Low Carbon Resources for Deep Decarbonization

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EPRI International

ENERMADRID
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Goal

Project 2X to 2050

Provide EPRI's vision on a deep decarbonization roadmap to 2050, taking US as an example

Born in a Blackout

Founded in 1972 as an independent, nonprofit center for public interest energy and environmental research

New York City, The Great Northeast Blackout, 1965

EPRI: Leading Collaborative Energy R&D Around the World

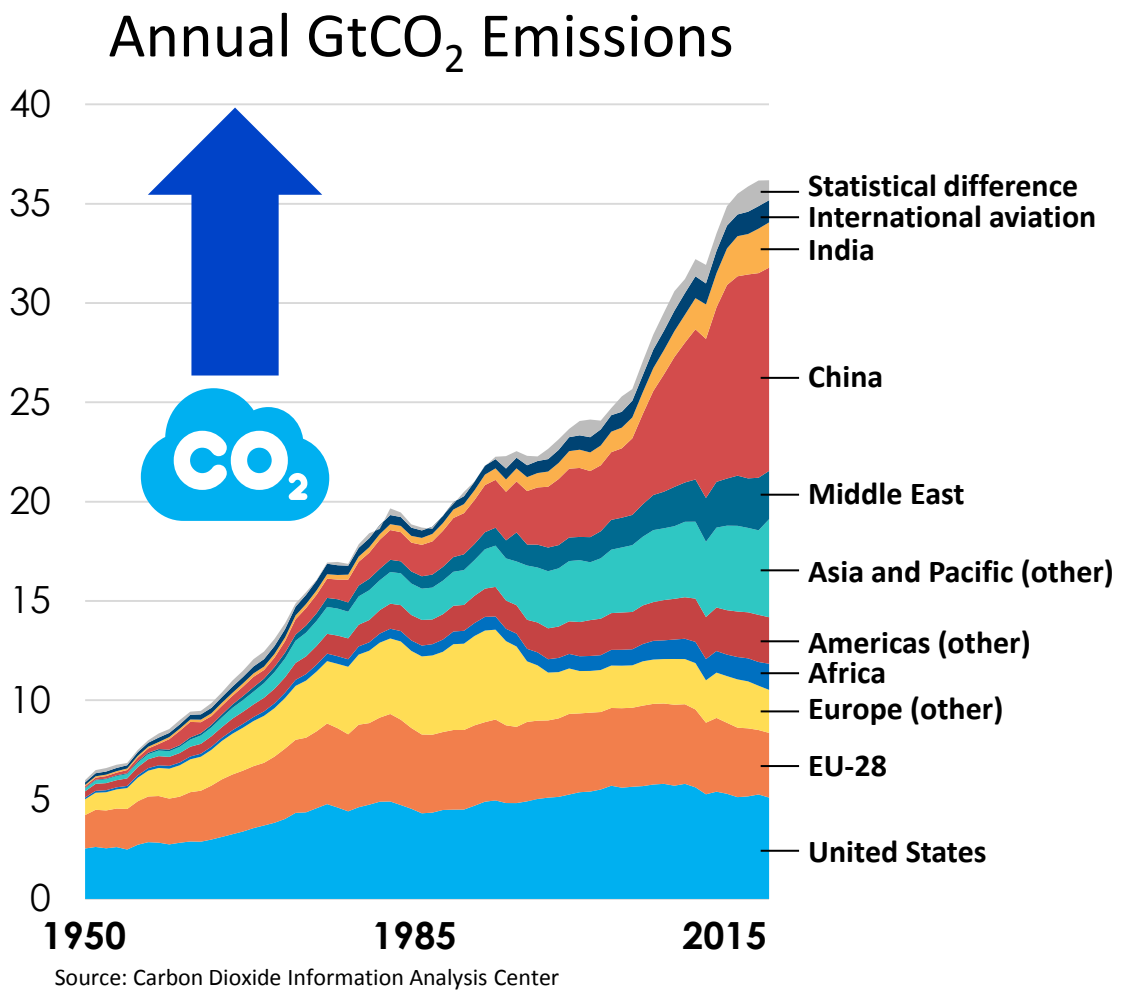
EPRI advances energy technologies and informs decision-making through ~$420M in collaborative annual research involving nearly 400 entities in ~40 countries - spanning the generation, delivery, and use of electricity.

Our Global Challenge

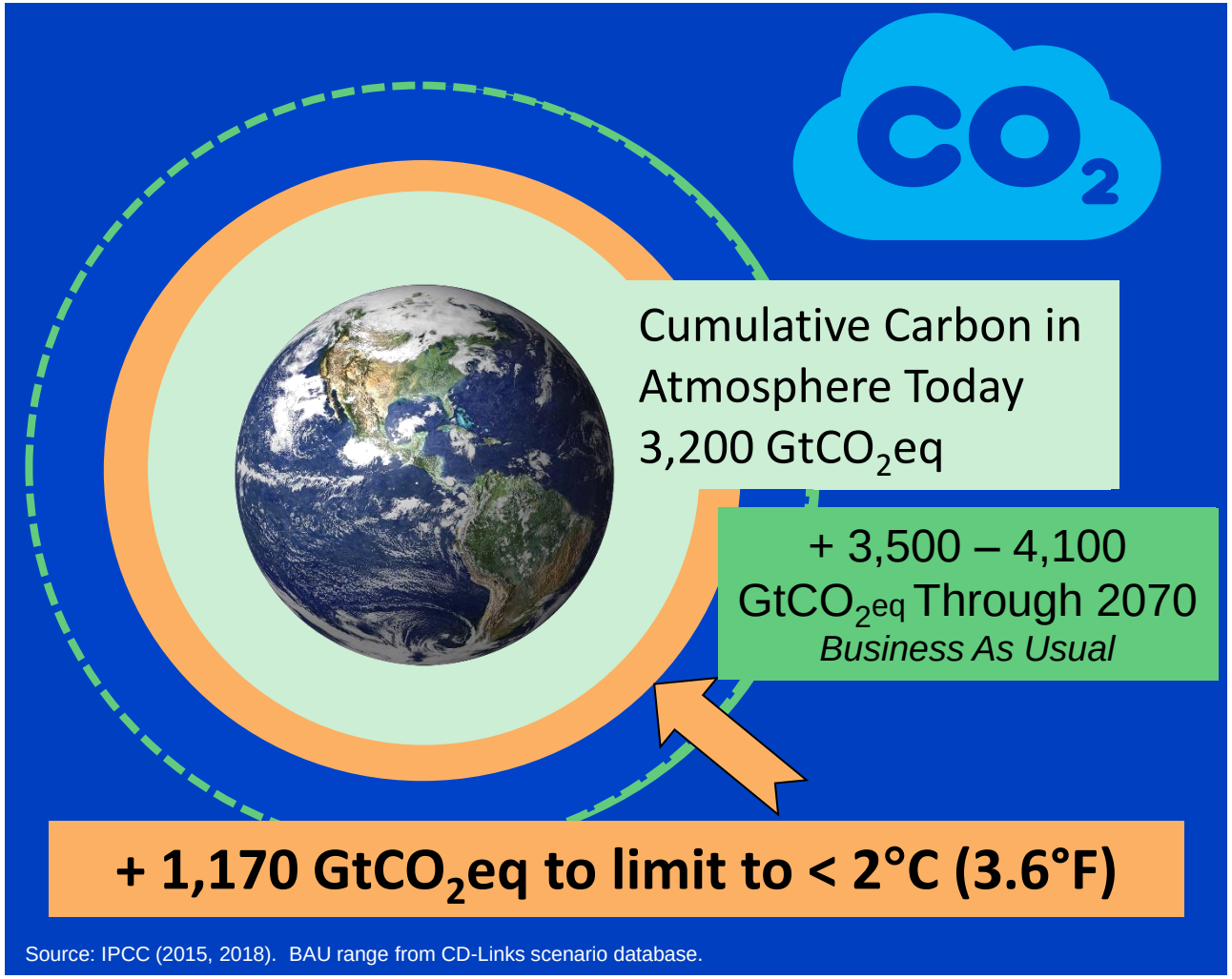
- **Affordable**
- **Reliable**
- **Safe, and**
- **Clean Energy**

While Also Improving the Quality of Life for Everyone

Much Less Carbon



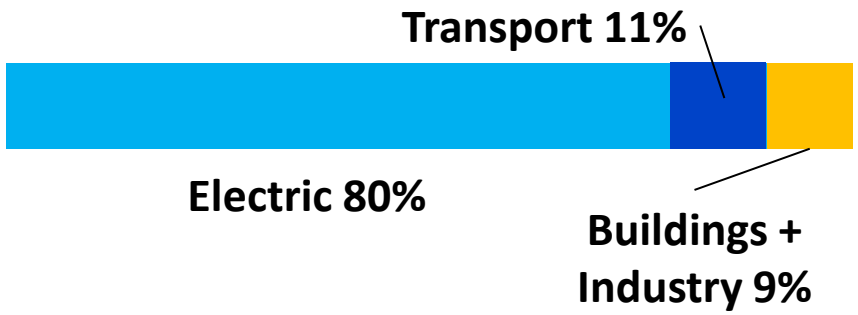
Source: Carbon Dioxide Information Analysis Center



Source: IPCC (2015, 2018). BAU range from CD-Links scenario database.

While Global CO_2 Emissions Rose Since 2005,

36 Nations Have Reduced Emissions



The US accounted for 44% of Global CO_2 Reductions.

The Electric Sector accounted for 80% of US CO_2 Reductions

Carbon Commitments Across the Economy

QANTAS

net-zero emissions by 2050

MÆRSK

carbon neutral by 2050

VALE

carbon neutral by 2050

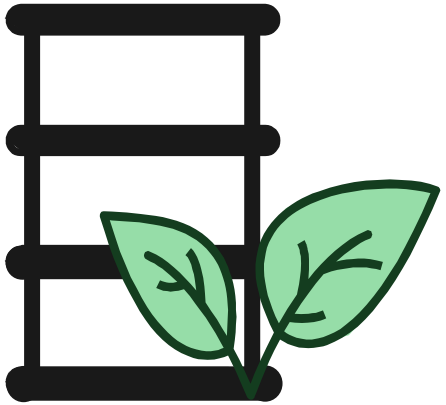
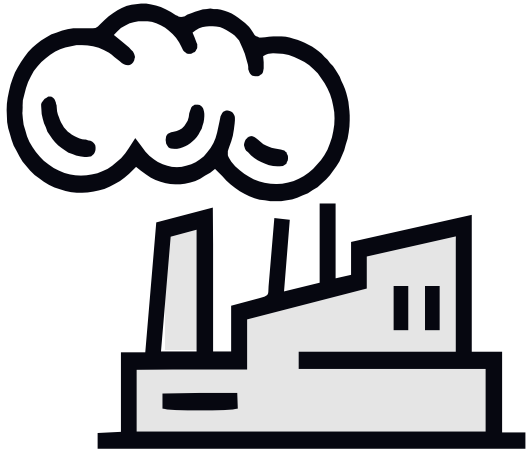
thyssenkrupp

climate neutral by 2050

HEIDELBERGCEMENT

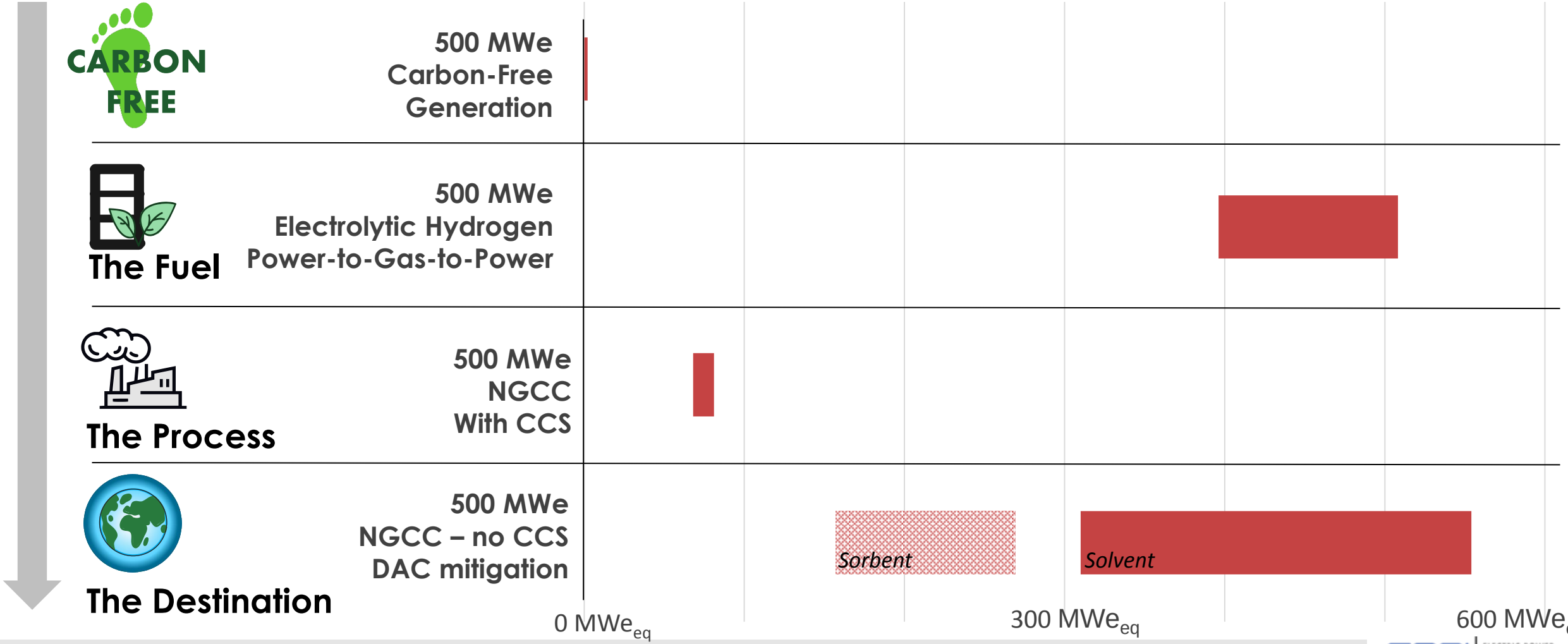
carbon neutral concrete by '2050 at the latest'

Pathways to CO_2 Mitigation

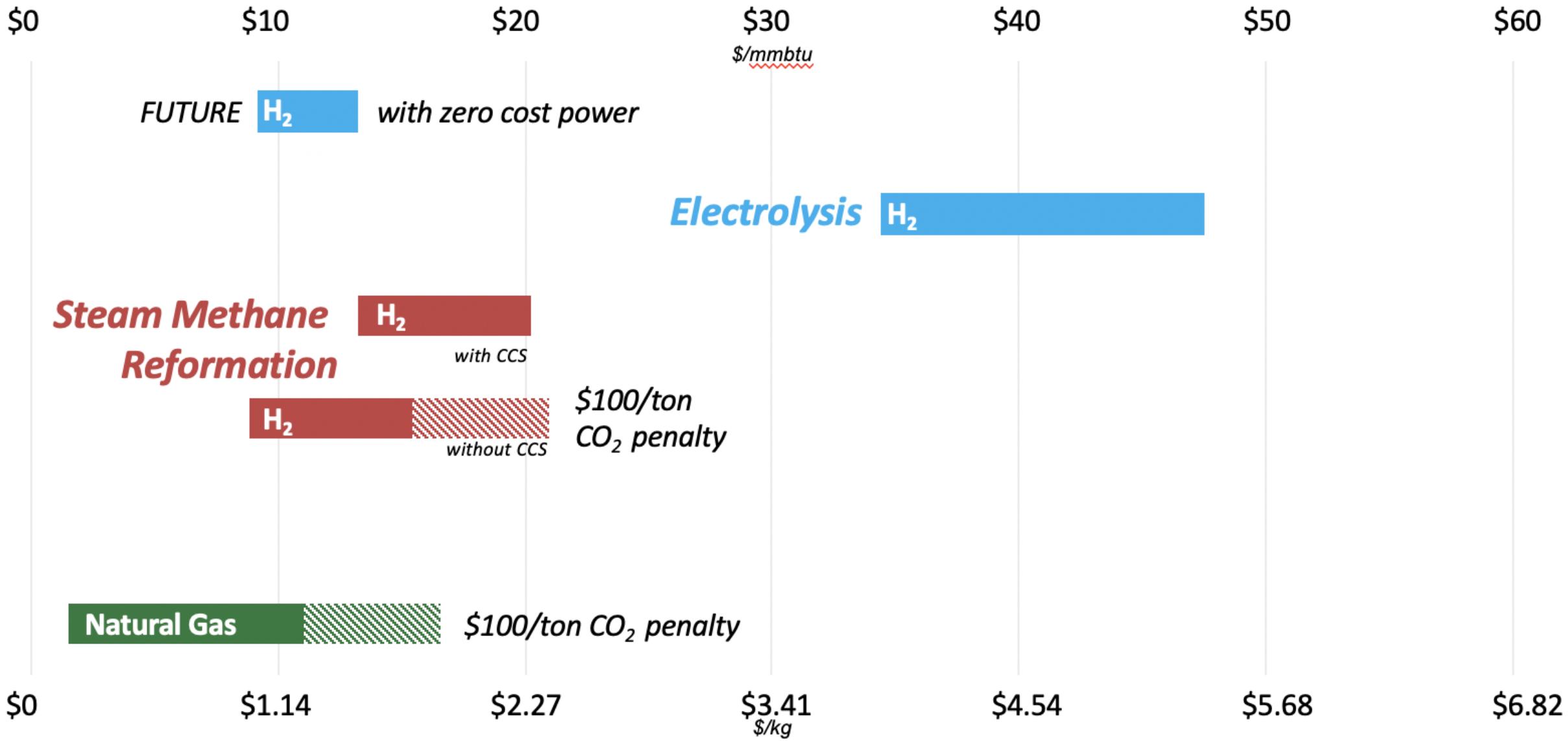
The Source	The Fuel	The Process	The Destination
			
Displacement	**Low Carbon Fuel**	**CO_2 Capture**	**Carbon Dioxide Removal**
Nuclear	Hydrogen	Pre-combustion	Direct Air Capture
Renewable	Ammonia	Post-combustion	Bio-energy with CCS
Storage	Biofuel	Oxy-combustion	Land Use and Mineralization

Pathways of Carbon-Free 500 MW

How much additional energy will it take to decarbonize 500 MWe?



What is the cost?



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.

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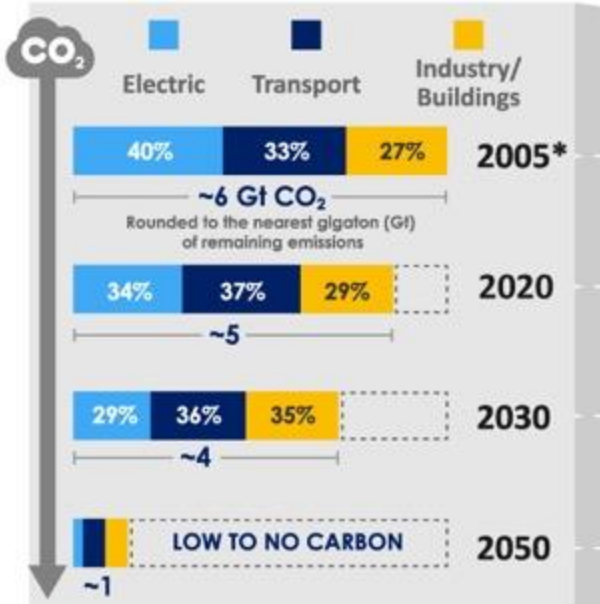
PROJECT 2X TO 2050

Accelerating Carbon Reduction Across the Economy

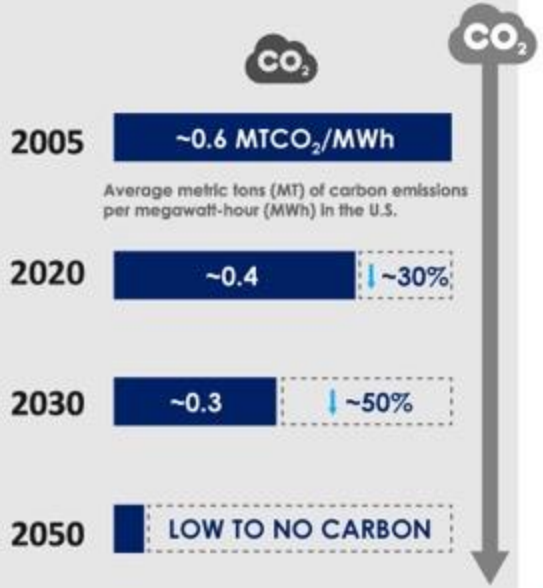
U.S. Energy-Related CO_2 Emissions



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

The Carbon Reduction Technology Timeline

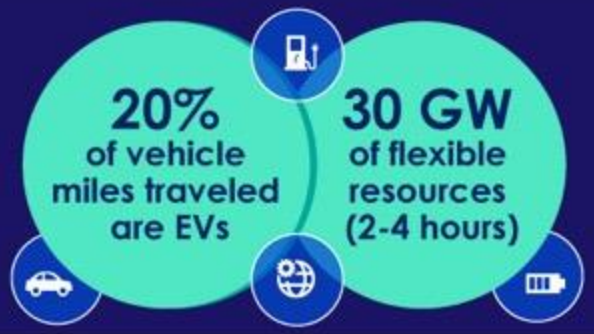
Cleaner Electricity Generation



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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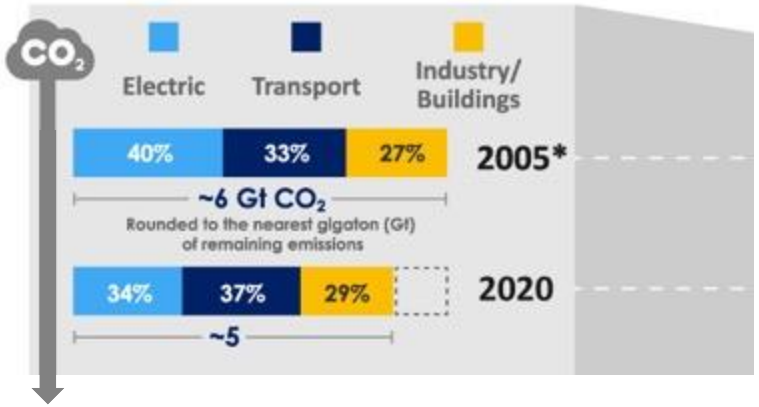
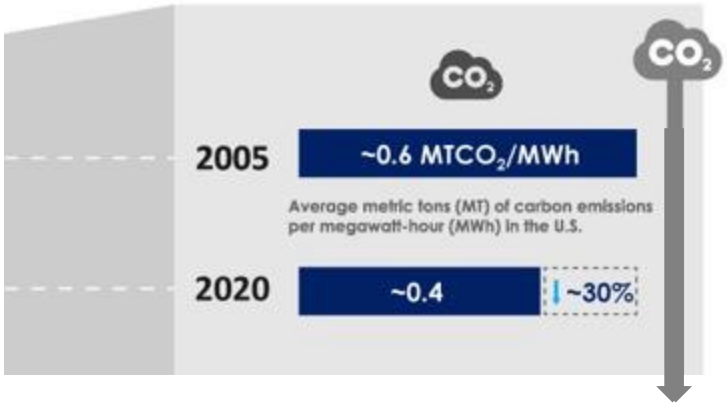
PROJECT 2X TO 2050

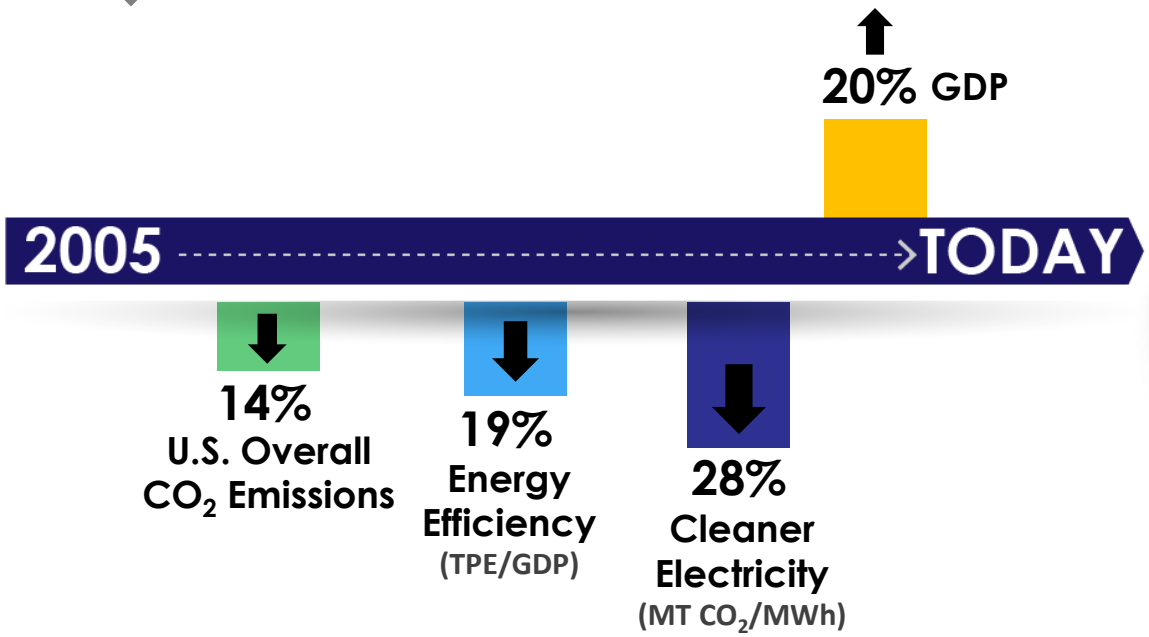
Accelerating Carbon Reduction Across the Economy

U.S. Energy-Related CO_2 Emissions

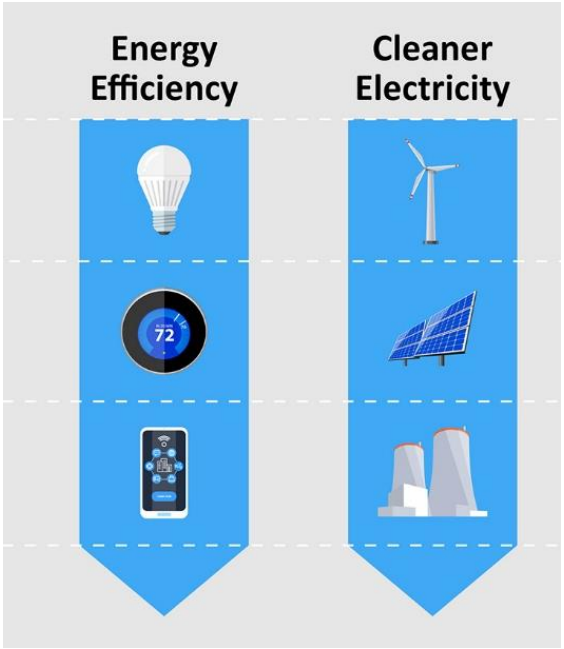


Cleaner Electricity Generation





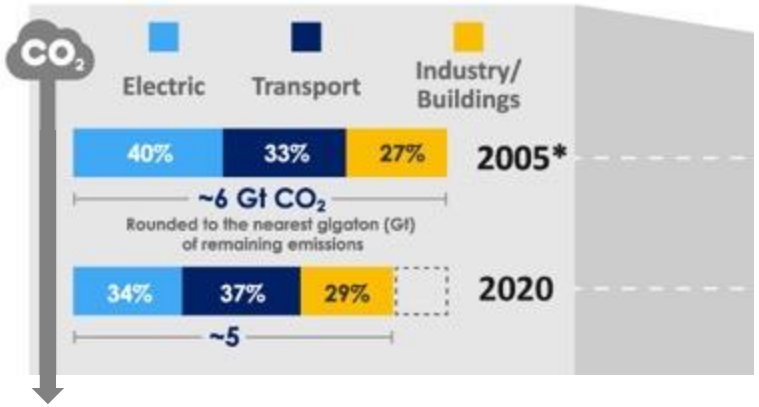
Essentially no increase in real electric price



PROJECT 2X TO 2050

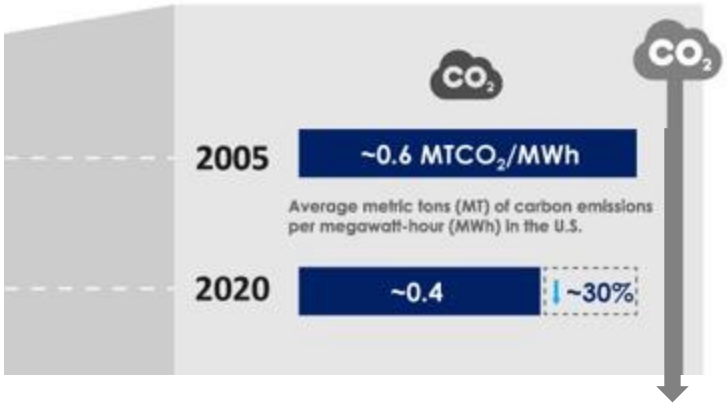
Accelerating Carbon Reduction Across the Economy

U.S. Energy-Related CO_2 Emissions



How will we achieve 2X in 2030?

Cleaner Electricity Generation



2005 → TODAY

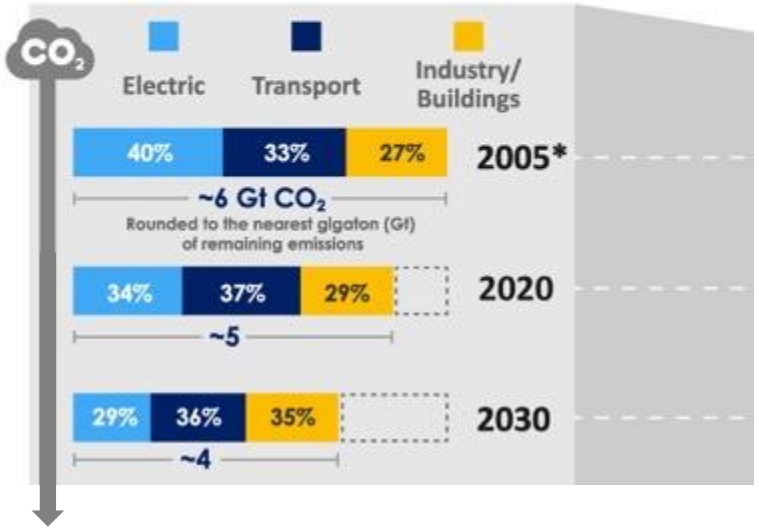
- **14%** U.S. Overall CO_2 Emissions
- **19%** Energy Efficiency (TPE/GDP)
- **28%** Cleaner Electricity (MT CO_2/MWh)

2005 → 2030 → 20

PROJECT 2X TO 2050

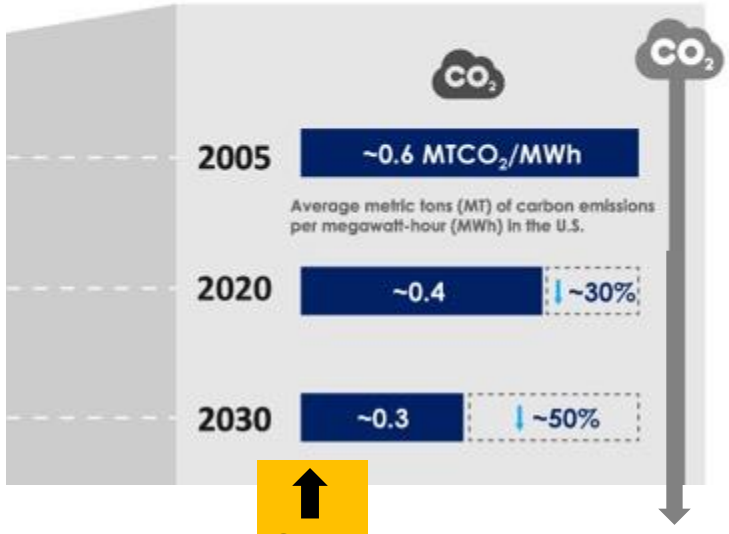
Accelerating Carbon Reduction Across the Economy

U.S. Energy-Related CO_2 Emissions



Efficient Electrification

Cleaner Electricity Generation



GDP 59%

U.S. Overall CO_2 Emissions 29%

Energy Efficiency (TPE/GDP) 43%

Cleaner Electricity 51% ($MT CO_2/MWh$)

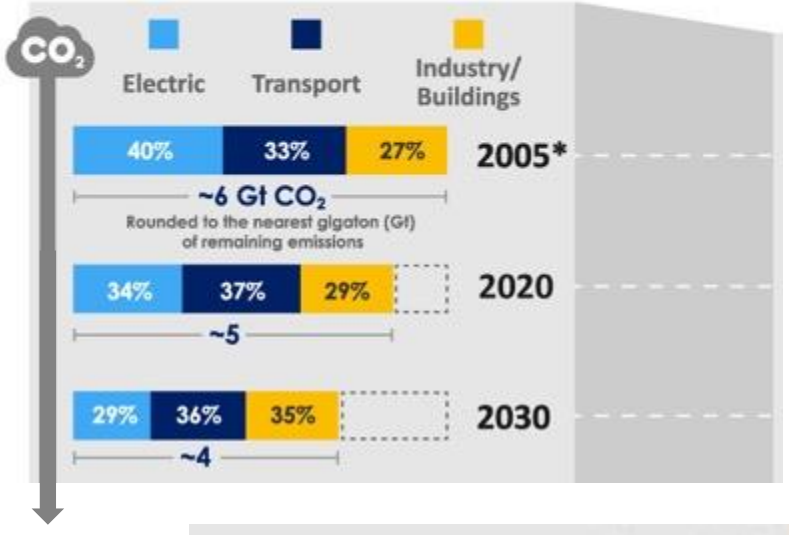
23% Cleaner Transport ($MT CO_2$)

2005 → 2030 → 20

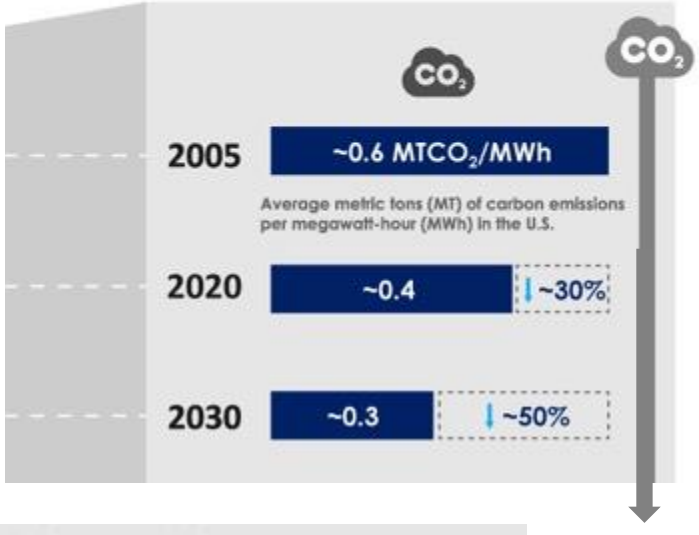
PROJECT 2X TO 2050

Accelerating Carbon Reduction Across the Economy

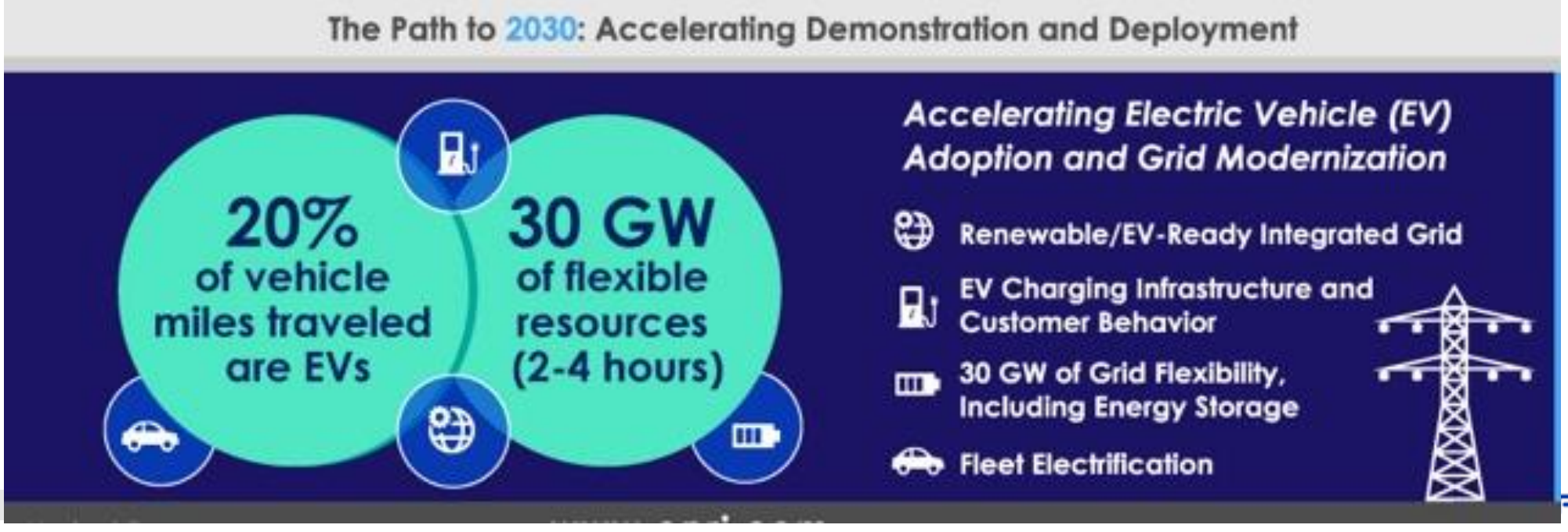
U.S. Energy-Related CO_2 Emissions



Cleaner Electricity Generation

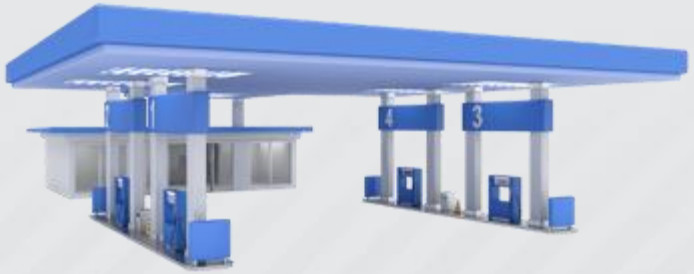


The Path to 2030: Accelerating Demonstration and Deployment



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

Electrification of Vehicles Reduces Emission and Energy Cost

Household with 2 Gasoline Vehicles

Expenses:

Gasoline | Electricity | Natural Gas | Other

Average Energy Bill:	$4,528/year
Average CO_2 Emissions:	18 tCO_2/year

Household with 1 Gasoline Vehicle and 1 Electric Vehicle

Average Energy Bill:	Average CO_2 Emissions:
$4,050/year	15 tCO_2/year
↓ 11%	↓ 17%

Average Energy Bill:	Average CO_2 Emissions:
$3,571/year	12 tCO_2/year
↓ 21%	↓ 34%

Household with 2 Electric Vehicles

Based on data from Energy Information Administration (EIA). The average U.S. household has 2.1 vehicles and 26,000 vehicle miles.

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PROJECT 2X TO 2050

Accelerating Carbon Reduction Across the Economy

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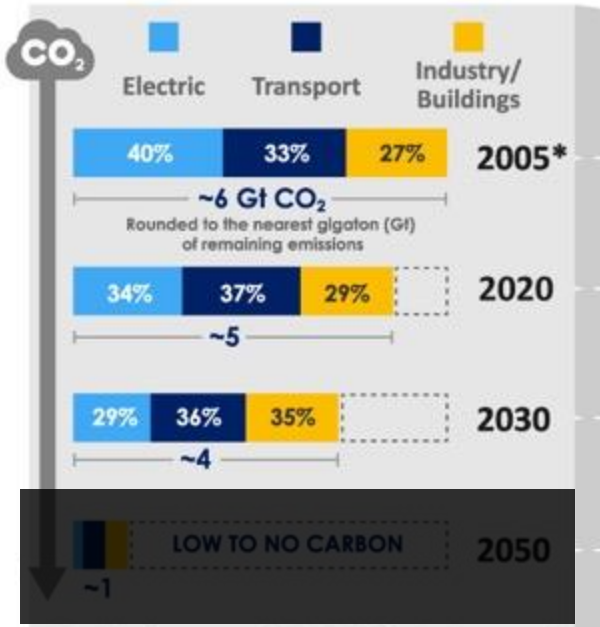

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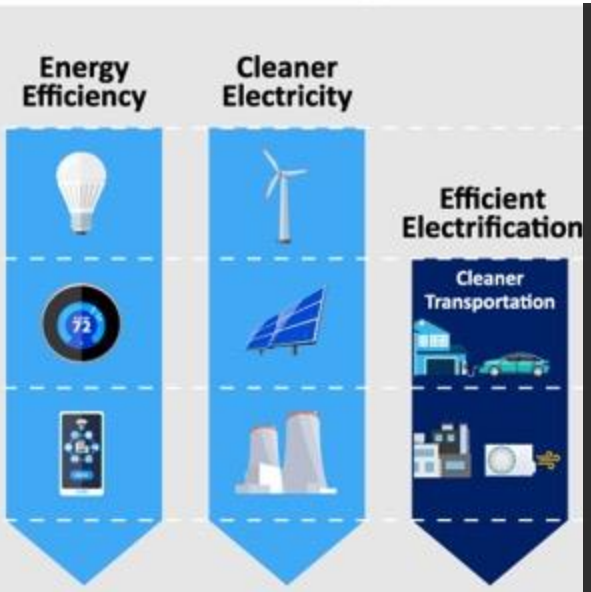

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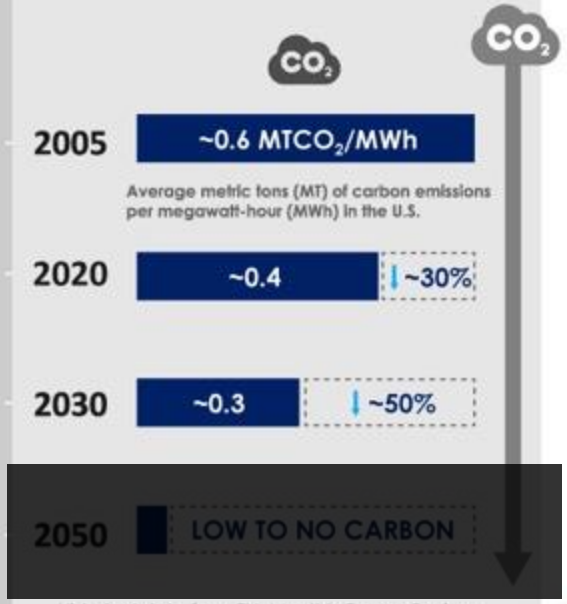
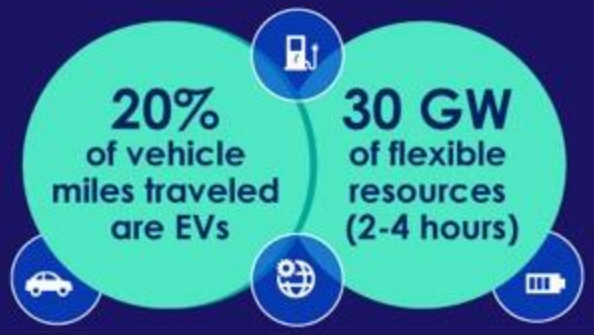


Historical data from EIA *Monthly Energy Review*, February 2019. 2030 projections from *US-REGEN 2X reference case*.

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

Low-Carbon Power Generation
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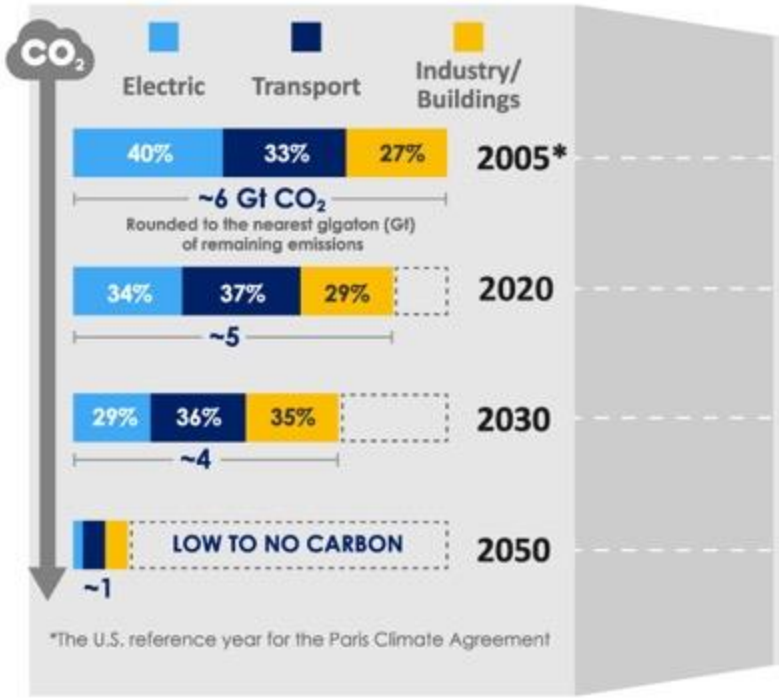

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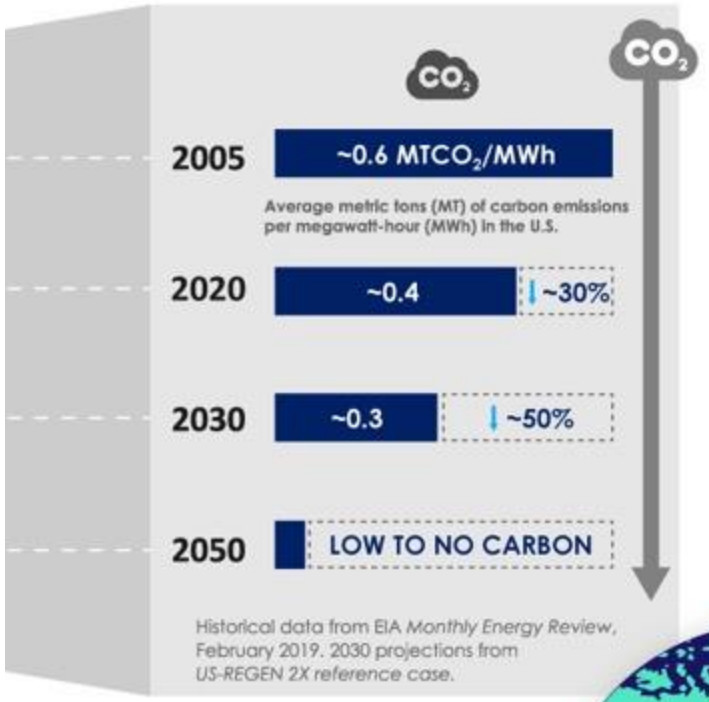
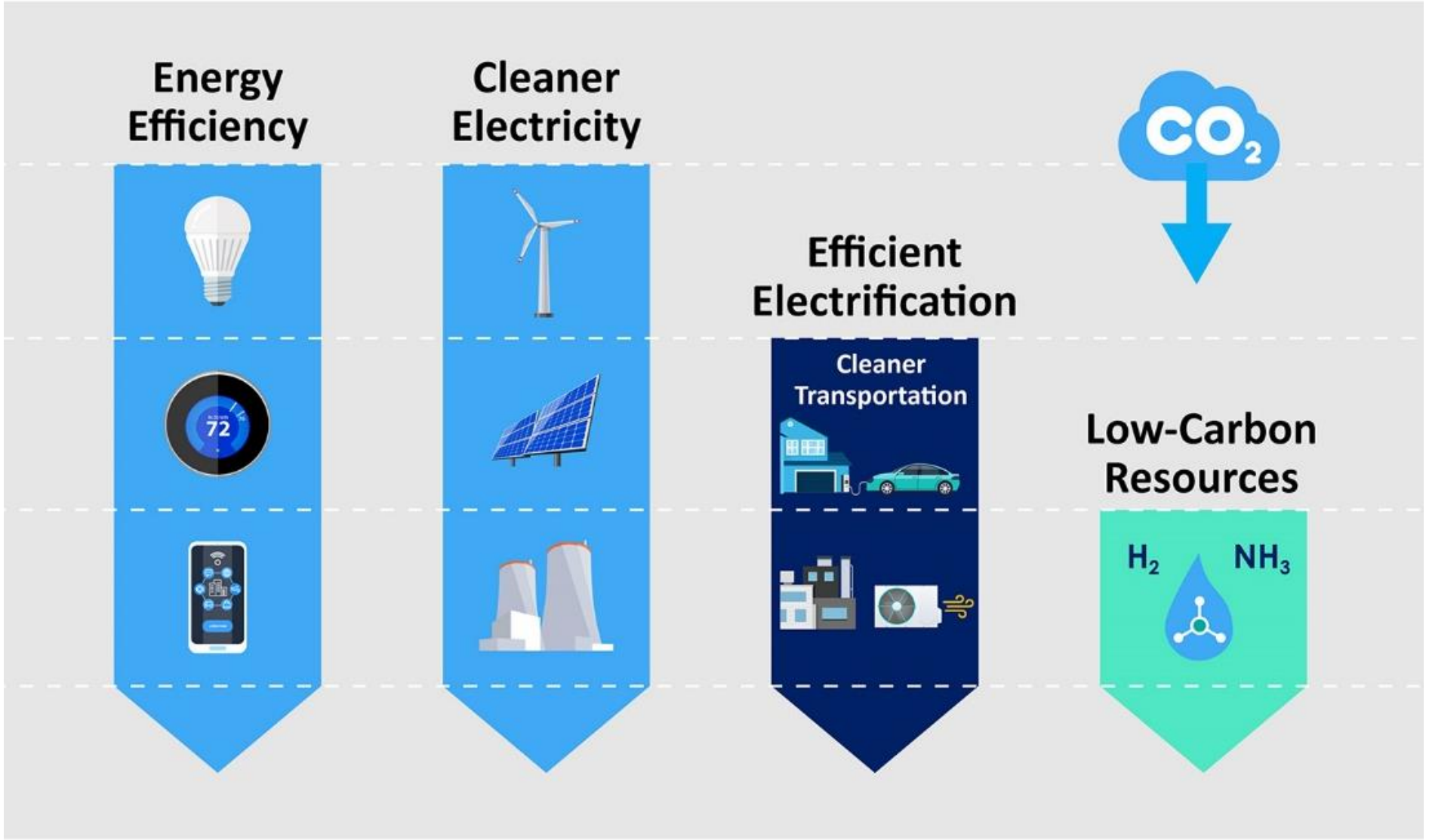
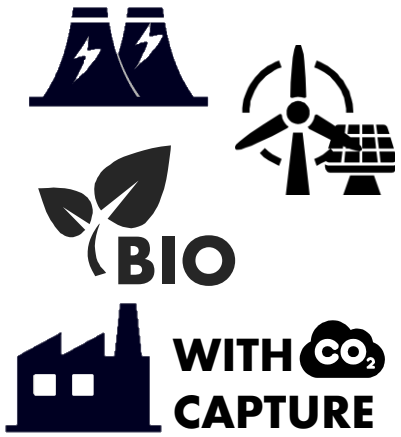


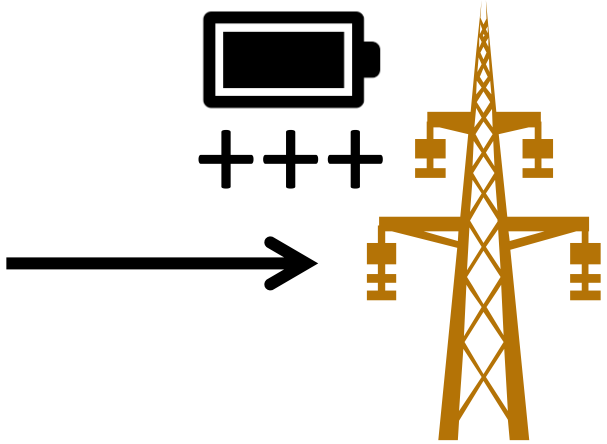
The tools that have enabled reductions through 2030 will not be enough to achieve deep decarbonization by 2050.

The Carbon Reduction Technology Timeline



Low-Carbon Generation



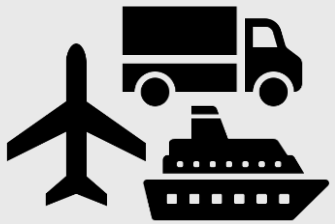


ELECTRIFICATION

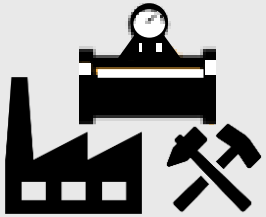
What does the next phase of decarbonization look like?

How will we continue to decarbonize our Generation Fleet?

How will we decarbonize 'hard to abate' places?

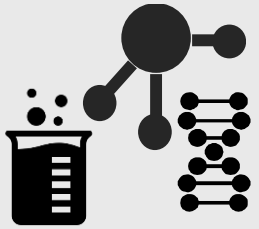


Shipping & Heavy-Duty Transportation

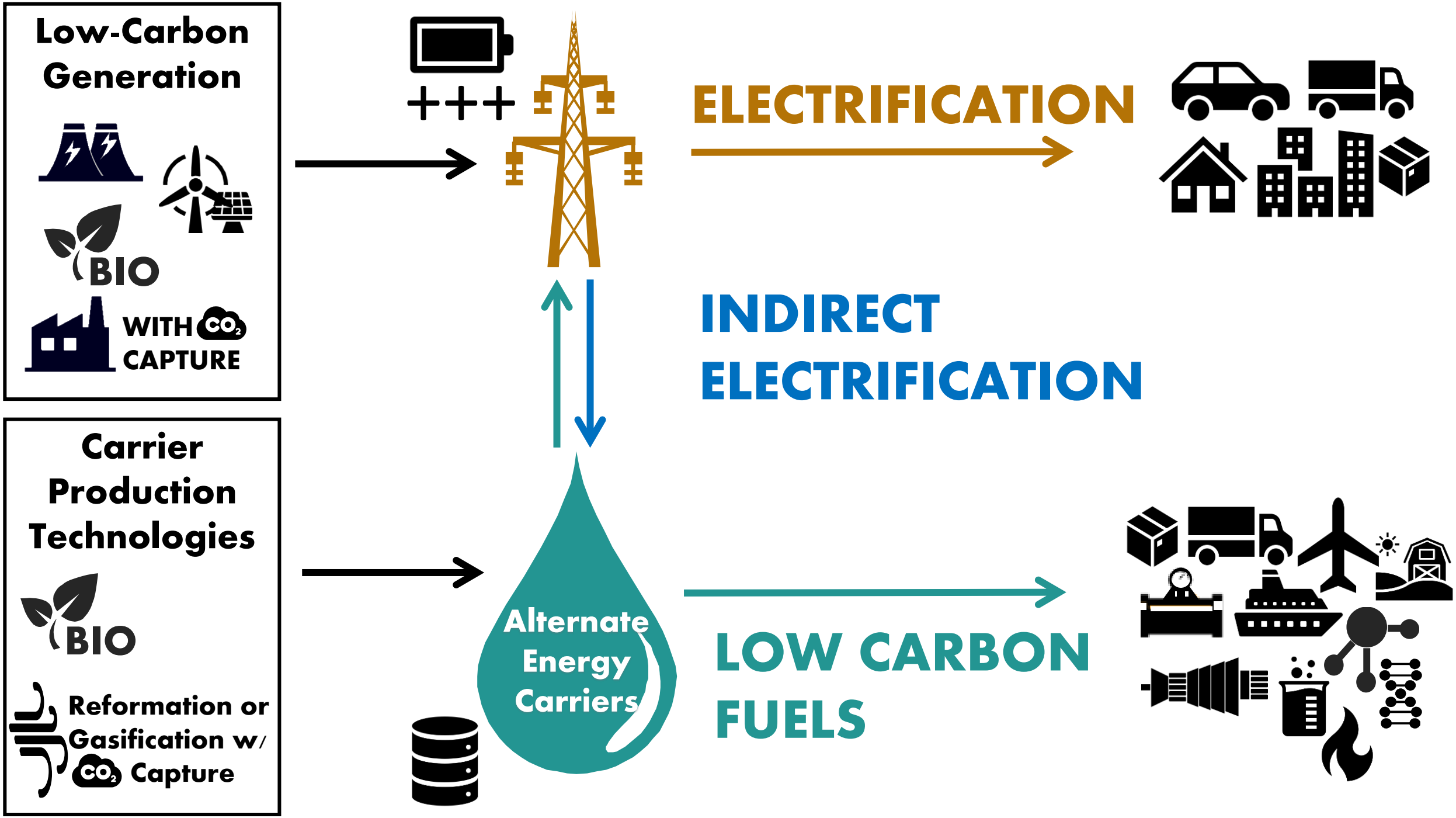


Oil & Gas Steel

High Grade Heat



Chemical Production


Low-Carbon Generation
BIO
WITH CO2 CAPTURE
ELECTRIFICATION
INDIRECT ELECTRIFICATION
Carrier Production Technologies
BIO
Reformation or Gasification w/ CO2 Capture
Alternate Energy Carriers
LOW CARBON FUELS

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PROJECT 2X TO 2050

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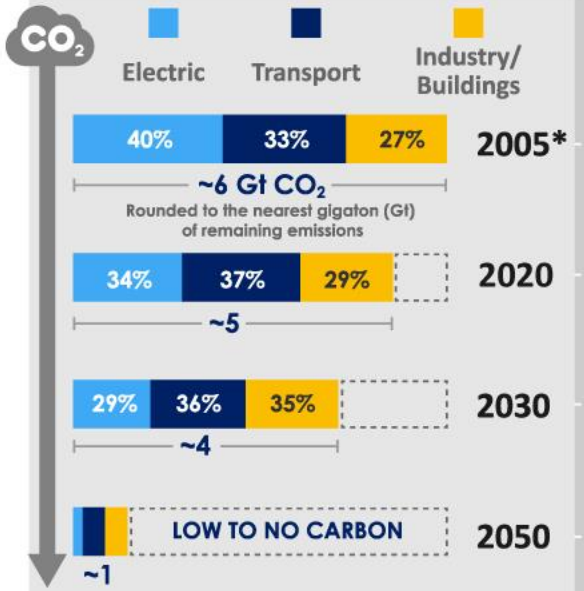
U.S. Energy-Related CO_2 Emissions



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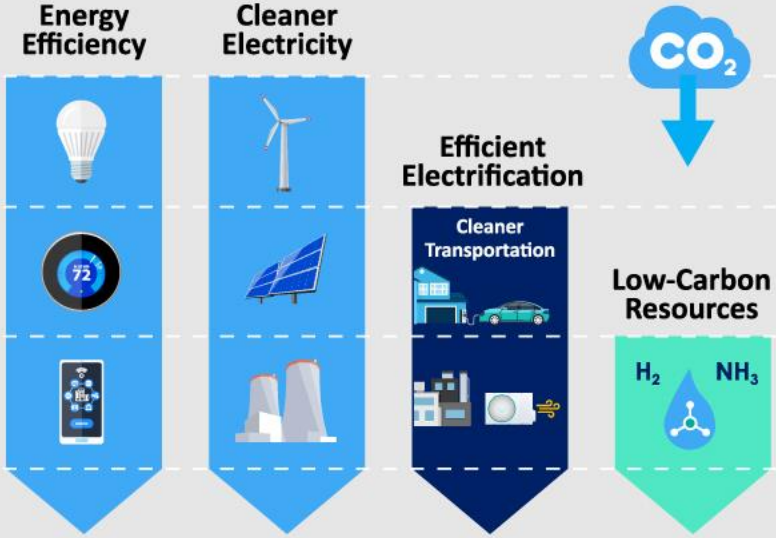

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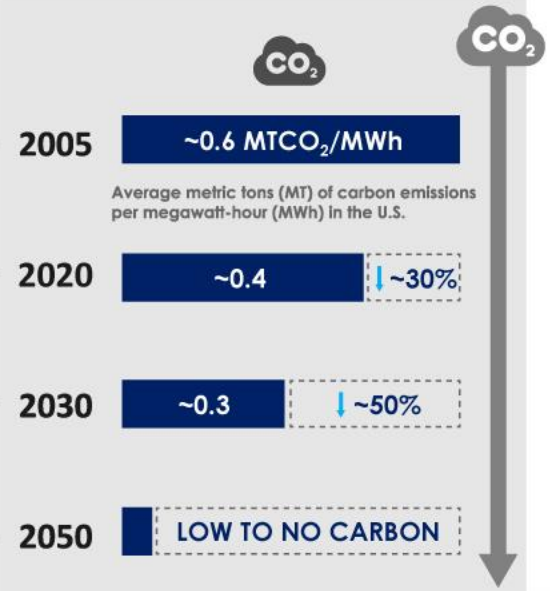

Historical data from EIA *Monthly Energy Review*, February 2019. 2030 projections from *US-REGEN 2X reference case.*

Next Steps: Expanding Low-Carbon R&D

The Path to 2030: Accelerating Demonstration and Deployment

20% of vehicle miles traveled are EVs

30 GW of flexible resources (2-4 hours)

Accelerating Electric Vehicle (EV) Adoption and Grid Modernization

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- Fleet Electrification

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

Hydrogen and related, low-carbon resources

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Low-Carbon Resources Initiative

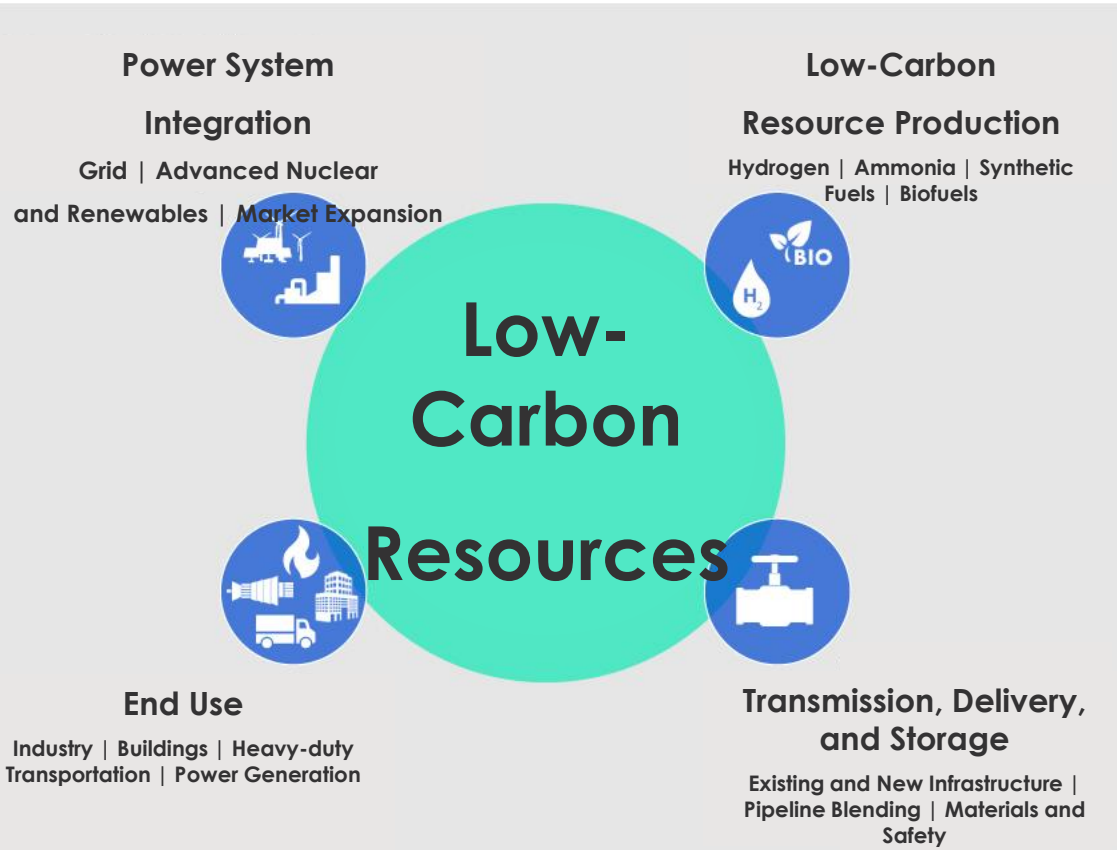
The **Low-Carbon Resources Initiative** (LCRI) is a five-year, focused R&D commitment to develop the pathways to advance low-carbon technologies for large-scale deployment. This initiative is jointly led by EPRI and GTI. The goal of the initiative is to enable a risk-informed understanding of options 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



VALUE

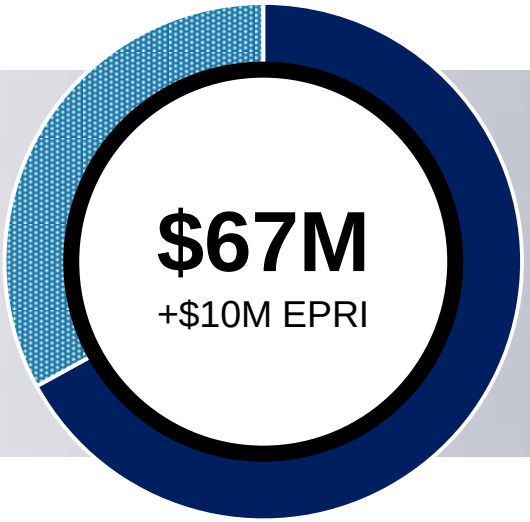
Individual commitment to environmental, social, and governance (ESG) efforts

Increase optionality of low-carbon solutions

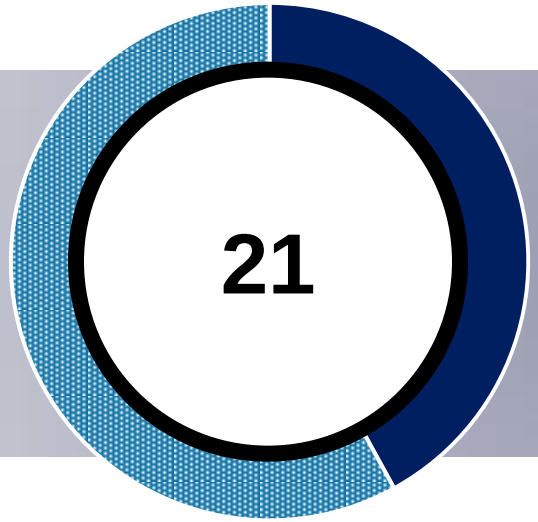
Leverage investments across relevant sectors

Enable resiliency and affordability of low-carbon energy system

Membership & Engagement



Funding
$100M



Members
50

Press Release

August 10th

Link to Release

Key Element to success

Worldwide Engagement and Insights

Track global demonstrations for experiential learning, best practices, and identification of R&D gaps

Development of test facilities, protocols, and demonstration projects where R&D gaps are identified

Leverage existing global facilities and collaborate with strategic labs and universities to enable lab-scale testing and development

LCRI Governance & Research Portfolio

LCRI ADVISORY STRUCTURE

LCRI Governance and Oversight

LCRI Member Executive Council

LCRI Technical Scope and Execution

LCRI Technical Advisory Group

Technical Subcommittees

- Electrolysis
- Hydrocarbons
- Renewable Fuels
- Storage & Delivery
- Power Generation
- Transportation, Industrial & Buildings
- Integrated Energy Analysis
- Safety and Environmental Aspects

STRATEGIC GUIDANCE

EPRI BOARD WORKING GROUP

gti BOARD OF DIRECTORS

TECHNICAL ADVICE

TECHNICAL COLLABORATOR NETWORK

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 Digital Library
- LCRI Technology Pipeline
- LCRI Roadmap Reviews
- Colors of Hydrogen
- Who is GTI

LCRI@epri.com

Email Us!

www.LowCarbonLCRI.com

Check it out!

LCRI Launch Document

LCRI Technical Workshop Series

10:30 am to 12:00 pm (ET)
Oct 22, *Pathways to Decarbonization*
Oct 29, *Valuing Low-Carbon Resources*
Nov 5, *Industrial Use of Low-Carbon Resources*

(Additional webinars are listed on our webpage)

Join Us!

Maria Martin
mmartin@epri.com
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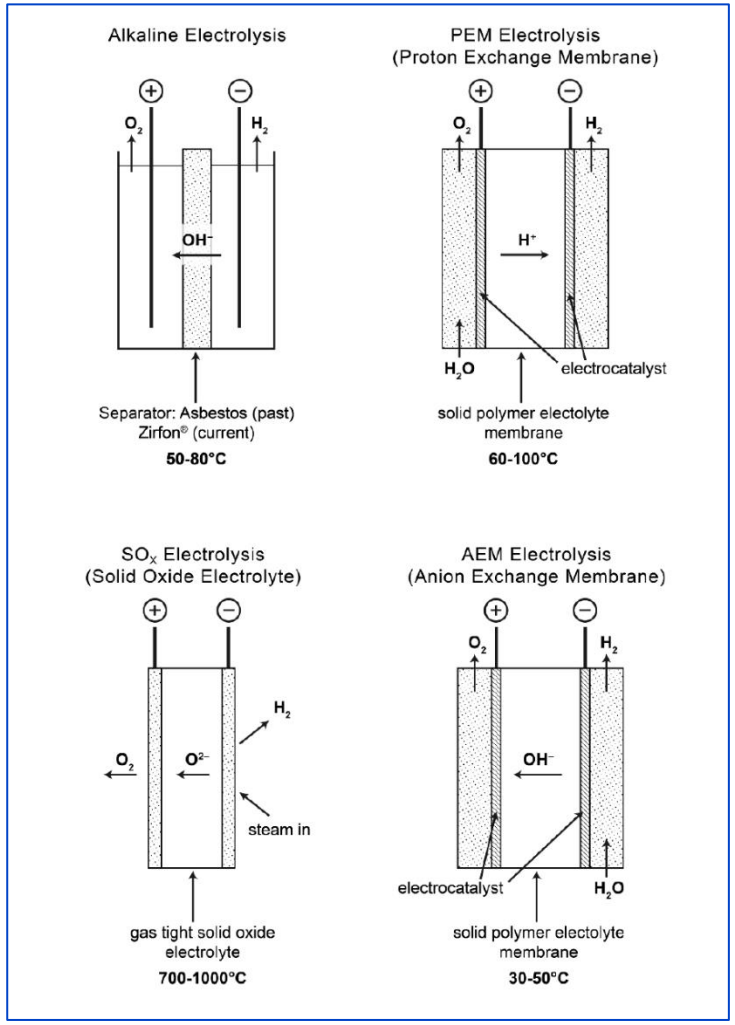
LCRI Research Areas

Electrolytic Processes

- **Objective:** Evaluate electrolysis technologies for hydrogen production that use clean energy resources
- **Current Approach:**
  - Technology and System Integration: Commercial technologies, integration, and performance
  - Advanced Technologies: Future designs and technologies to improve cost and reliability
  - Process Modeling & Analysis: Techno-economic and performance analysis for existing and future technologies
- **2020 Deliverables:**
  - Technology Insight Report on electrolyzer technologies
  - Feasibility framework case study examining electrolyzer integration for hydrogen production
  - Research plan and technology roadmap



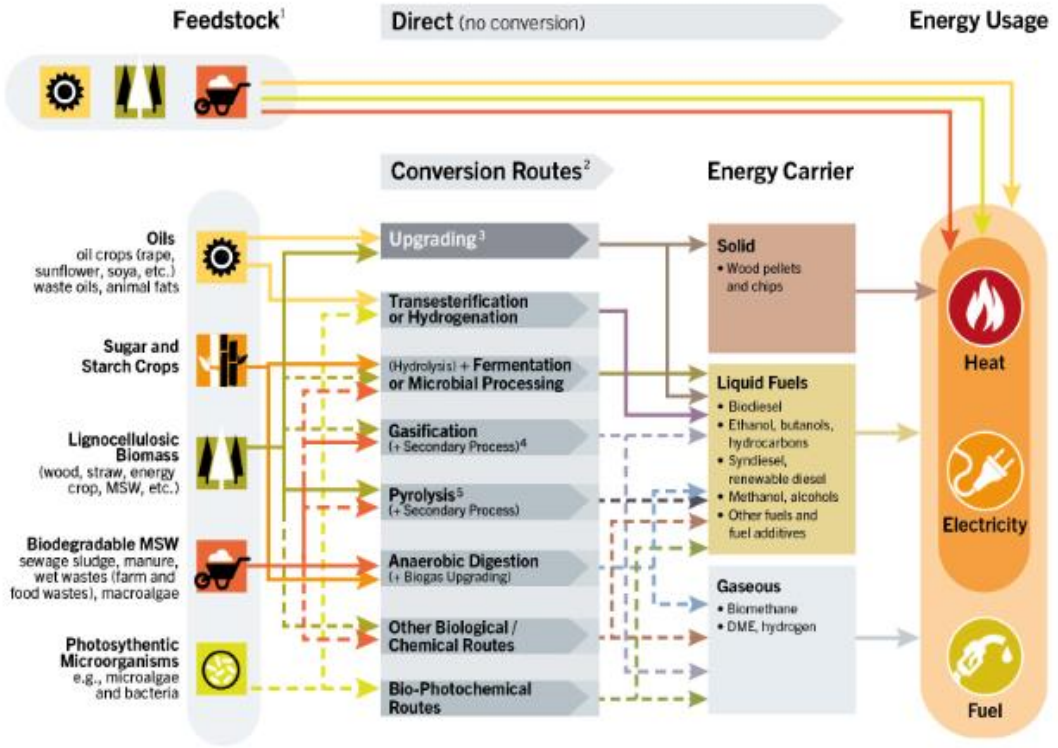
Renewable Fuels

Scope

- **Overall**
  - Production of alternative energy carriers from biomass thermochemical and biochemical processes (liquid, solid, gas) with a focus on Renewable Natural Gas and other Biofuels
- **Technical**
  - Biomass feedstock production and conversion
  - Renewable natural gas production
  - Biofuels production (e.g., ethanol, methanol, hydrocarbon drop in fuels) from feedstocks such as biomass, biogas, and bio-CO_2

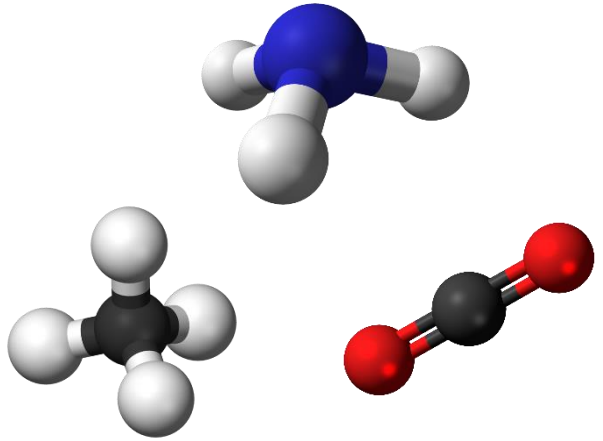
Many possible bioenergy pathways

(feedstocks, handling logistics, conversions, and end-uses)



Hydrocarbon-Based Processes

- **Objective:** Evaluate technologies for production of low-carbon energy carriers, processes for converting of hydrogen to other fuels, and carbon capture and storage for power generation and industrial applications
- **Current Approach:**
  - Hydrogen production from steam-methane reformation, gasification
  - Hydrogen production from methane cracking (i.e., splitting methane into hydrogen gas and solid carbon)
  - Hydrogen-intensive conversion processes such as Fischer Tropsch for liquid hydrocarbons, Haber Bosch for ammonia, and methanation for synthetic natural gas production
  - Carbon capture and storage
- **2020 Deliverables:**
  - Technology Insight Report on production technologies and CCS (including direct air capture)
  - Research plan and technology roadmap

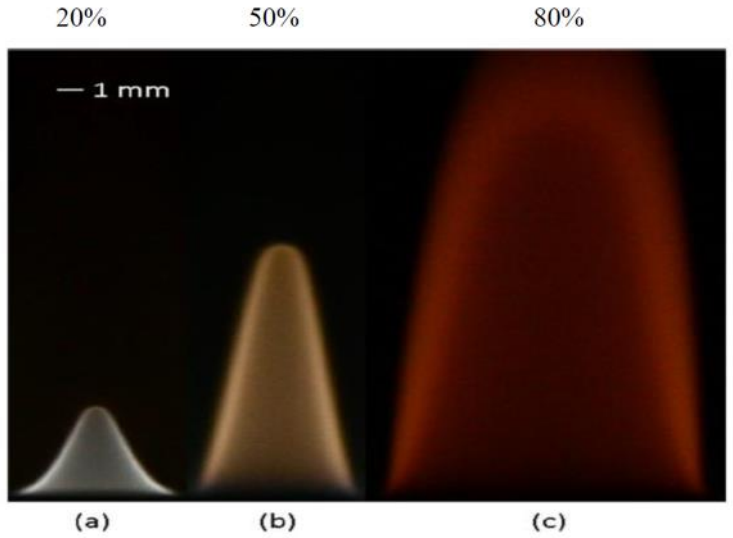


Storage & Delivery

- **Objective:** Storage and deliver of alternative energy carriers, including dedicated/purpose-built and repurposed infrastructure
- **Current Approach:**
  - Modifying existing infrastructure and/or adding new infrastructure for pipeline blending, storage and delivery
  - Transport (ships, trains, trucks)
  - Storage (underground and above ground)
  - Ammonia for storage and delivery, Metal Hydrides and Liquid Organic Hydrogen Carriers
  - Carbon transportation and sequestration
- **2020 Deliverables:**
  - Infrastructure evaluations to support network of upstream fuel and downstream users
  - Research plan to address gaps and challenges

Power Generation

- **Objective:** Confirm the viability of alternative energy carriers as fuels for power generation – both in pure or blended forms
- **Current Approach:** Review and assess power generation technologies as related to burning carbon-free fuels with emphasis on Ammonia and Hydrogen
  - Include summary of key worldwide players and projects
  - Identify R&D gaps and collaboration opportunities
- **2020 Deliverables:**
  - Technology Insight Reports:
    - Gas Turbines, HRSG Duct Burners, Electric Generation and Industrial Applications Boilers, Reciprocating Engines, Fuel Cells
  - Establish collaboration with worldwide universities and research organizations
  - Finalize multi-year roadmap

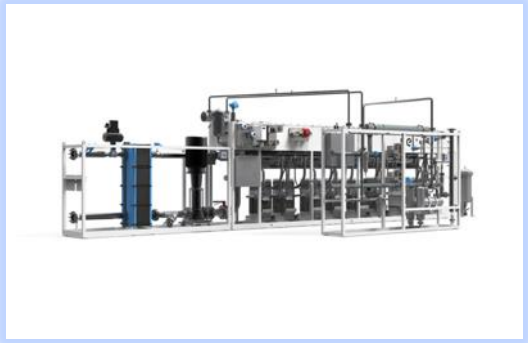


Instantaneous laminar flame images at Ø = 1.0, for E%NH_3 of (a) 20, (b) 50 and (c) 80.
(Courtesy of Iowa State University)

HRSG Runner-type Duct Burner (*EPRI*)

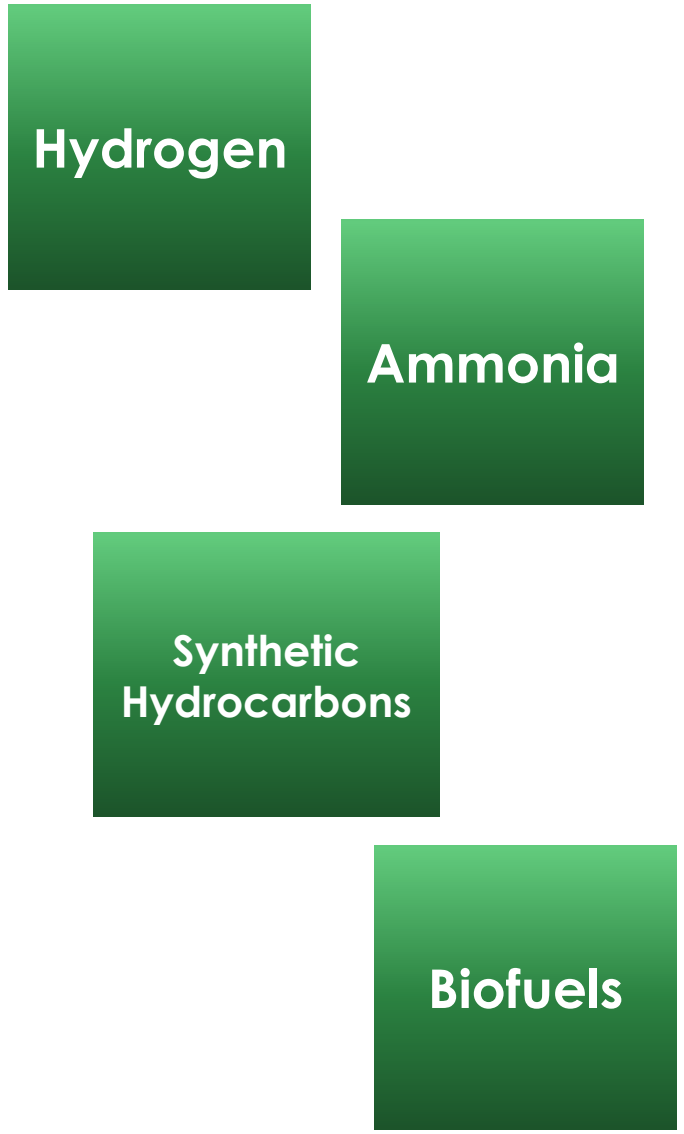
Transportation, Buildings, & Industry

- **Objective:** Assess the relative viability of alternate energy carrier fuels and electric technologies to deliver maximum carbon reduction while maintaining cost effectiveness and competitiveness at end-use. Develop technoeconomic framework for research prioritization and market rationalization.
- **Current Approach:** Review and assess emerging low carbon end-use technologies that deliver thermal inputs, work/power or drive electro-chemical processes as alternatives to hydrocarbon combustion.
  - Quick Insights (District Heating, Hydrogen in Residential Space Heating, Post-pandemic Manufacturing re-alignment/reshoring Impacts)
  - Market Sector based secondary research approach
- **2020 Deliverables:**
  - Establish long-range vision and organize sector specific teams.
  - Establish collaboration with worldwide universities, research organizations, national labs, end-use customers, sector industry consortia, utilities.
  - Produce Technology Insight Reports to inform Road-mapping
    - Commercial/Residential: Space/Water Heating & Cooking
    - Transportation: On-road and Off-road
    - Industry: Primary Metals, Petro-Chemicals, Cement, Food & Beverage, All Other



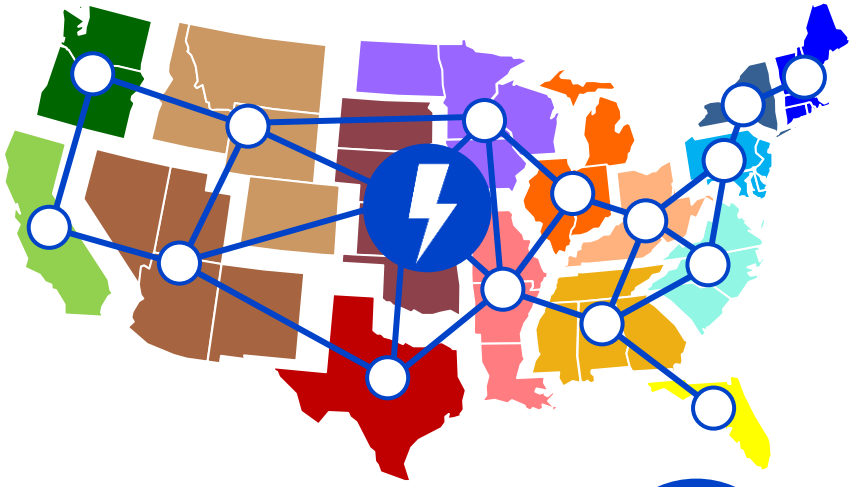
Safety & Environmental Aspects

- **Objective:** Identify and define safety and environmental impacts associated with production, transport, storage, and end use of alternative energy carriers
- **Current Approach:** Review and assess power generation technologies as related to burning carbon-free fuels with emphasis on Ammonia and Hydrogen
  - Goal 1: Quantify EHS impacts and develop frameworks
  - Goal 2: Develop, test, and demonstrate emissions reduction technologies
  - Goal 3: Develop modeling and procedures for obtaining carbon credits and quantifying ESG metrics
- **2020/21 Key Deliverable:** White paper including review of key literature, process flow diagrams outlining workflows and technologies, and R&D gap analysis



Integrated Energy System Analysis

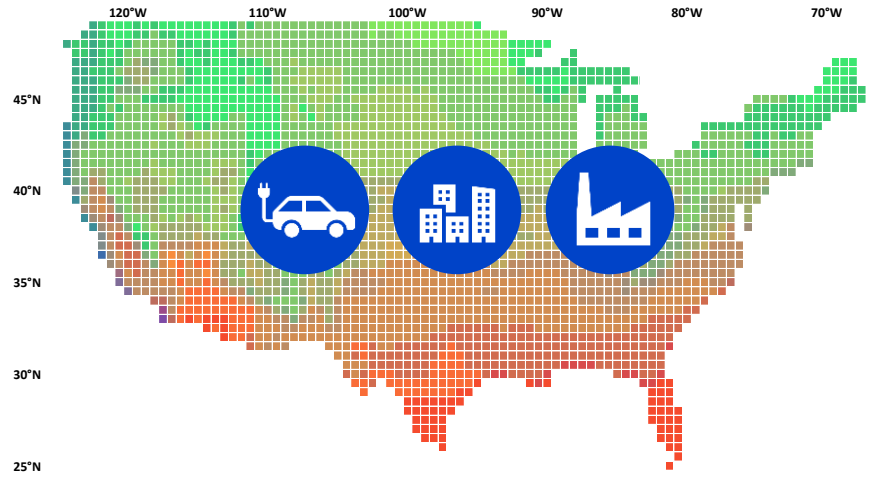
Electric Generation



Synchronized

Hourly Load, Renewables, and Prices

Energy Use



New Model Features

Hydrogen

- Production and storage
- Conversion to end-use fuels
- Power-gas-power

Bioenergy

- Feedstock supply and conversion
- Agriculture and forestry
- Renewable natural gas

Other Low-Carbon Options

- Industrial CCS
- CO2 removal
- Advanced low-carbon energy

Infrastructure

- Electricity T&D
- Natural gas pipelines
- Delivery of low-carbon fuels

Integrated Energy System Analysis