The Path to 2050: Enabling an Affordable and Reliable Clean Energy Transition

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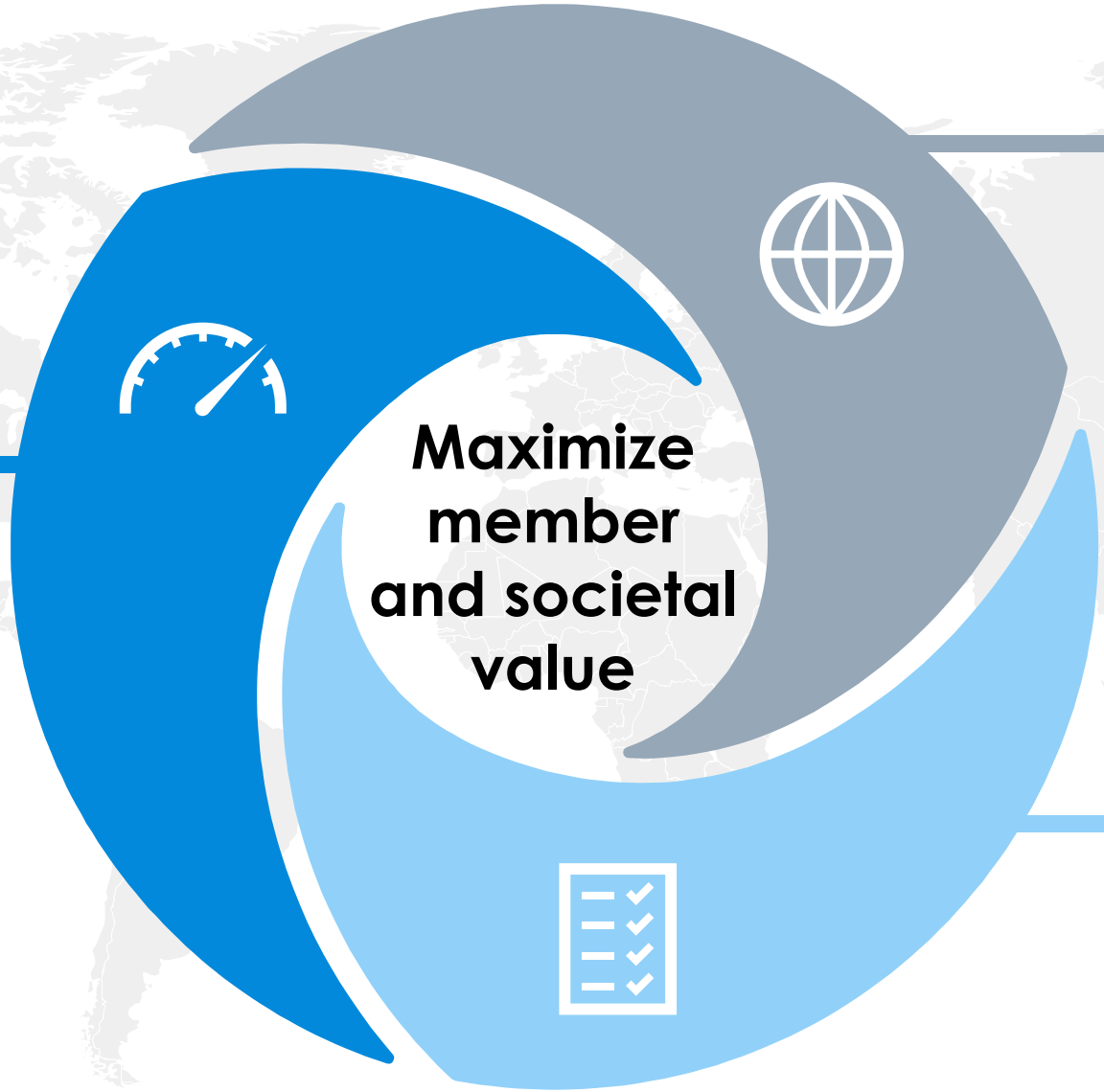
Decarbonization Briefing
May 7, 2021

Our Role

Chauncey Starr
EPRI Founder

"You can't wipe out society and make a whole new society. You have to deal with the society that exists. But you have to figure out how you're going to change it to something that's better."

EPRI's Role



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

Accelerate technology innovation

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

Provide independent and objective information

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

Reimagining the Future Energy System

Decarbonization

Within ~10-15 years

Accelerate economy-wide, low-carbon solutions

- Electric sector decarbonization
- Transmission and grid flexibility: storage, demand, EVs
- Efficient electrification

Within ~15-30 years

Achieve a net-zero clean energy system

- Ubiquitous clean electricity: renewables, advanced nuclear, CCUS
- Negative-emission technologies
- Low-carbon resources: hydrogen and related, low-carbon fuels, biofuels, and biogas

Transformation

Drive affordability of a clean and resilient energy system through digital transformation

- Power system modernization: pervasive sensors, monitoring, advanced analytics using AI
- Upgraded and expanded communications infrastructure and control systems

Resiliency

Within ~10-15 years

Mitigate climate impacts and cyber/physical risks

- System and asset hardening
- Improved response
- Faster recovery
- Cybersecurity

Within ~15-30 years

Future proof energy system design basis

- Resilient power system design
- Advanced asset design and strategic undergrounding
- Smart integration of energy carriers

Making Energy More

Clean | **Affordable** | **Reliable**

V2.0

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

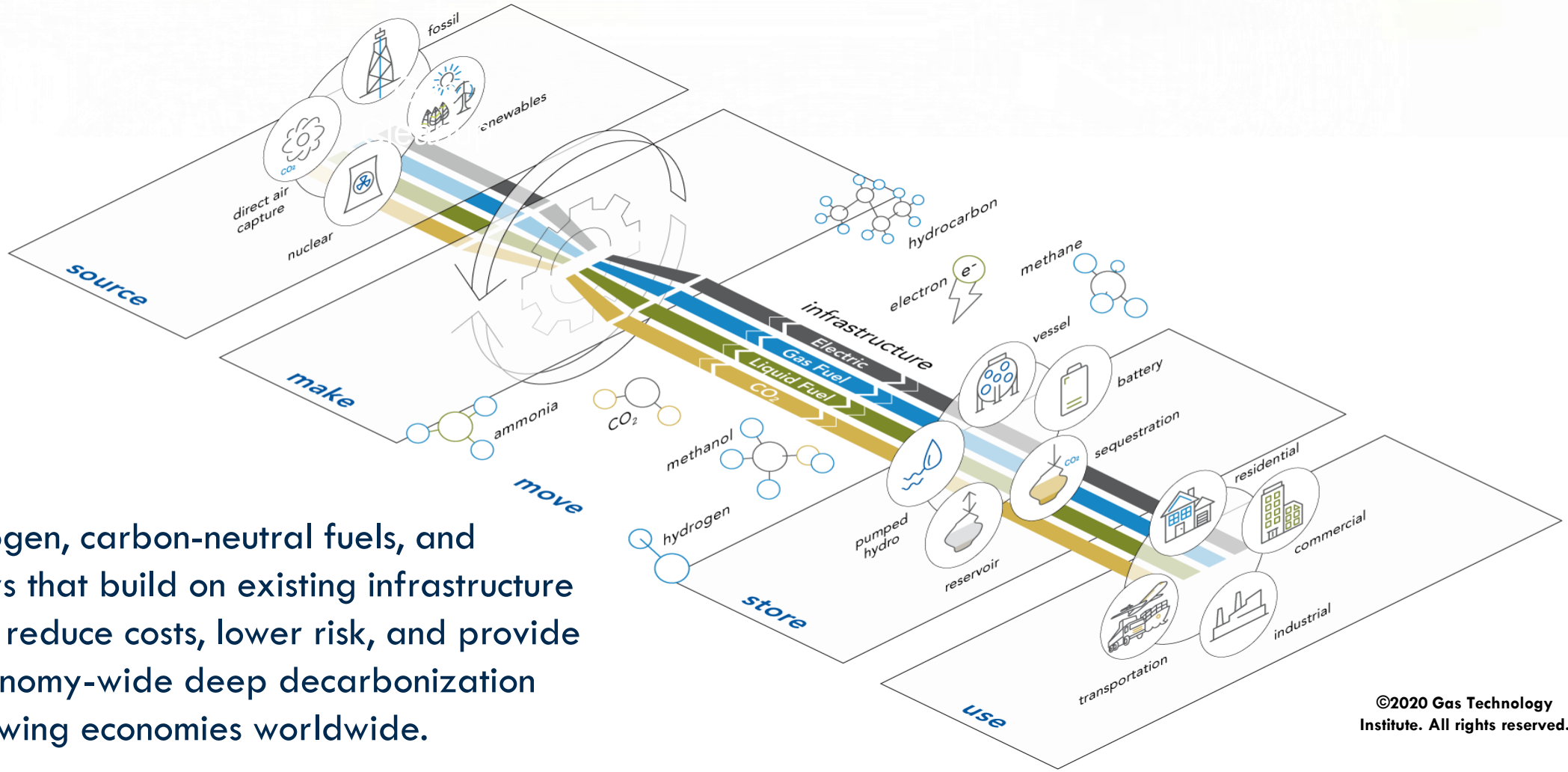
TRAINING

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.



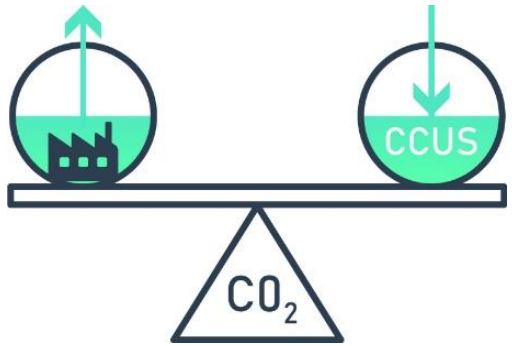
Deploying hydrogen, carbon-neutral fuels, and chemicals in ways that build on existing infrastructure and systems can reduce costs, lower risk, and provide pathways to economy-wide deep decarbonization that support growing economies worldwide.

What does Deep Decarbonization Mean?

LCRI LOW-CARBON RESOURCES INITIATIVE

- Solar/Wind/ Hydro
- Storage (Battery)
- Storage (H_2)
- Nuclear
- CCUS
- CO_2 Removal (BECCS)

NET ZERO



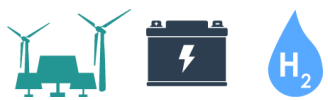
Net carbon emissions equal zero. Any emissions produced from operations are balanced by an equivalent amount of carbon removal or offsets.

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.



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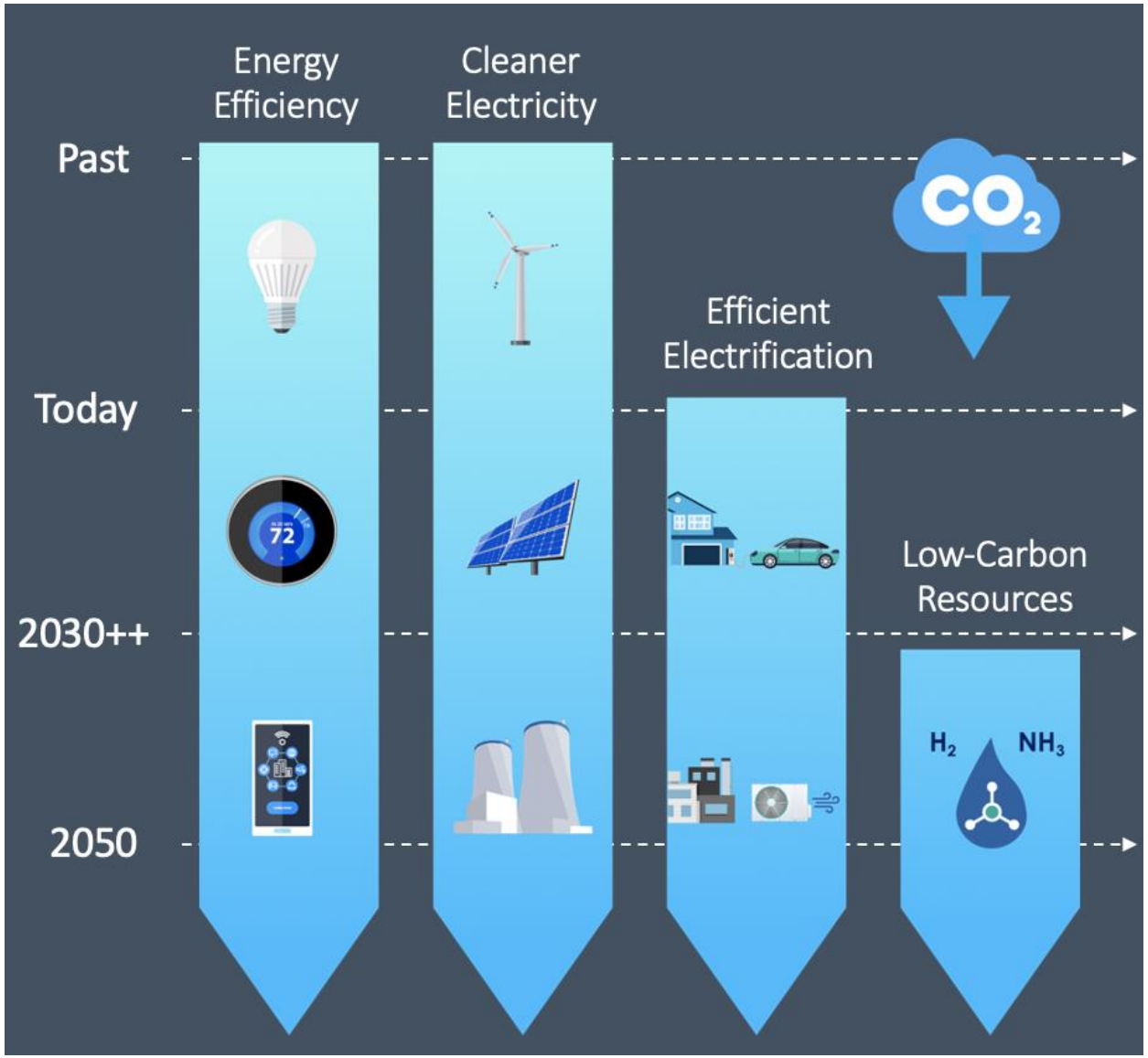
Energy Transformation to Enable Decarbonization



Commitments from electric, gas and end-use sectors to significantly reduce CO_2 emissions by 2050

An economy-wide perspective is critical

4 key energy transformations needed to enable economy-wide decarbonization

Decarbonizing the energy economy will require technologies that are not scaled today

Time to develop and scale is typically greater than a decade

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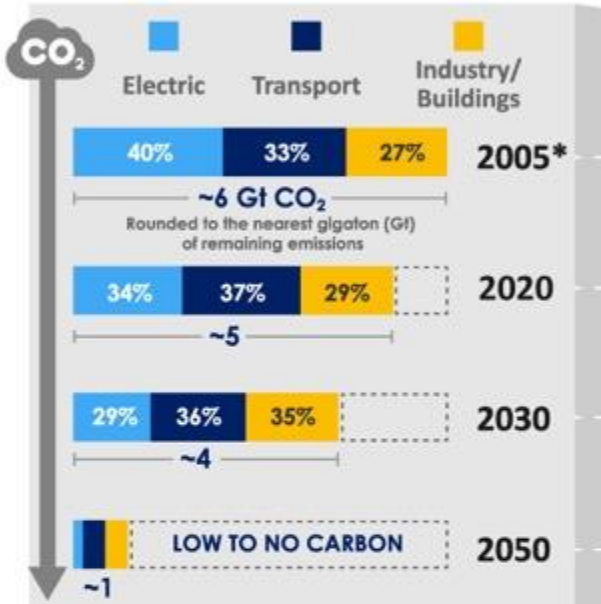
PROJECT 2X TO 2050

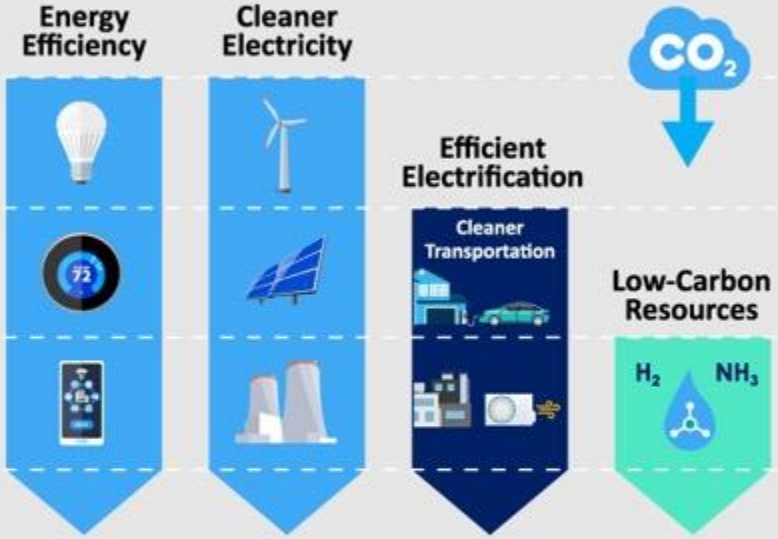
Accelerating Carbon Reduction Across the Economy

U.S. Energy-Related CO_2 Emissions

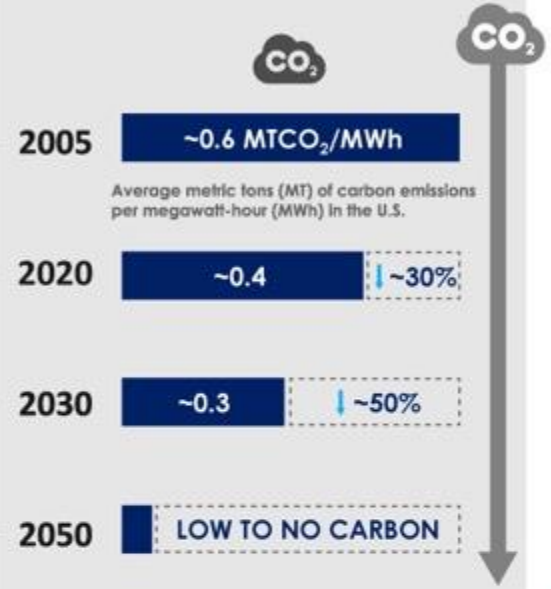


*The U.S. reference year for the Paris Climate Agreement

The Carbon Reduction Technology Timeline



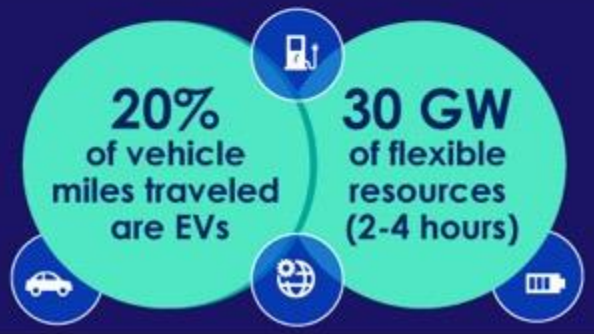
Cleaner Electricity Generation



Historical data from EIA *Monthly Energy Review*, February 2019. 2030 projections from *US-REGEN 2X reference case.*

Next Steps: Expanding Low-Carbon R&D

The Path to 2030: Accelerating Demonstration and Deployment



Accelerating Electric Vehicle (EV) Adoption and Grid Modernization

- Renewable/EV-Ready Integrated Grid
- EV Charging Infrastructure and Customer Behavior
- 30 GW of Grid Flexibility, Including Energy Storage
- Fleet Electrification

The Path to 2050: Creating Affordable, Low-Carbon Options

- **Low-Carbon Power Generation**
  Advanced Nuclear and Renewables | CCUS
- **Low-Carbon Resource Production**
  Hydrogen | Biofuels
- **Transmission, Delivery, and Storage**
  Existing and New Infrastructure | Pipeline Blending
- **End Use**
  Industrial | Buildings | Hydrogen Turbines | Heavy-Duty Transportation

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PROJECT 2X TO 2050

Decarbonization delivers near-term, local benefits

Affordability *Benefits of Switching to EVs**

BEFORE

Total Energy Bill: $4,528

CO_2 Emissions: 18 tons

AFTER

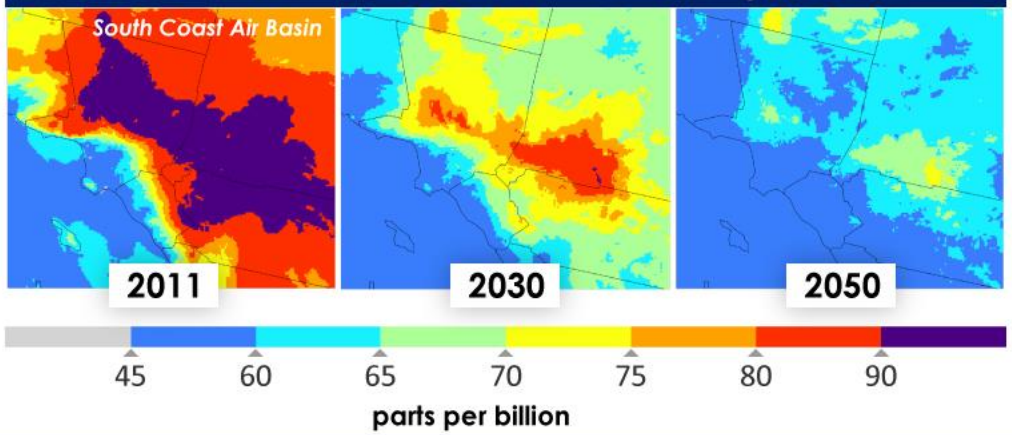
Total Energy Bill: $3,571 ↓ 21%

CO_2 Emissions: 12 tons ↓ 34%

*Based on 2015 data for an average U.S. household. With rapidly declining purchase prices, EVs are projected to be a lower total cost option for most households in the early 2020s.

Cleaner Air *Through Efficient Electrification*

Ozone declines substantially in a low-emission, high-electric future



Lower Energy Bill - Cleaner Air - Clear Choice

Key Innovations for an Affordable, Low-Carbon Grid

Energy Efficiency | Cleaner Electricity | Efficient Electrification | Low-Carbon Resources

- Advance Low-Carbon Resources (CCUS, Advanced Nuclear, Hydrogen, Biofuels)
- Modernize the Grid for Affordable Customer, DER, and EV Integration
- Expand and Strengthen Transmission System
- Inform Forward-Looking, Economy-Wide Policies
- Increase Grid Flexibility
- Improve Energy System Resilience
- Facilitate Energy System Integration and Transformation
- Inform Interconnection Rules and Communications Technology Standards
- Reimagine Energy Market Design

Technology Innovation

CO_2

Innovation-Enabling Policy and Regulation

Key to Lower Carbon: Expanded Charging Infrastructure to Support EV Adoption

160,000 gas stations

The Utility's Role

- Charge-ready grid infrastructure and charging stations
- Rates to incentivize EV smart charging
- Energy storage infrastructure for fast charging

Level 2 Stations (Workplace and Public)

2018	50,000
2030*	1,000,000 – 3,000,000

Fast Charging Stations

2018	10,000
2030*	50,000 – 80,000

**Projections based on U.S. DOE Alternative Fuels Data Center EVI-Pro Lite tool and EPRI USNEA Progressive scenario*

2018-2030 estimated installation cost of public and workplace charging infrastructure:

$4B-$30B

Key to Lower Carbon: An Integrated Grid Efficiently Linking Resources and Active Demands

LCRI LOW-CARBON RESOURCES INITIATIVE

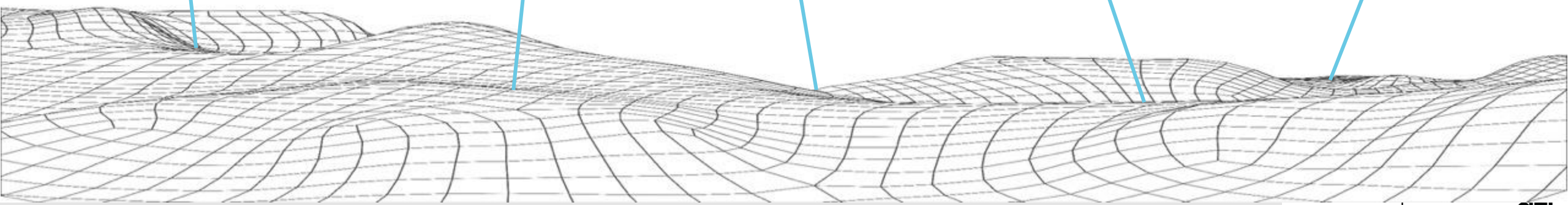
Smart and Fast Charging of EV

Enabling Higher Penetration of EV/Solar/DER

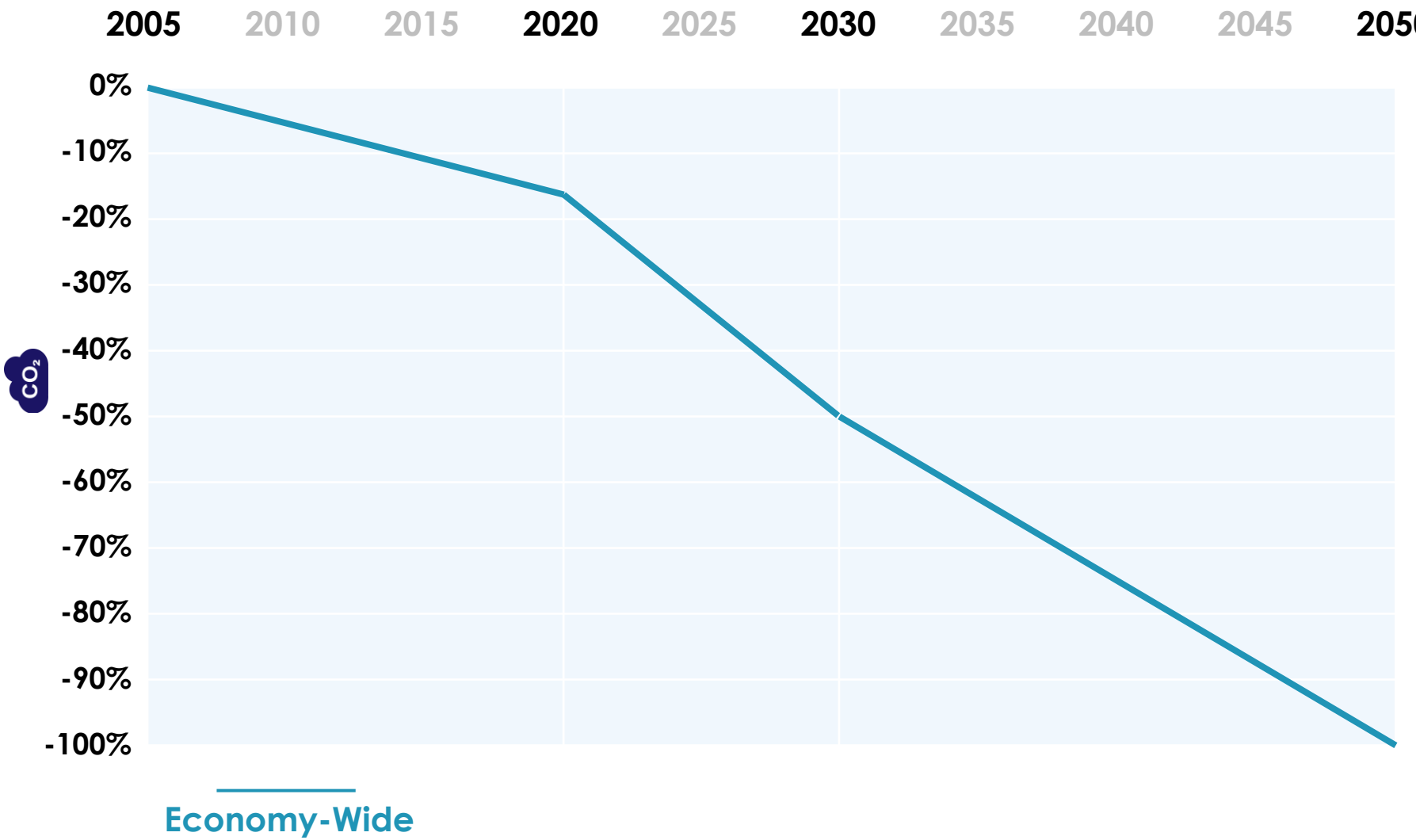
Grid-Integrated Energy Storage

Vehicle-to-Grid System Resource

Connected, Smart Demand-Responsive Load



Accelerating to 3X Carbon Reduction



2005-2020

In the U.S., annual energy-related **carbon emissions declined 1 GT** between 2005 and 2020.

2020-2030

Driving CO_2 about 50% below 2005 levels means **tripling the rate of decarbonization** – accelerating from 1 GT over 15 years to 1 GT every five years (3X).

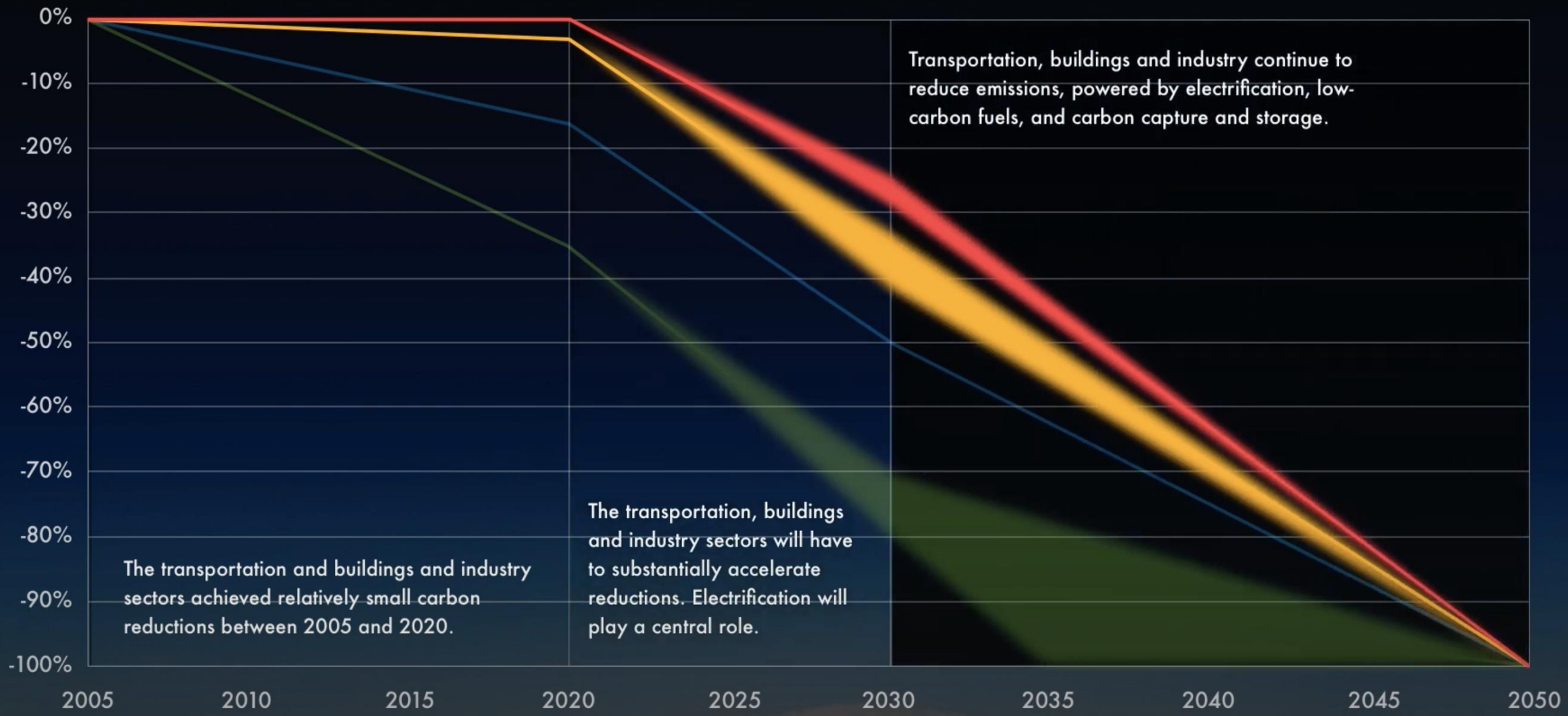
2030-2050

The U.S. is targeting **net-zero emissions economy-wide by 2050**.

https://www.youtube.com/watch?v=42UqxqCCYs4

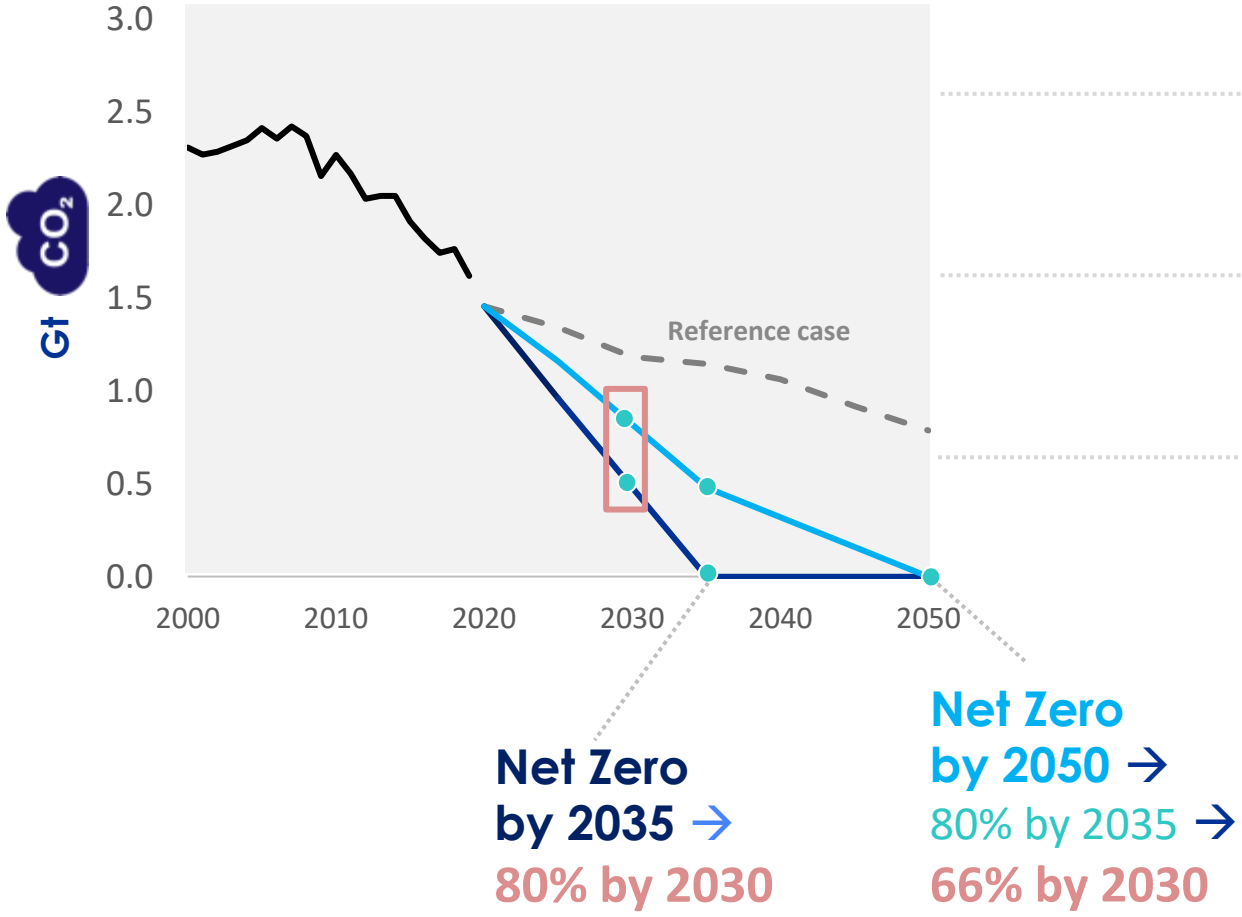
EXAMINING THE PACE OF U.S. CARBON REDUCTION BASED ON 2030 GOALS

Collaborative innovation essential to an affordable and reliable energy future



Potential Range for 2030 Emissions Targets

Powering Decarbonization White Paper Scenarios for Electric Sector Emissions



Electrification and efficiency drive
~20% reduction in non-electric emissions
~10% increase in load

66% below 2005 by 2030 for electric sector →
~40% below 2005 economy-wide

80% below 2005 by 2030 for electric sector →
~45% below 2005 economy-wide

What is required by 2030 to meet *assumed* emission target pathways?

Key Actions by 2030 in Electric Sector

- **Expand the grid** to maintain reliability with high wind and solar and electrification of other sectors
  - Ensure adequate backup capacity and load flexibility
  - Build associated transmission (intra-region essential, inter-regional valuable)

- **Extend and uprate existing nuclear and hydro**

- **Manage coal retirements** (community impacts, financial)

- **Add new natural gas capacity** to replace coal, balance renewables

- **Develop technologies for clean firm capacity** (CCUS, advanced nuclear, clean hydrogen, long-duration storage)

80% by 2030 target *requires* accelerated technology development and deployment

Worldwide Drivers of Economy-Wide Decarbonization

Commitments from electric & gas sectors to significantly reduce CO_2 emissions by 2050

- Renewables and nuclear power generation, battery/grid storage, and energy efficiency to achieve significant reductions
- Pathways may include carbon capture, utilization, and storage (CCUS); hydrogen (and other energy carriers); and negative carbon approaches

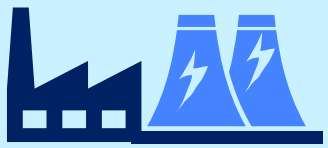
Decarbonizing the energy economy may require significant deployment of low-carbon fuels

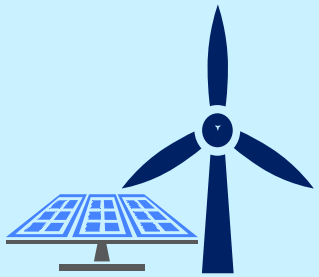
- Transitions are underway to incorporate bioenergy and renewable fuels, replace fossil fuels with alternate molecules, and deploy CCUS
- Consumers want options -- integrated primary and final energy systems could support the transition to a future energy economy

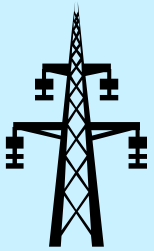
Achieving economy-wide net zero emissions will require low-carbon energy resources

Low-Carbon Fuels Pathway from the Electric Sector

Low-Carbon Generation, Transmission & Distribution



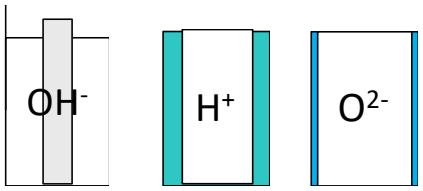


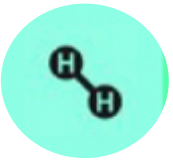


→ **Direct Electrification** →

→ **Indirect Electrification** → **Low-Carbon Fuels***

Electrolysis →





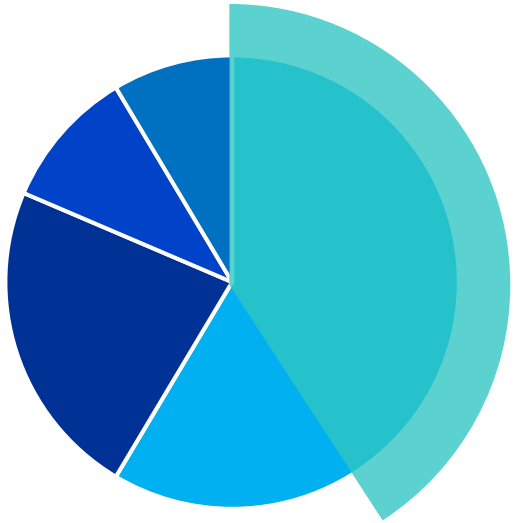
Hydrogen

Ammonia

Synthetic Hydrocarbons

Representative of one of several pathways

Low-Carbon Fuel Use Across the Economy



Low-carbon fuels becoming a key part of the decarbonization pathway

QANTAS — net-zero emissions by 2050

thyssenkrupp — climate neutral by 2050

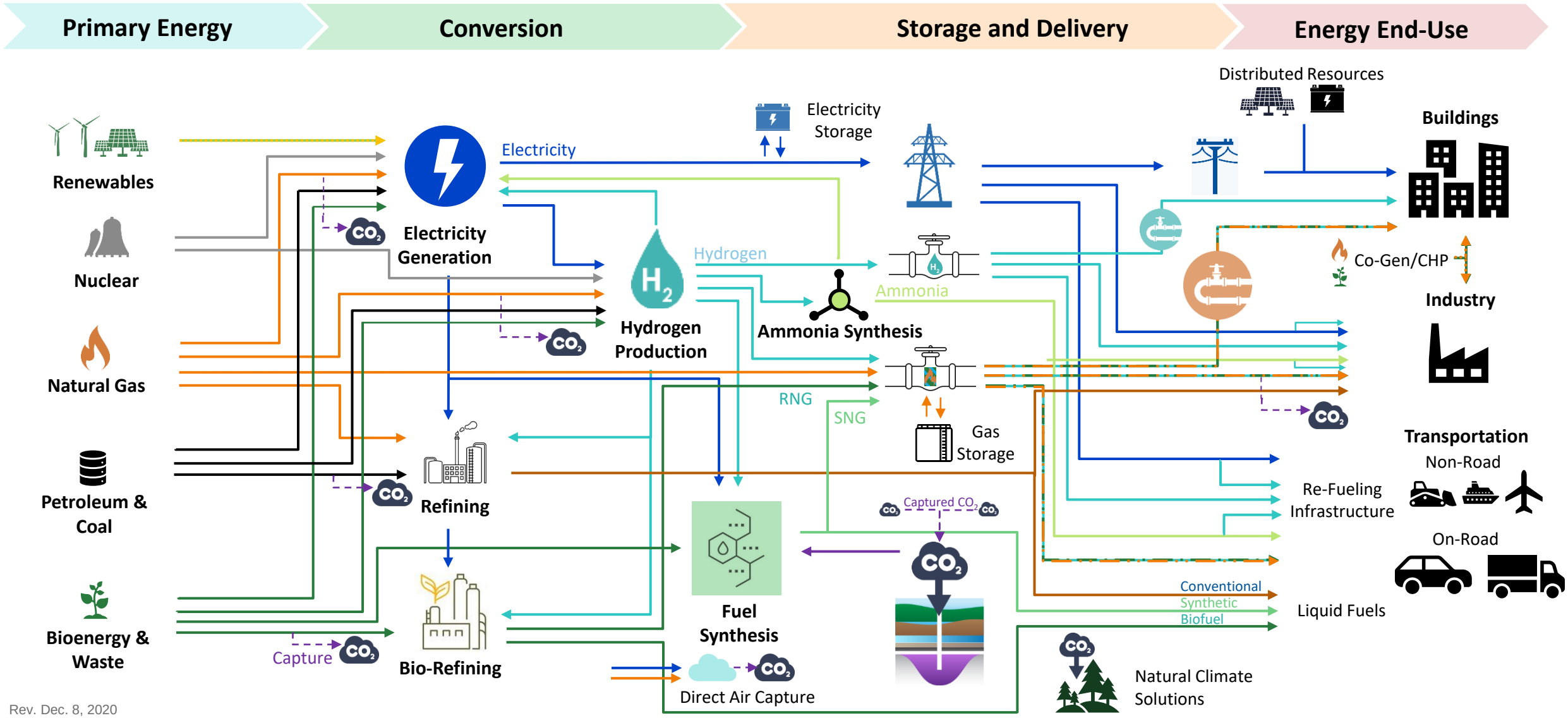
MÆRSK — carbon neutral by 2050

VALE — carbon neutral by 2050

HEIDELBERGCEMENT — carbon neutral concrete by '2050 at the latest'

*Visual Representation of potential future scenario

Low-Carbon Energy Ecosystem



Rev. Dec. 8, 2020

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

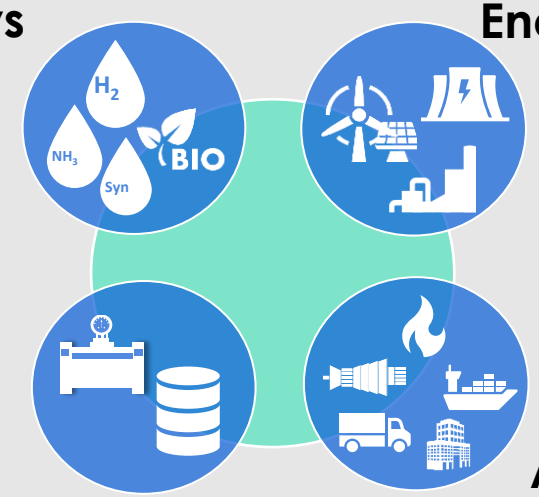
Affordable, reliable, and resilient integrated energy systems for the future

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

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
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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
MISource
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

2020 | 2030 | 2050+

LCRI LOW-CARBON RESOURCES INITIATIVE

Beyond 2030

How might value chains incorporate low-carbon energy carriers?

LCRI Focus:

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

Beyond 2030 - Hydrogen/Clean Electricity Production

LCRI LOW-CARBON RESOURCES INITIATIVE

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

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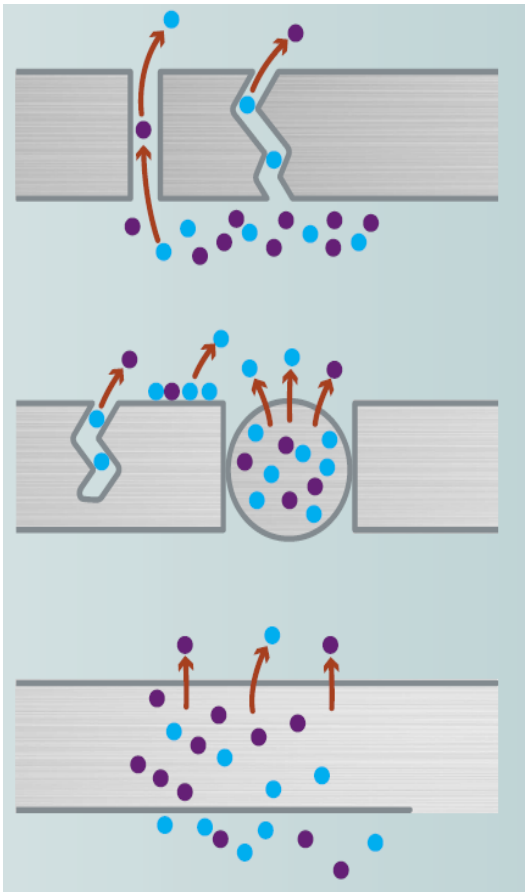
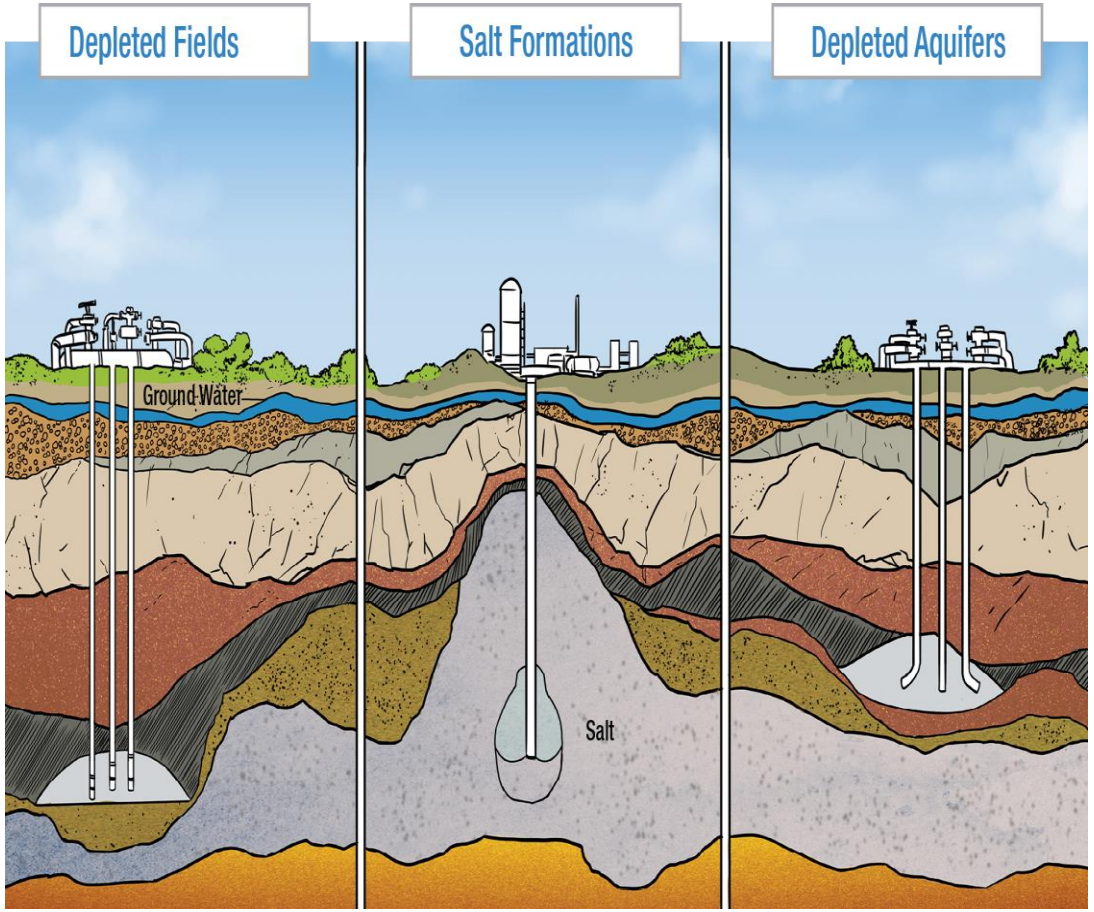
Impacts on Pipeline Applications

Metering Calibration

Leakage & Monitoring

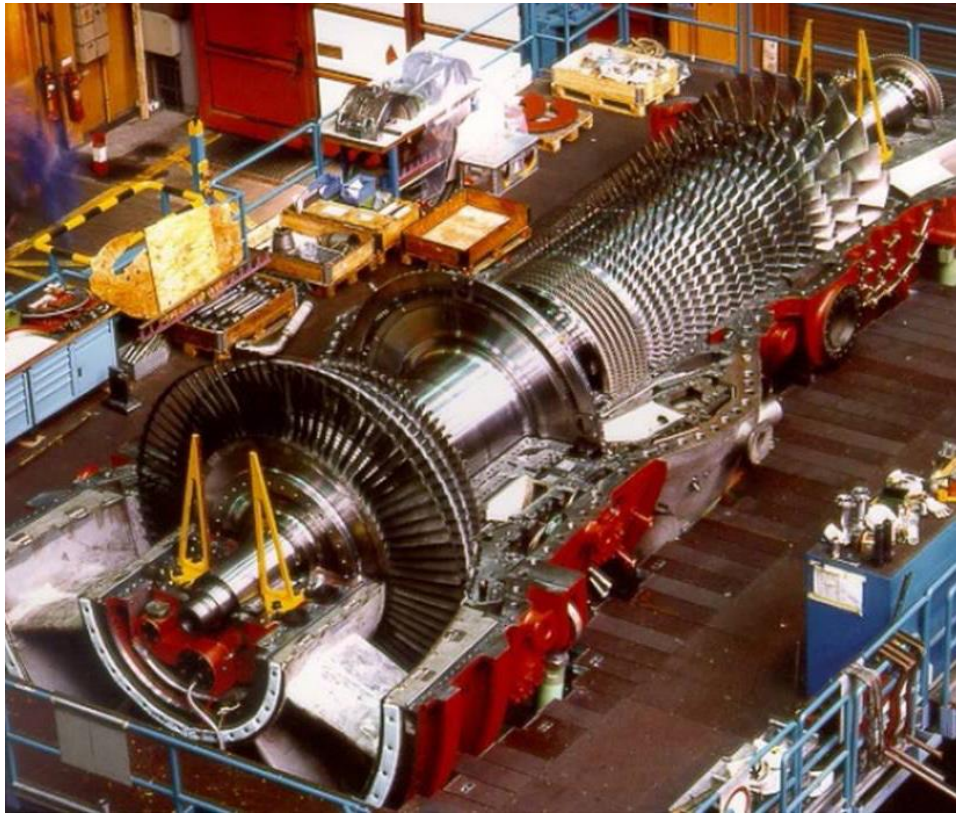


Compression & Underground Storage



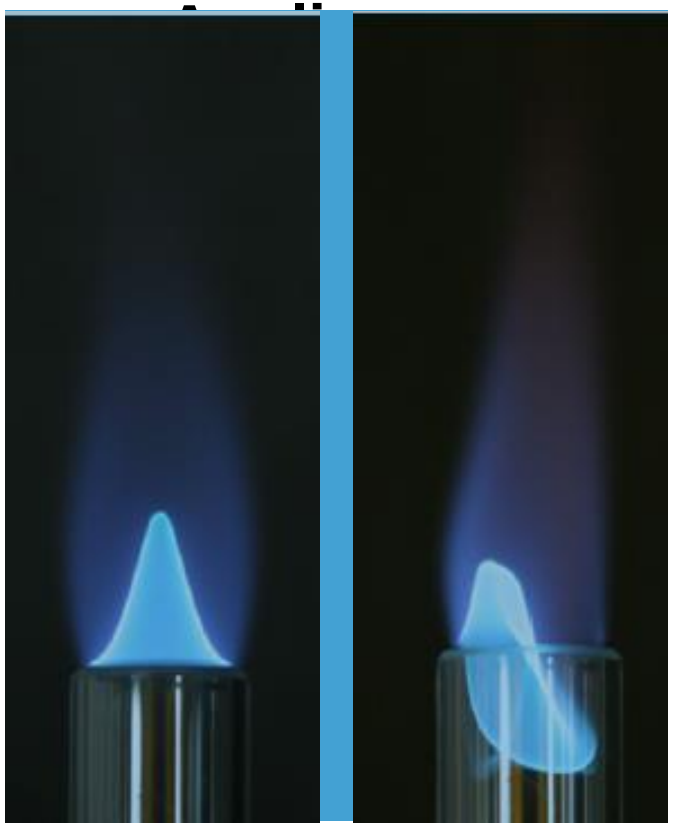
Impacts on End Use Applications

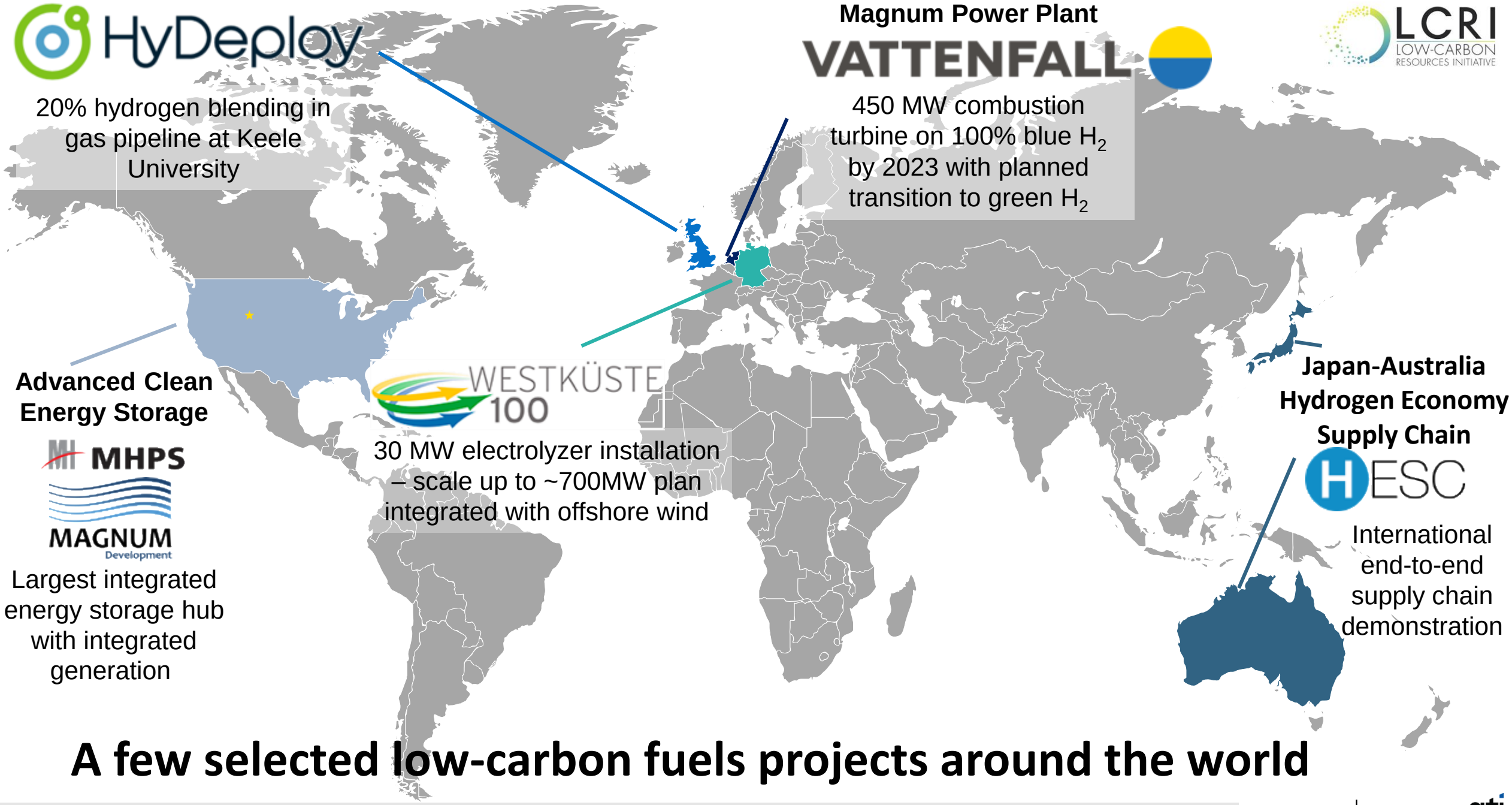
Industrial Scale Gas Turbines



Natural Gas Vehicles/ HD Trucks

Residential / Commercial



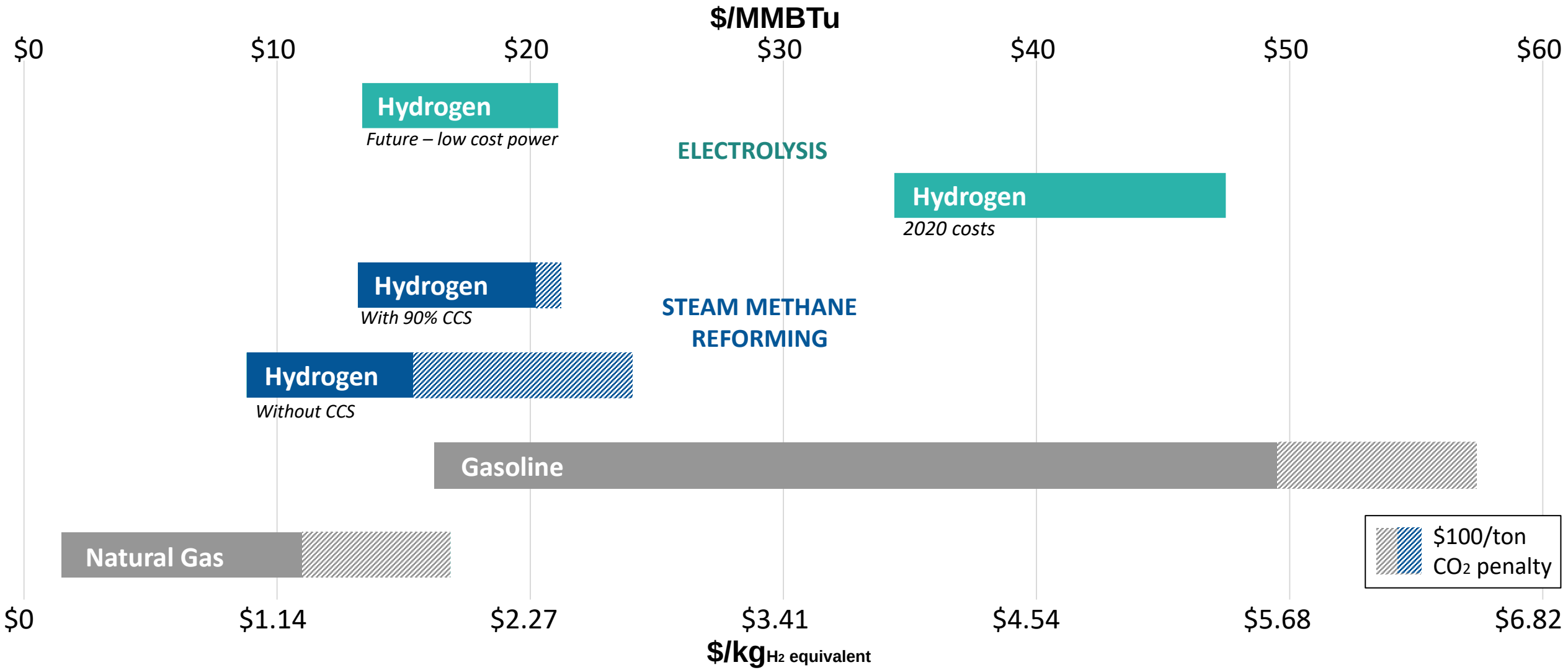


A few selected low-carbon fuels projects around the world

Example Technology Cost Insight

Energy Cost (USD/MMBTU and USD/kg$_{H_2eq.}$)

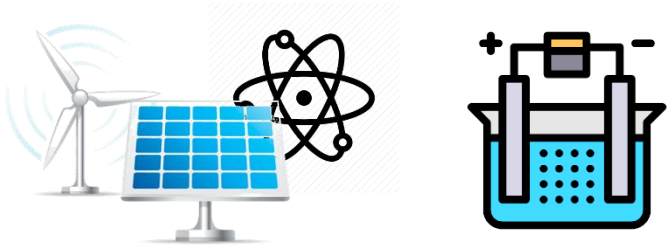
Initial calculations. For discussion purposes only.



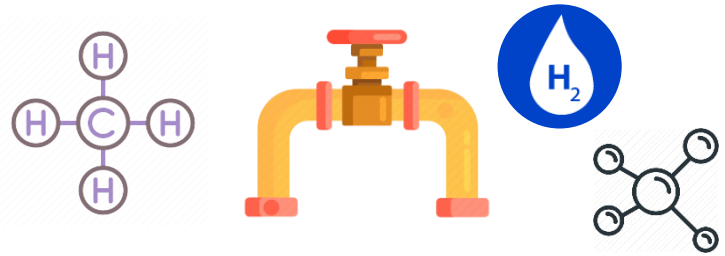
Source: EPRI analysis, based on data from: IEA, "The Future of Hydrogen" (2019); EPRI, "Prospects for Large-Scale Production of Hydrogen by Water Electrolysis" (2019); commodity price data.

Potential Pilot & Demonstration Projects

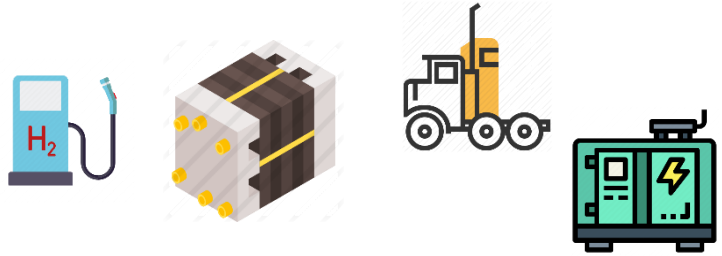
"Green" Hydrogen Production



Natural Gas Pipeline Integration/Conversion

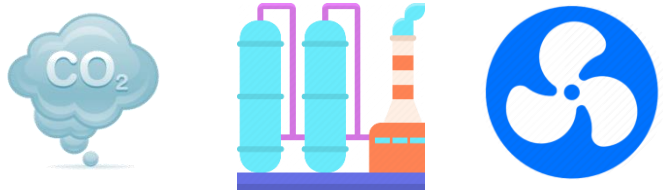


Transportation and Stationary Fuels Use



Power Generation and Industrial Fuels Use

Power Generation and Industrial Carbon Capture



Pilot & demonstration project opportunities will be determined by research area

Reimagining the Future Energy System

Decarbonization

~10-15 years

Accelerate economy-wide, low-carbon solutions

- Electric sector decarbonization
- Transmission and grid flexibility: storage, demand, EVs
- Efficient electrification

~15-30 years

Achieve a net-zero clean energy system

- Ubiquitous clean electricity: renewables, advanced nuclear, CCUS
- Negative-emission technologies
- Low-carbon resources: hydrogen and related, low-carbon fuels, biofuels, and biogas

Transformation

Drive affordability of a clean and resilient energy system through digital transformation

- Power system modernization: pervasive sensors, monitoring, advanced analytics using AI
- Upgraded and expanded communications infrastructure and control systems

Resiliency

~10-15 years

Mitigate climate impacts and cyber/physical risks

- System and asset hardening
- Improved response
- Faster recovery
- Cybersecurity

~15-30 years

Future proof energy system design basis

- Resilient power system design
- Advanced asset design and strategic undergrounding
- Smart integration of energy carriers

Making Energy More

Clean | **Affordable** | **Reliable**

Learn More About LCRI

Technical Areas

Integrated Energy Systems Analysis
Renewable Fuels
Hydrocarbon-Based Processes
Electrolytic Processes
Storage, Delivery, & Transport
End Use Applications
Power Generation
Safety
Environmental Aspects

Quick Links & Information

LCRI General Info

- LCRI 1 Pager
- LCRI Scope
- LCRI FAQ

LCRI Introductory Videos

- LCRI Advisory Structure
- LCRI Roadmap Approach
- LCRI Technology Pipeline
- LCRI Roadmap Reviews
- Colors of Hydrogen
- Who is EPRI – Who is GTI

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Public Webpage

LCRI References

LCRI Launch Document

Low-Carbon Fuels White Paper