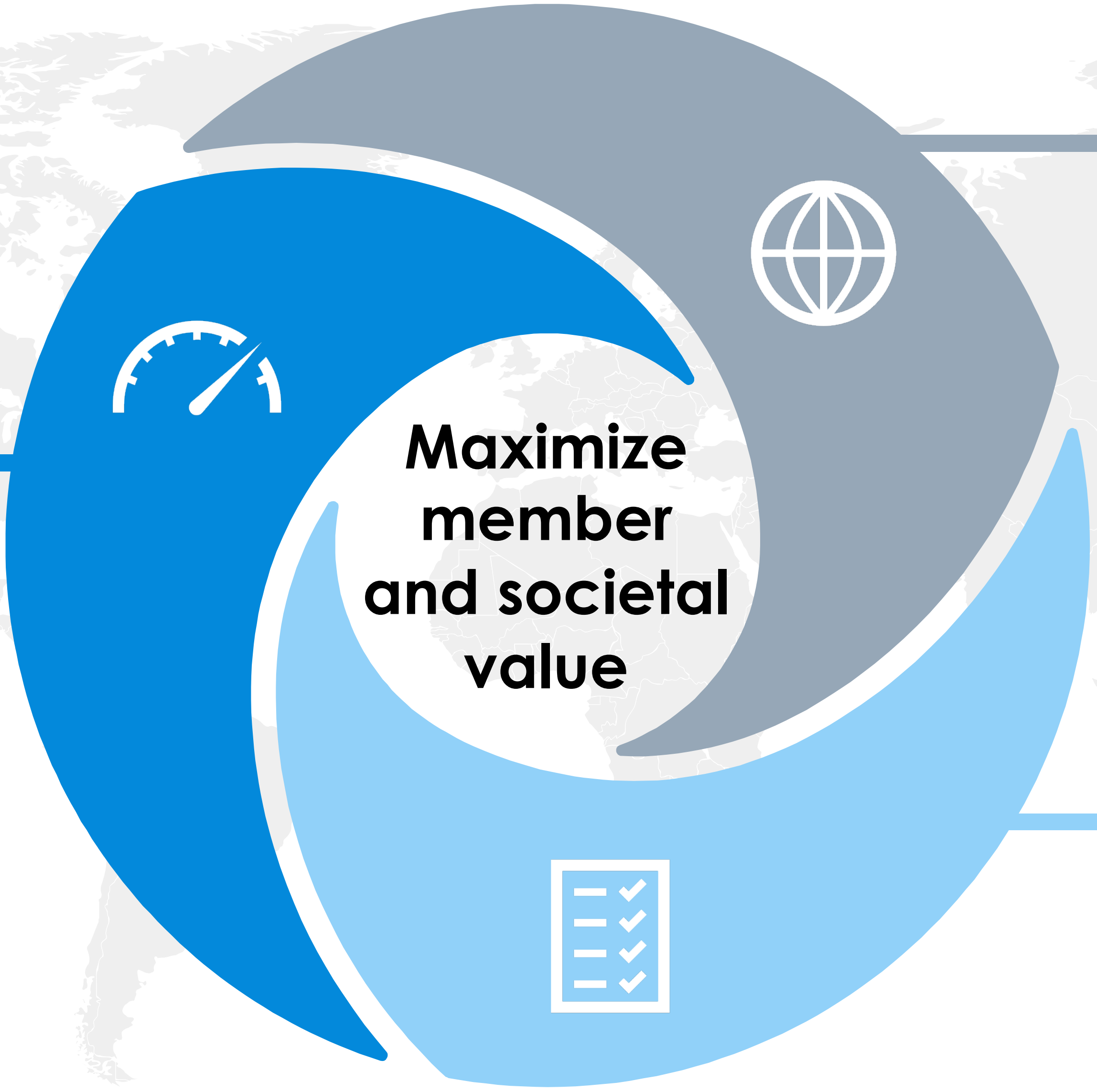
EPRI's Role

Accelerate technology innovation

Develop and evaluate energy system solutions through broad global engagement with technical partners and other stakeholders



Enable the future energy system

Conduct economy-wide technology, economic, and policy analyses and research to make an affordable, sustainable, and resilient energy future possible

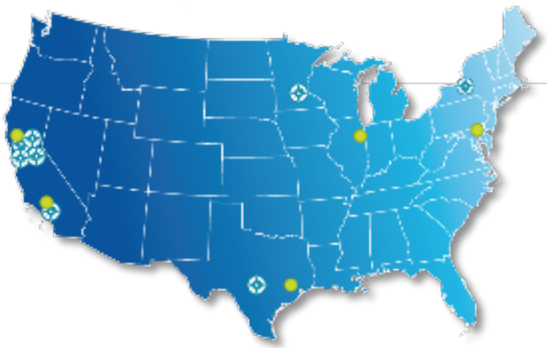
Provide independent and objective information

Inform investment, policy, and regulatory decisions, deliver intelligence on the energy system, and train the industry workforce

GTI 80+ Year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY	CONVERSION	DELIVERY	UTILIZATION



RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

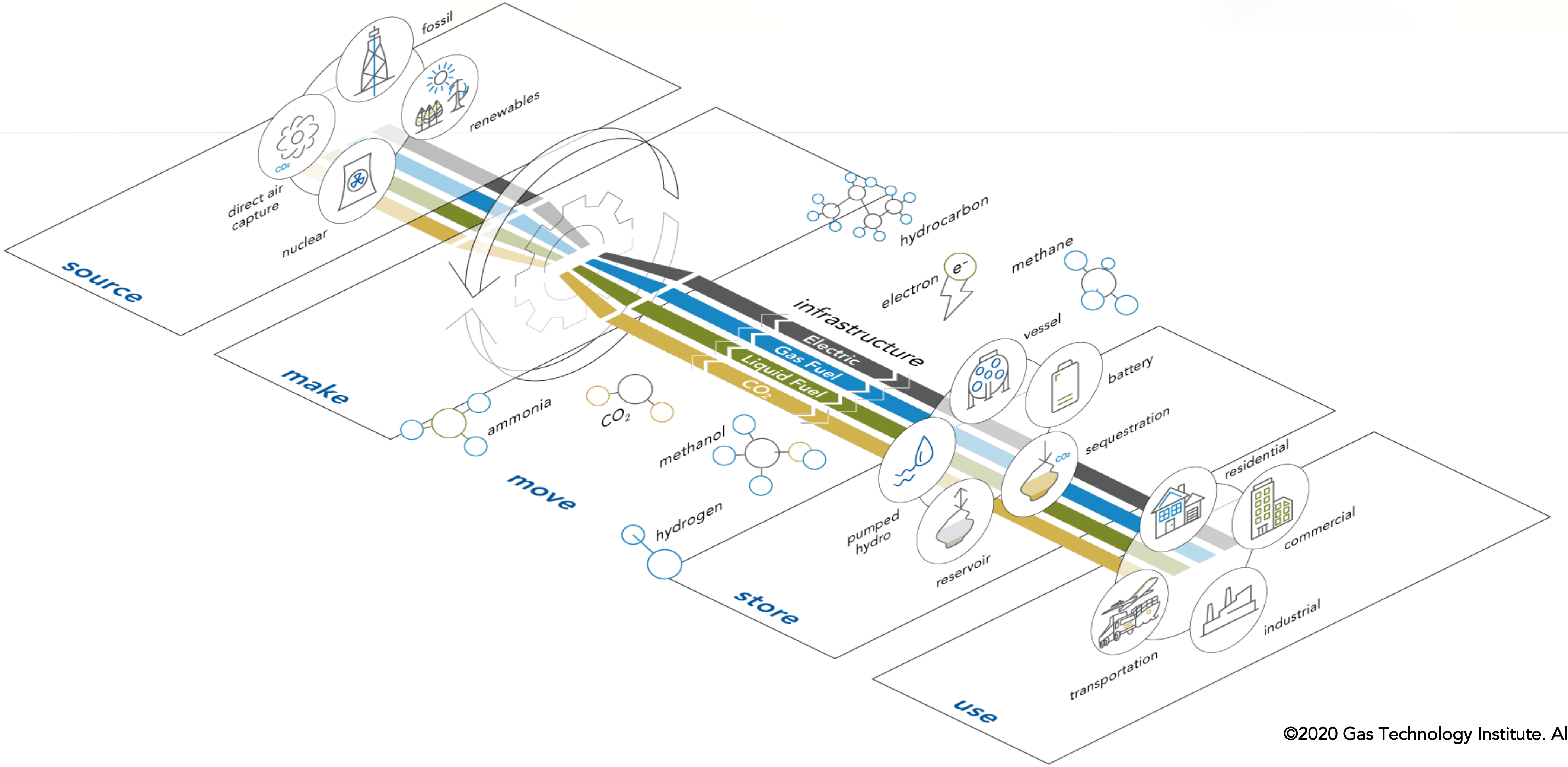
TRAINING

COMMERCIALIZATION

400+ EMPLOYEES

World-class piloting facilities headquartered in Chicago area

GTI sees a carbon-managed future where integrated energy systems leverage low-carbon fuels, gases, and infrastructure.



What does Deep Decarbonization Mean?

Solar/Wind/ Hydro

Storage (Battery)

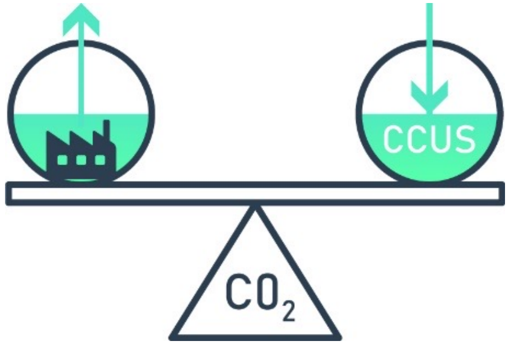
Storage (H_2)

Nuclear

CCUS

CO_2 Removal (BECCS)

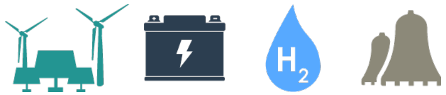
NET ZERO



Net carbon emissions equal zero. Any emissions produced from operations are balanced by an equivalent amount of carbon removal or offsets.

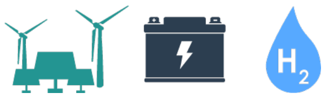
CARBON FREE

Entity, system, or set of resources that does not use fossil fuels or emit carbon.



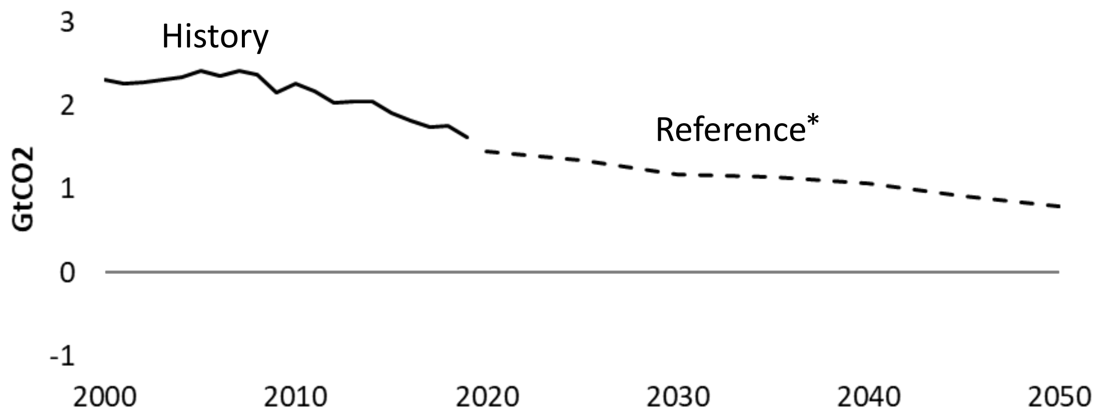
100% RENEWABLES

100% of electricity generated must come from renewable sources such as wind, solar, and hydro.



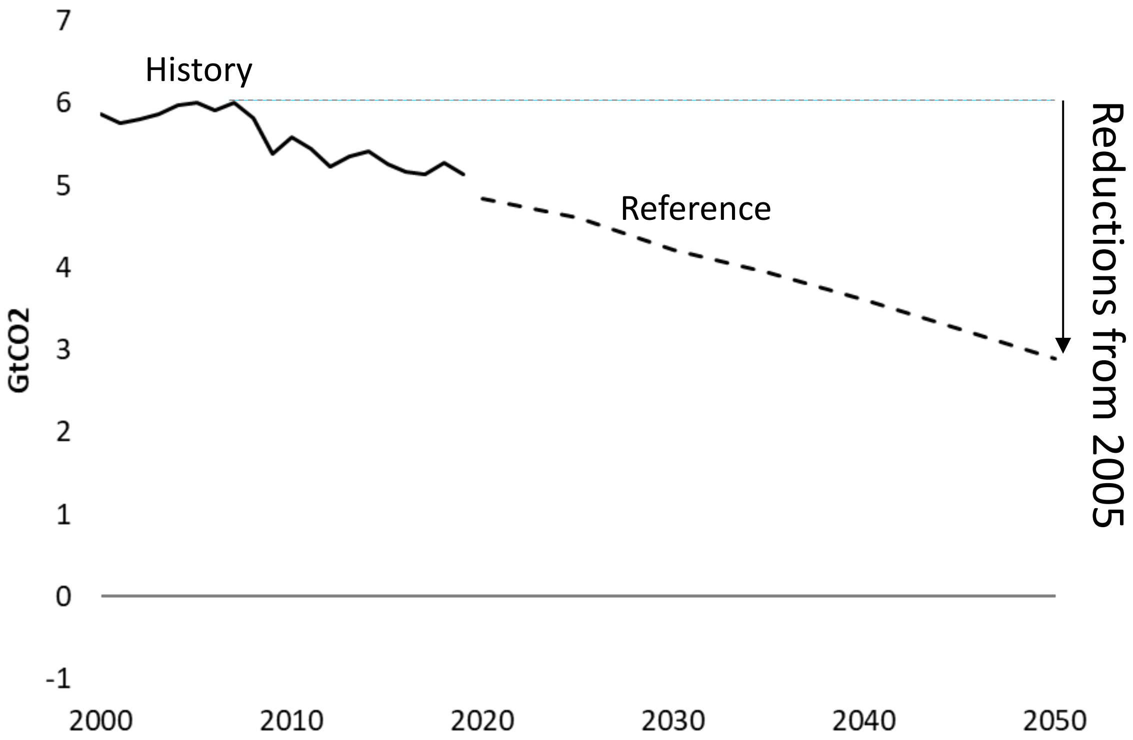
The electric sector has had significant contribution to decarbonize over the past 15 years

Electric Sector CO_2 Emissions



Electric sector emissions decline in reference case; CO_2 intensity of generation declines faster

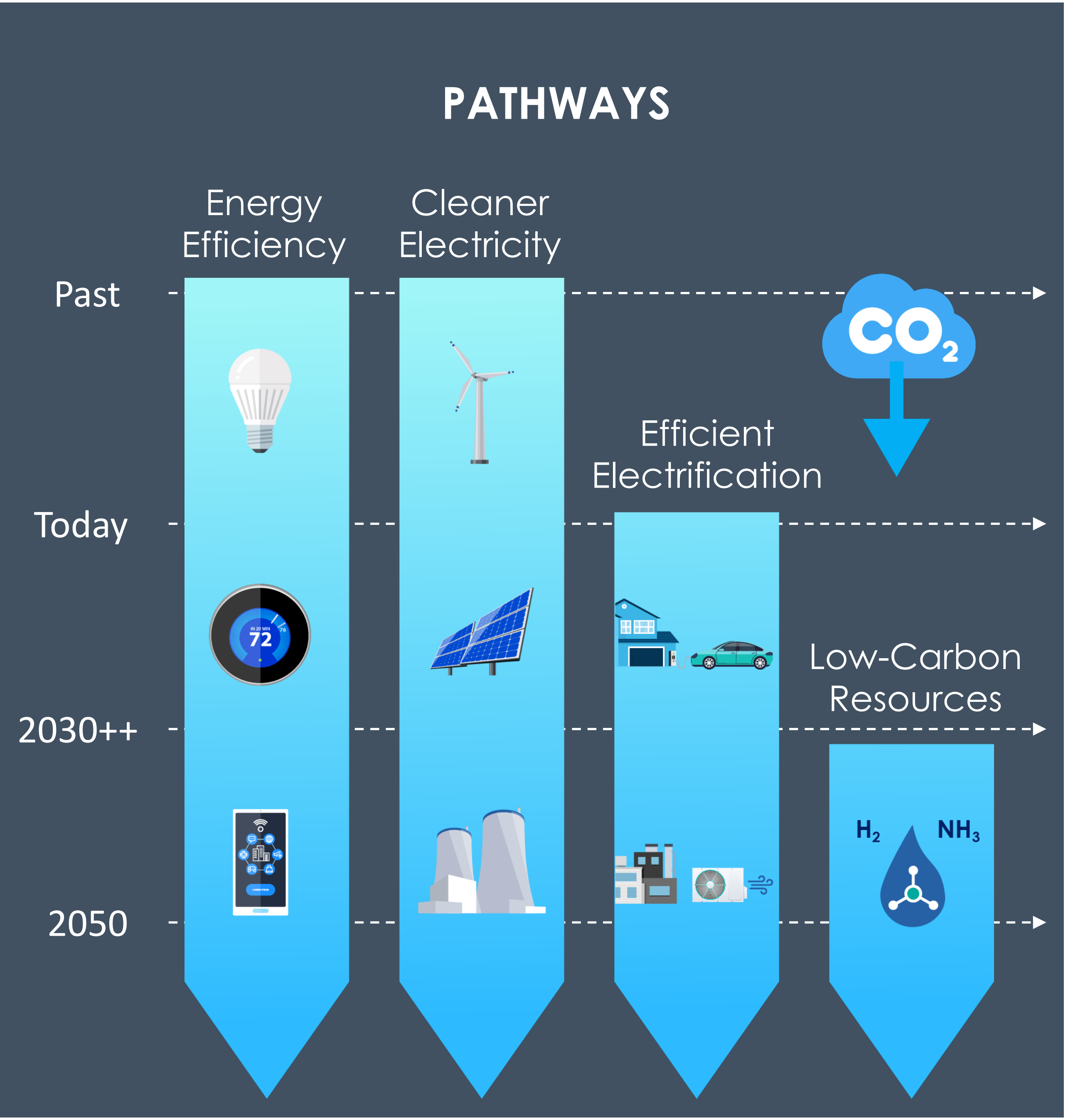
Economy-Wide CO_2 Emissions



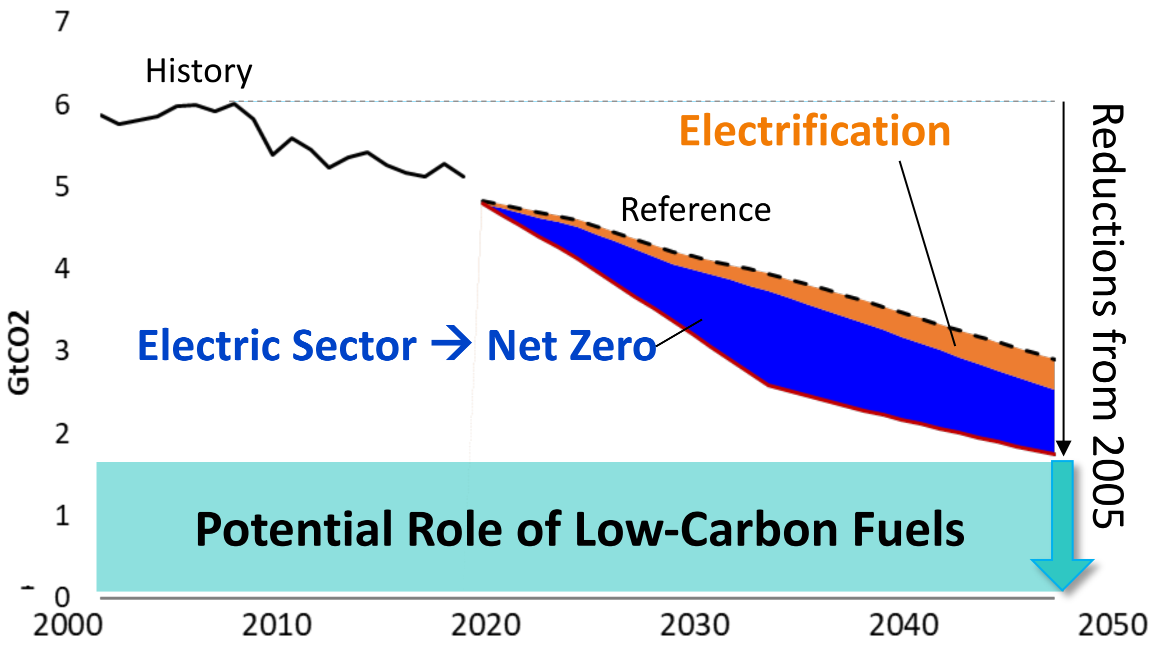
Economy-wide emissions fall to 50% below 2005 by 2050 based on renewables/gas/electrification

EPRI Report [3002020700](3002020700)

*Reference case includes state-level policies. All cases use fuel prices and energy service demands from the EIA Annual Energy Outlook 2020 Reference case



Economy-Wide CO_2 Emissions



Low-carbon fuels may be required to achieve economy-wide decarbonization

Low-Carbon Resources Initiative

The **Low-Carbon Resources Initiative** (LCRI) is a five-year, focused R&D commitment to develop the pathways to advance low-carbon technologies for large-scale deployment. This initiative is jointly led by EPRI and GTI. The goal of the initiative is to enable a risk-informed understanding of options and technologies enabling significant economy-wide decarbonization through global partnerships and demonstrations, applied engineering developments, and technology acceleration of the most promising options.

WHY

Enable infrastructure for future low-carbon fuel options

Decarbonize sectors such as bulk transportation, large industries, and heating networks in cold climates

Large-scale clean power utilizing combustion turbines

Production

- Electrolysis from clean energy sources
- Biofuel and low-carbon processes
- Carbon capture & storage
- Innovative technologies

Integration

- Energy system modeling & analysis
- Grid electricity, renewables & nuclear energy
- Gas networks/ infrastructure
- Consumer optionality

Storage & Delivery

- Pipeline blending
- Safety and codes/ standards
- Underground & aboveground storage
- Chemical storage

End Use

- Transportation
- Industrial
- Power Generation
- Heating
- Commercial
- Residential

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

VALUE

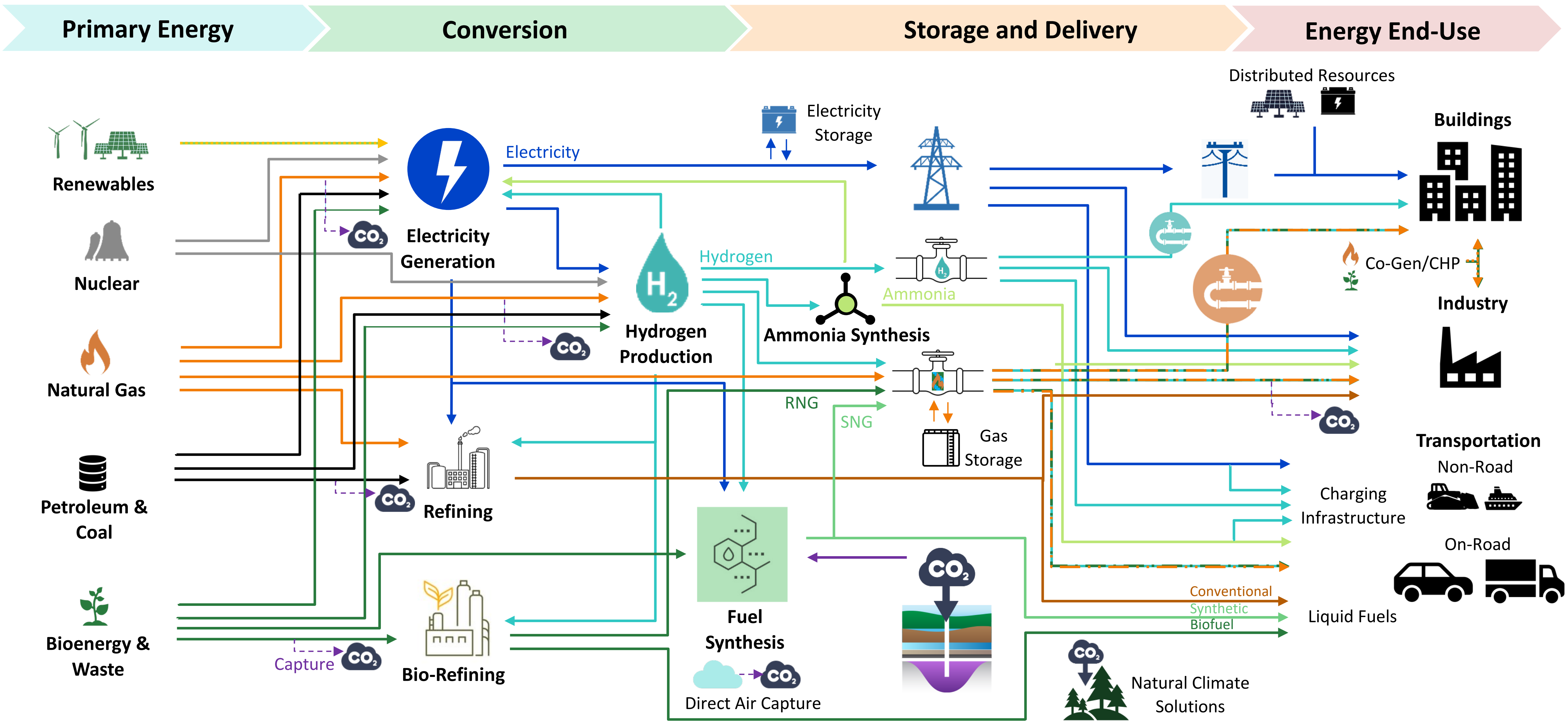
Individual commitment to environmental, social, and governance (ESG) efforts

Increase optionality of low-carbon solutions

Leverage investments across relevant sectors

Enable resiliency and affordability of low-carbon energy system

Possible Low-Carbon Energy Pathways



Beyond 2030 - Hydrogen/Clean Electricity Production

H_2 Production

Advanced Nuclear

Next Gen Electrolysis

Existing Clean Generation

Natural Gas CCS

H_2 Delivery

Utilize Existing Natural Gas Pipeline through Blending

Shipping and Trucking

H_2 End-Use

Boiler

Heavy Duty Transportation

Electric Generation

Advanced Fuel Cell

Large Industry

Chemical Process

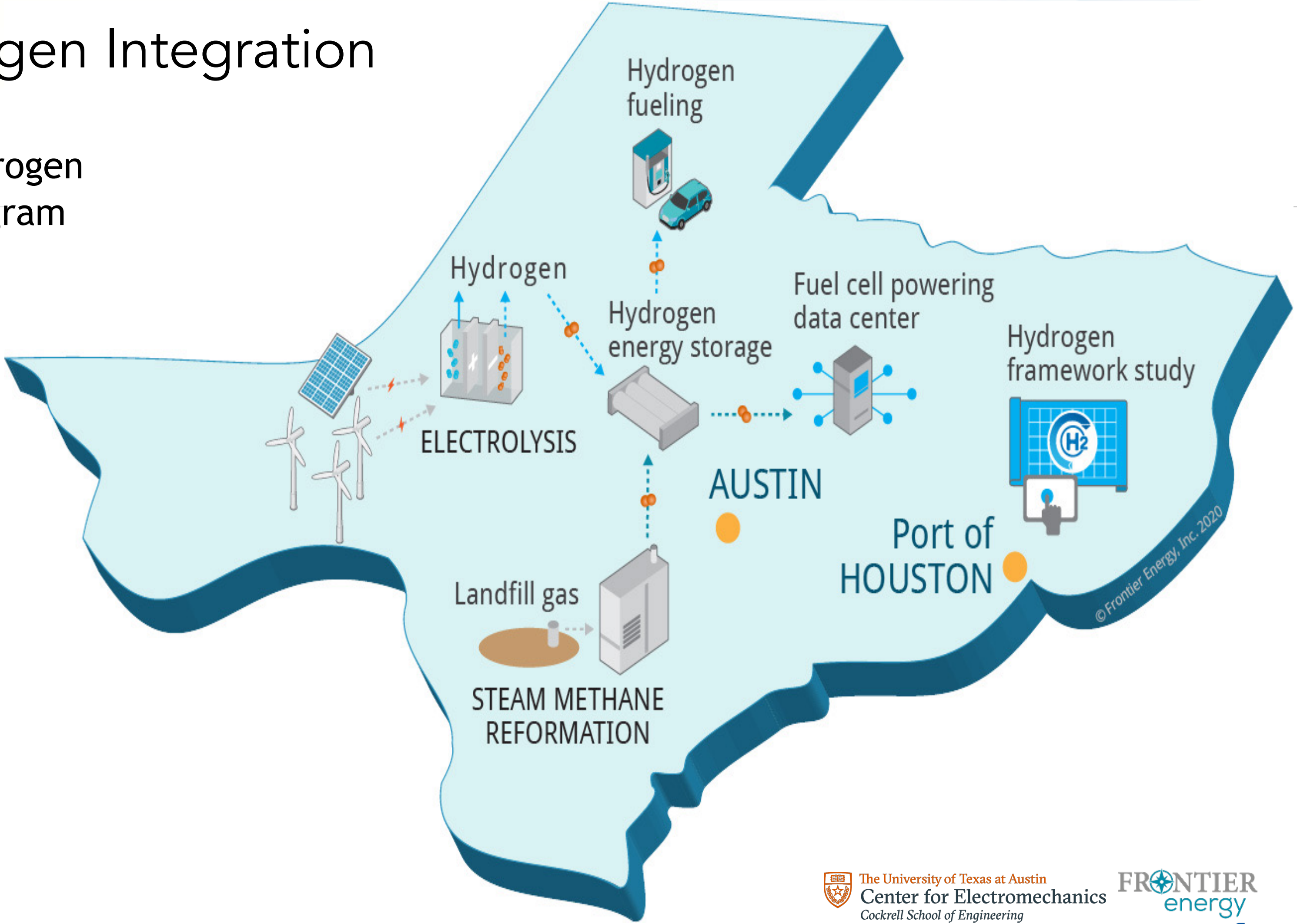
Demonstration and Strategic Planning for H2@Scale in Texas

Building a Framework for Hydrogen Integration

Design, build, and operate the first dedicated hydrogen infrastructure network under DOE's H2@Scale program

Hydrogen Framework Study - Port of Houston

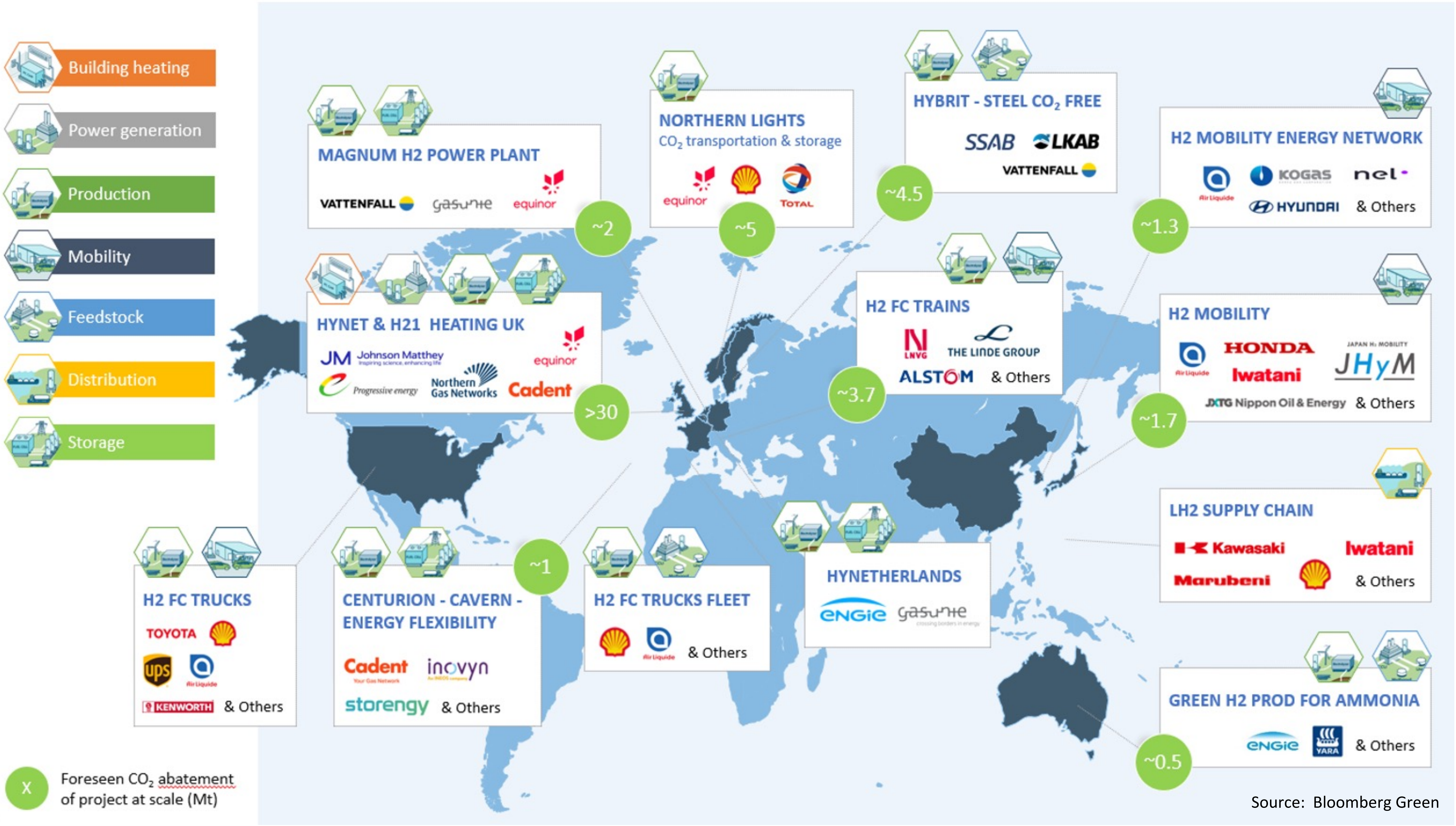
- Analysis of the integration of Texas wind power and natural gas resources and infrastructure
- Actionable 5-year framework for the Port of Houston to enable used to enable the deployment of stationary fuel cell power and hydrogen-fueled vehicles
- Viability of "renewable hydrogen" opportunities
- Ways to increase resiliency of the power grid by low or zero-emissions, on-site power generation using hydrogen or natural gas/ hydrogen blends for fuel



The University of Texas at Austin Center for Electromechanics Cockrell School of Engineering

FRONTIER energy

Project Pipeline of $90 Billion

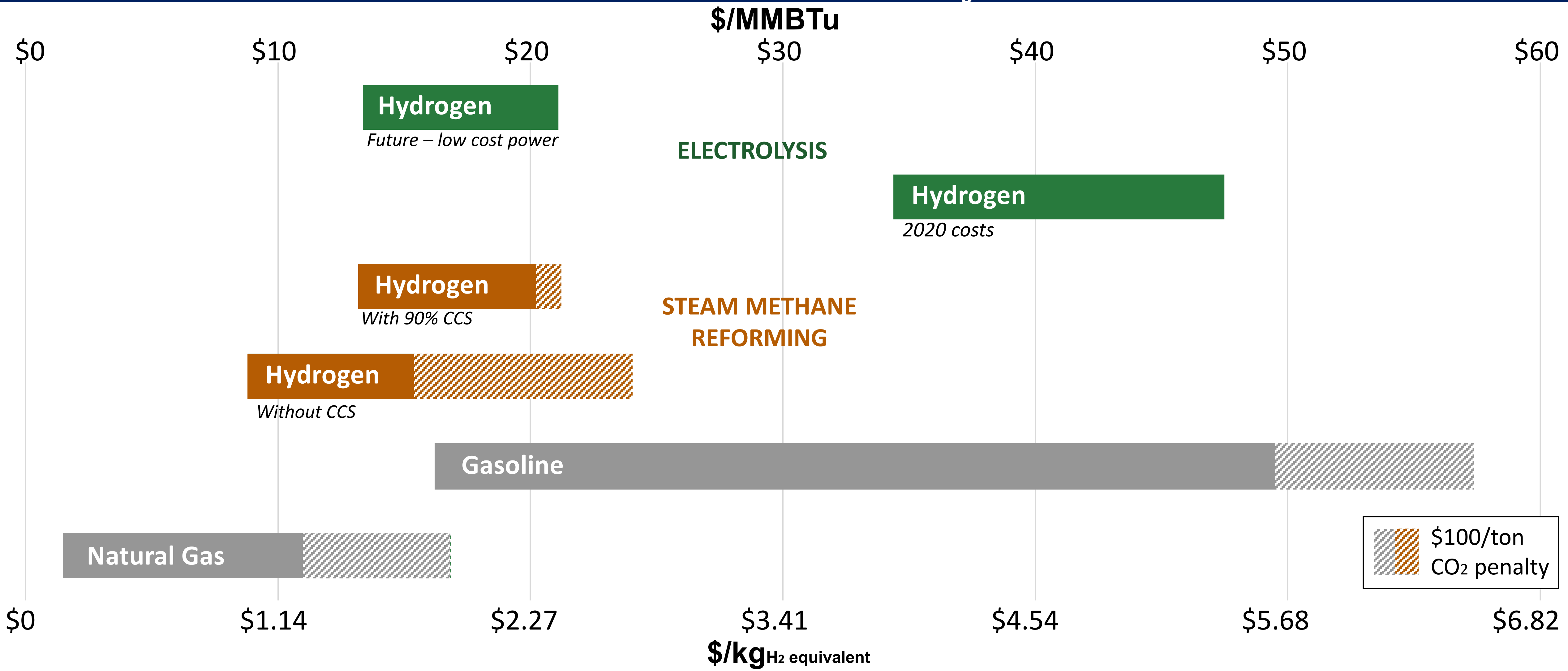


Source: Bloomberg Green

Example Technology Cost Insight

Energy Cost (USD/MMBTU and USD/kg$_{H_2 eq.}$)

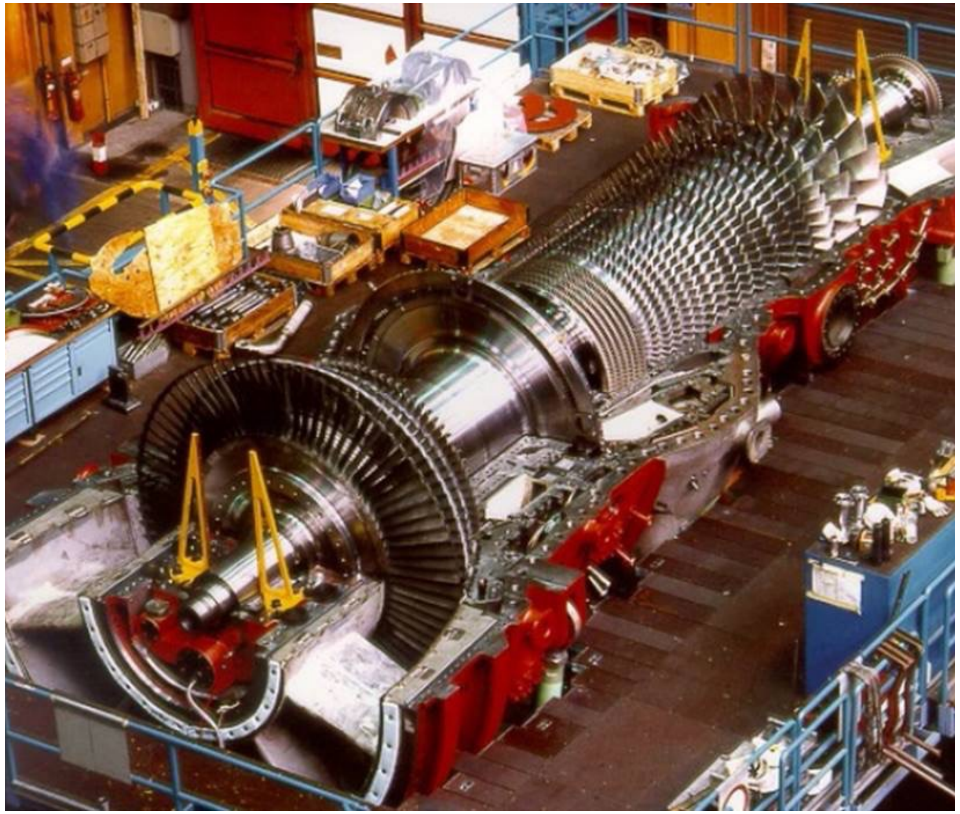
Hydrogen estimates exclusive of delivery and storage initial calculations. For discussion



Source: EPRI analysis, based on data from: IEA, "The Future of Hydrogen" (2019); EPRI, "Prospects for Large-Scale Production of Hydrogen by Water Electrolysis" (2019); commodity price data.

Impacts on End Use Applications

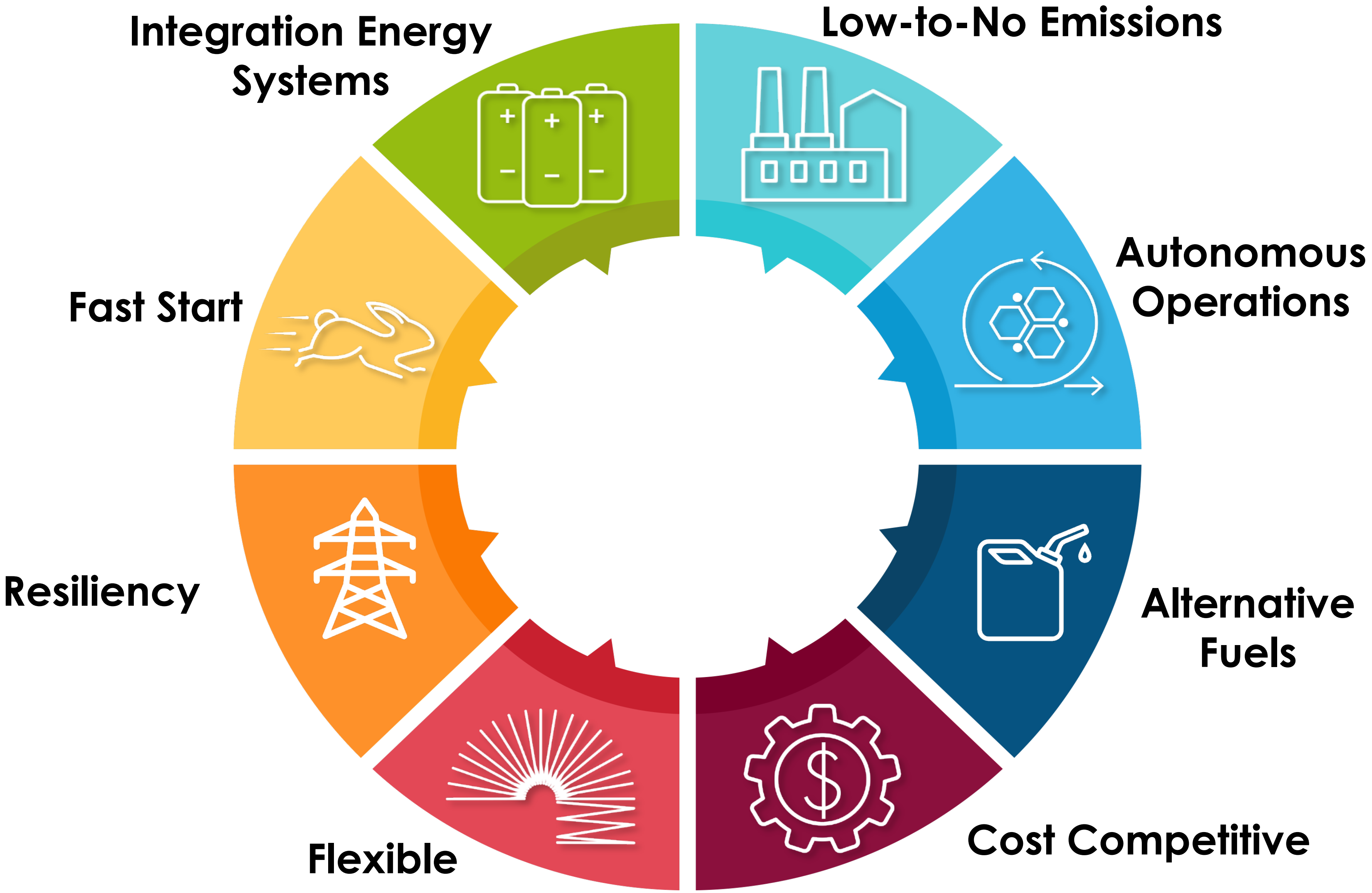
Industrial Scale Gas Turbines



Natural Gas Vehicles/ HD Trucks

Residential / Commercial

What will be the role Gas Turbines in a Decarbonized World?



LCRI Sponsorship

LCRI LOW-CARBON RESOURCES INITIATIVE

Alliant Energy
Ameren
American Electric Power
aps
Black & Veatch
CenterPoint Energy
conEdison
Consumers Energy Count on Us
cps Energy
Dominion Energy
Duke Energy
Exelon
FirstEnergy
GE
Intermountain Gas Company A Subsidiary of MDU Resources Group, Inc.
LES
LA DWP Los Angeles Department of Water & Power
Missouri River Energy Services
Mitsubishi Power
National Fuel
nationalgrid
Nebraska Public Power District Always there when you need us
New York State of Opportunity. NY Power Authority
NOMAC
OglethorpePower
OPPD Omaha Public Power District
Portland General Electric
PowerSouth Energy Cooperative A Touchstone Energy Cooperative
ppl
SRP
Southern California Edison
SoCalGas A Sempra Energy utility
Southern Company
TVA Tennessee Valley Authority
TEPCO
Tri-State
WEC Energy Group
Xcel Energy

Appendix

LCRI Resources

LCRI General Information

- [LCRI Overview 2 pager]
- LCRI Scope
- LCRI FAQ

Email Us!

LCRI@epri.com

Check it out!

www.LowCarbonLCRI.com

www.LCRI.epri.com

LCRI Launch Document

Quick Reads

- Hydrogen-Capable Gas Turbines for Deep Decarbonization
- Safety Considerations of Blending Hydrogen
- Hydrogen's Role in Decarbonizing Heat in the UK

LCRI Introductory Videos

- Advisory Structure
- Roadmap
- Digital Library
- Technology Pipeline
- Global Hydrogen Roadmap
- Colors of Hydrogen
- EPRI Overview
- GTI Overview

Low-Carbon Resources Initiative Research Vision

Focused on technologies that will be commercially deployed beyond 2030 to scale through 2050

Addressing the challenges and gap in achieving deep decarbonization across the energy economy

Living Document

annual updates

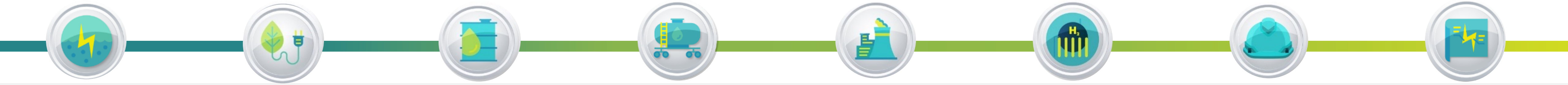
real-time learnings

Input & Development

- 400+ ADVISORS
- TECHNOLOGY LANDSCAPING
- LCRI REQUEST FOR INFORMATION
- GLOBAL INSIGHTS
- EXISTING AND EMERGING ROADMAPS

LCRI Research Vision Framework

Low-Carbon Resource Value Chain



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

R,D&D Approach

Goals – Strategies – Actions

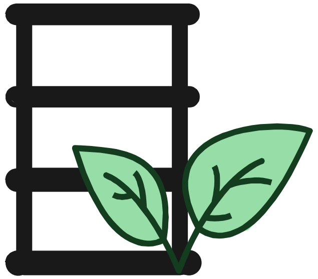
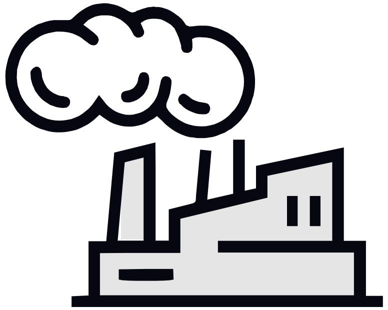
Technology Spectrum

Track – Participate – Lead

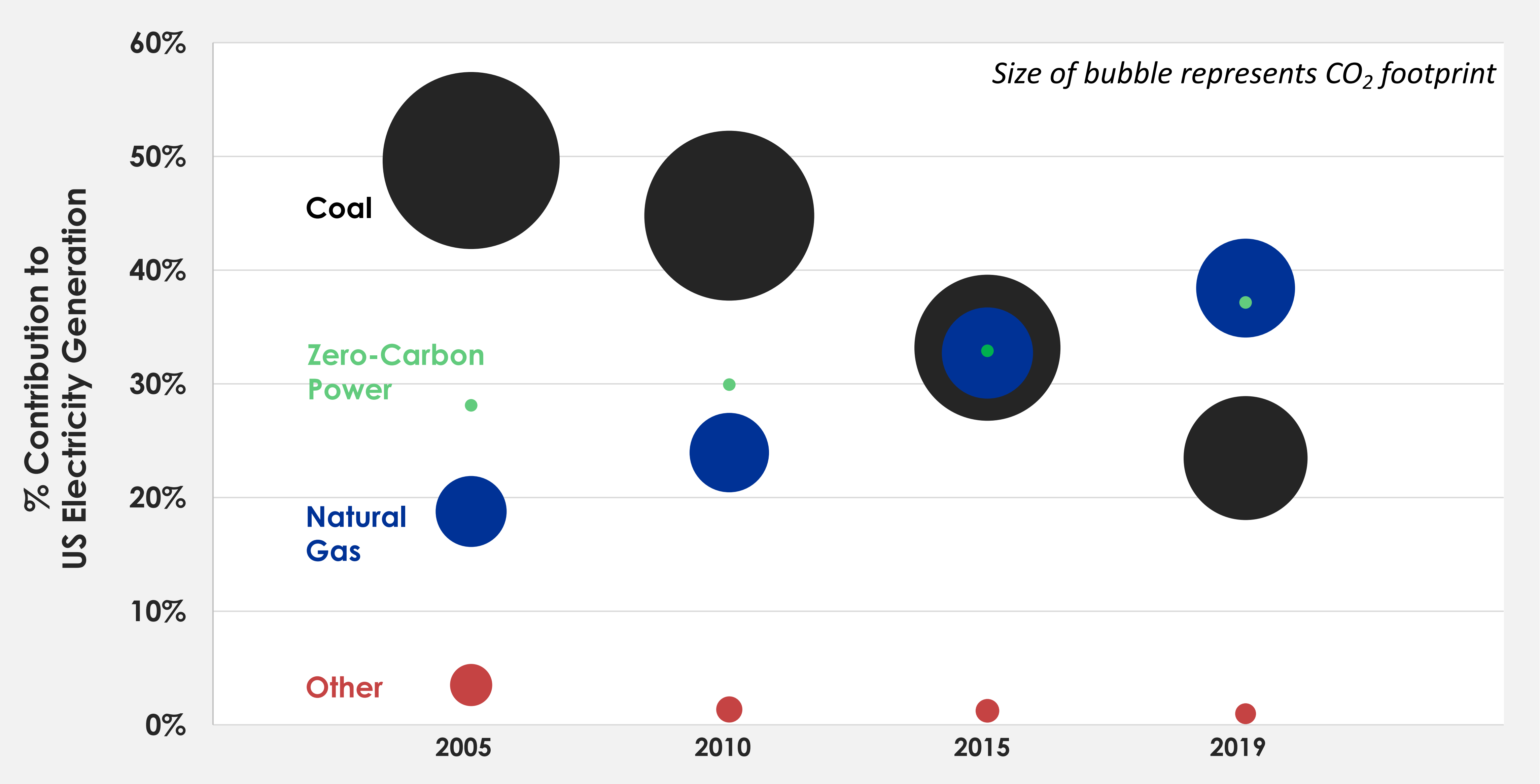
Earth Week Engagement Plan

April 19	April 20	April 21	April 22	April 23
			Earth Day	
Session 1: Pathways to Decarbonization **Press Release** **Launch social media campaign**	**Session 2:** Electrification **Session 3:** Nuclear	**Session 4:** Low-Carbon Resources Initiative: Research Vision to Economy-wide Deep Decarbonization	**Session 5:** Low-Carbon Resources Initiative: Unpacking the Vision	**Session 6:** Sustainability and Equity in the Just Energy Transition

OPTIONALITY Mitigation Strategies across the carbon chain

The Source	The Fuel	The Process	The Destination
			
Displacement	**Low Carbon Fuel**	**CO_2 Capture**	**Carbon Dioxide Removal**
Nuclear	Hydrogen	Pre-combustion	Direct Air Capture
Renewable	Ammonia	Post-combustion	Bio-energy with CCS
Storage	Biofuel	Oxy-combustion	Land Use and Mineralization

Natural Gas increasingly more important to the Electric System



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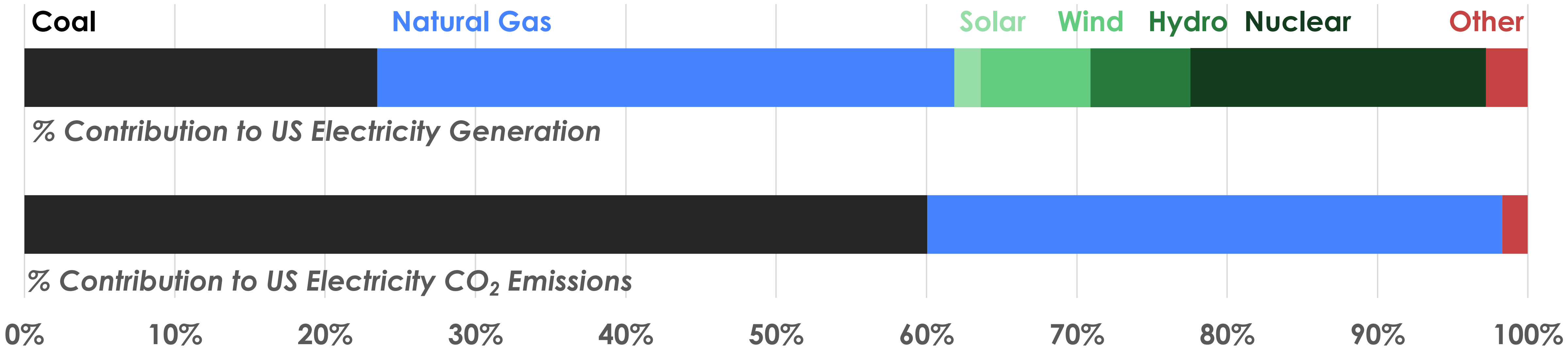
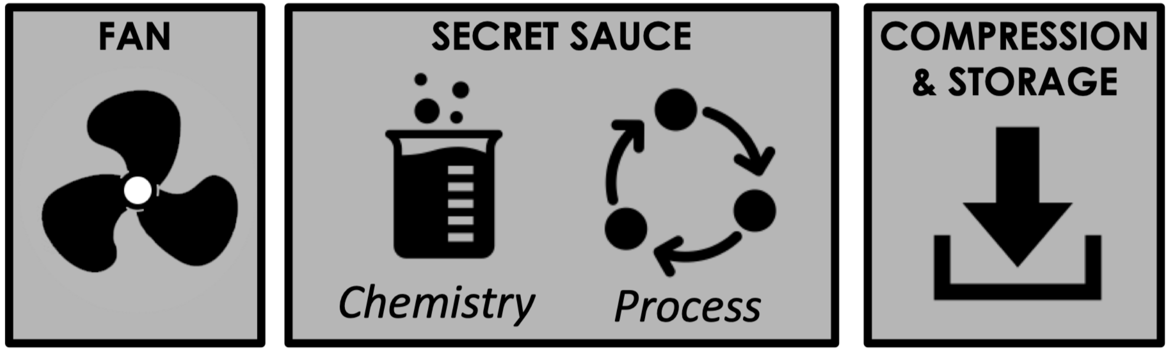


~3500 Combustion Turbines (CT) in the US fleet today

65% of these machines are less than 20 years old, representing 82% of the installed CT capacity

MITIGATION TECHNOLOGIES

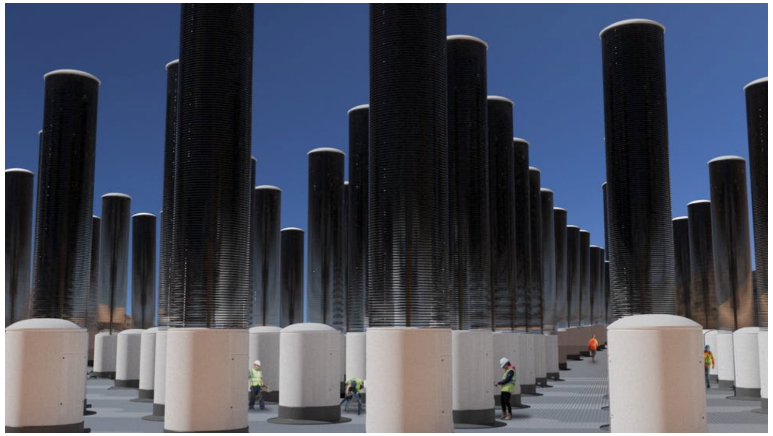
Removing CO_2 from the atmosphere



CLIMEWORKS

global thermostat
a carbon negative solution

Carbon Engineering



INNOVATION Gas Turbine Fleet

transition & beyond

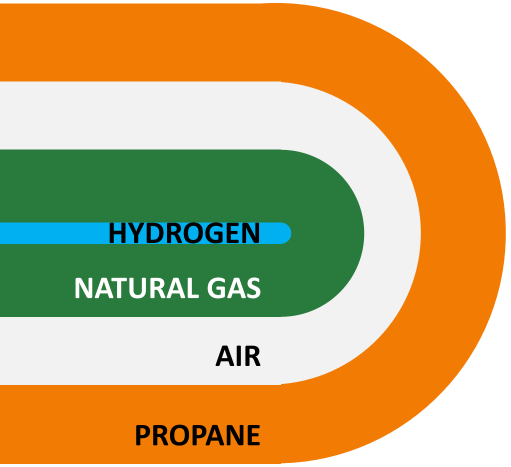


Illustration of relative molecular sizes

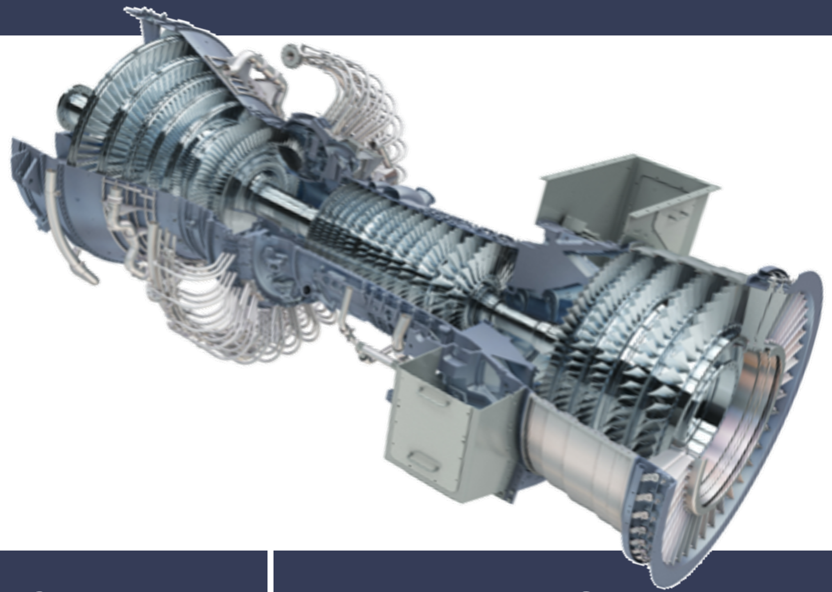
From natural gas to hydrogen

Faster Flame Speed
Order of magnitude above methane

Hotter Burn
Higher NO_x

Lower Heating Value
Hydrogen ~275 $^{BTU}/_{scf}$
Natural Gas 900 – 1000 $^{BTU}/_{scf}$

High Flammability Range
Hydrogen 4% – 75%
Natural Gas 7% – 20%



MITSUBISHI HITACHI POWER SYSTEMS	SIEMENS	ANSALDO	GE
Fired **29 gas turbine** units with **hydrogen** content ranging between **30% and 90%** with >**3.5M operating hours.**	Estimates it could unveil **a 25-MW to 50-MW hydrogen-burning** gas technology within **two years**.	Member of EUTurbines committed to provide GTs supporting **20% hydrogen by 2020**, and **100% hydrogen by 2030.**	Installed over **70 gas turbines** burning low-Btu **fuels that contain hydrogen** with **>4.5M operating hours**.
INNOVATION	**INNOVATION**	**INNOVATION**	**INNOVATION**
Diffusion Combustor 700 MW – 30% hydrogen – 10% carbon reduction (compared to conventional CCGT)	**Additive Manufacturing for Burners** Mid-February run of **100% hydrogen** turbine prototype in Germany	**Sequential Environmental (SEV)** combustion system platform ability to burn the **largest range of natural gas and hydrogen blended fuel mixture** for new power plants being offered today	Aero-derivatives can be configured with a **Single Annular Combustor (SAC),** which can operate on fuel blends, Heavy Duty Turbines offer 2 innovative combustor designs [Power 2019].