LCRI Update
TMCES 2021

August 2021

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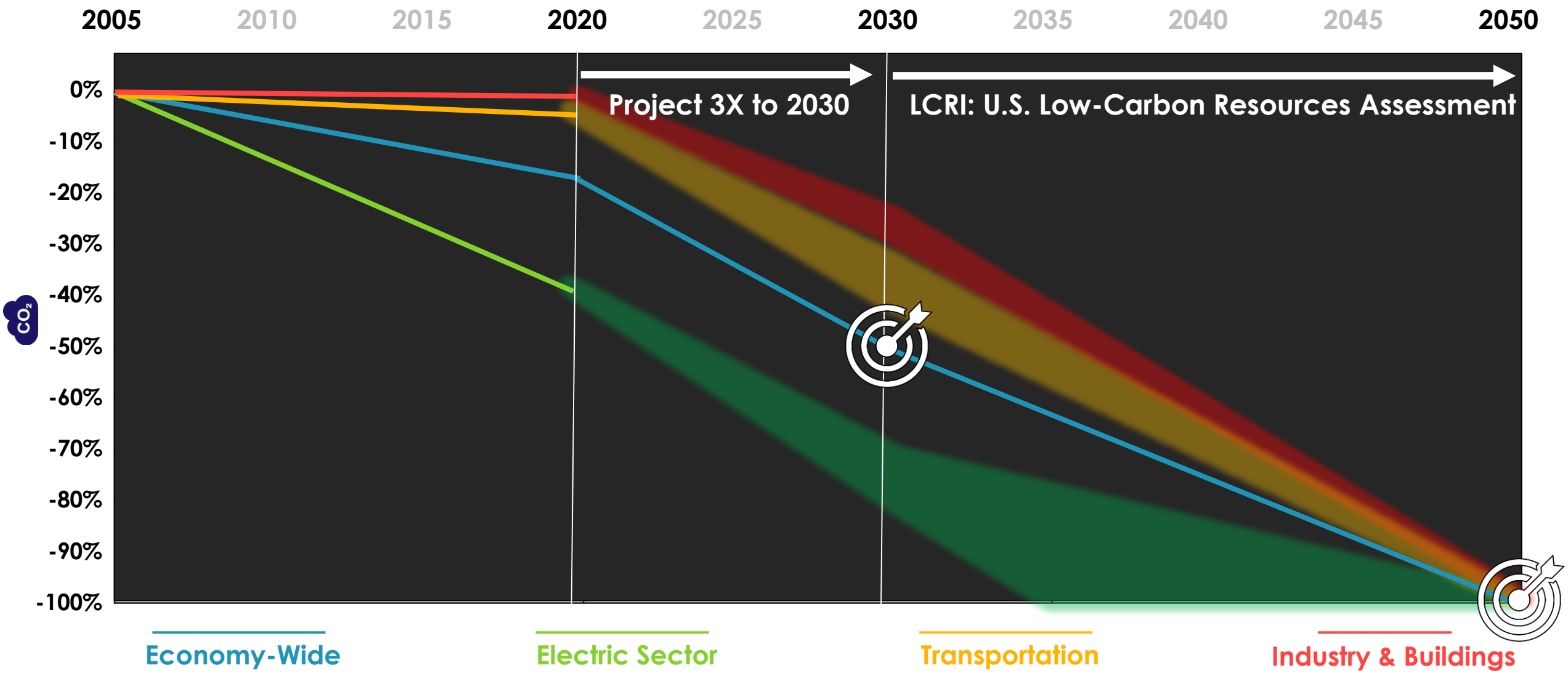
Outline

Click on title to jump to specific section. Click the LCRI graphic (top right) to return to this outline.

LCRI Motivation

Examining U.S. Carbon Reduction Goals



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

Two Major Decarbonization Trends are Emerging Worldwide

LCRI LOW-CARBON RESOURCES INITIATIVE

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

LCRI Research Areas

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

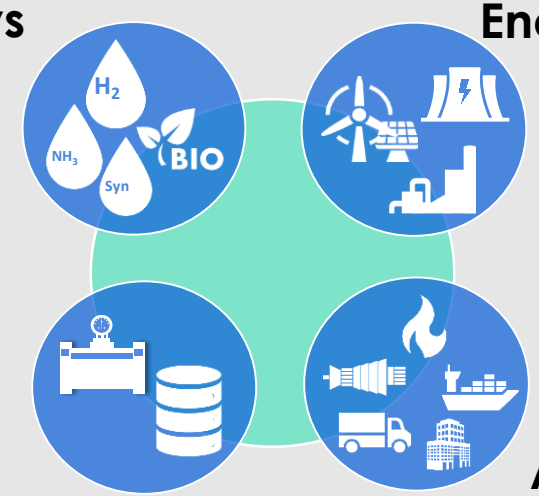
Affordable, reliable, and resilient integrated energy systems for the future

RESEARCH AREAS

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

Production Pathways

Integrated Energy Systems



Storage & Delivery

End Use Applications

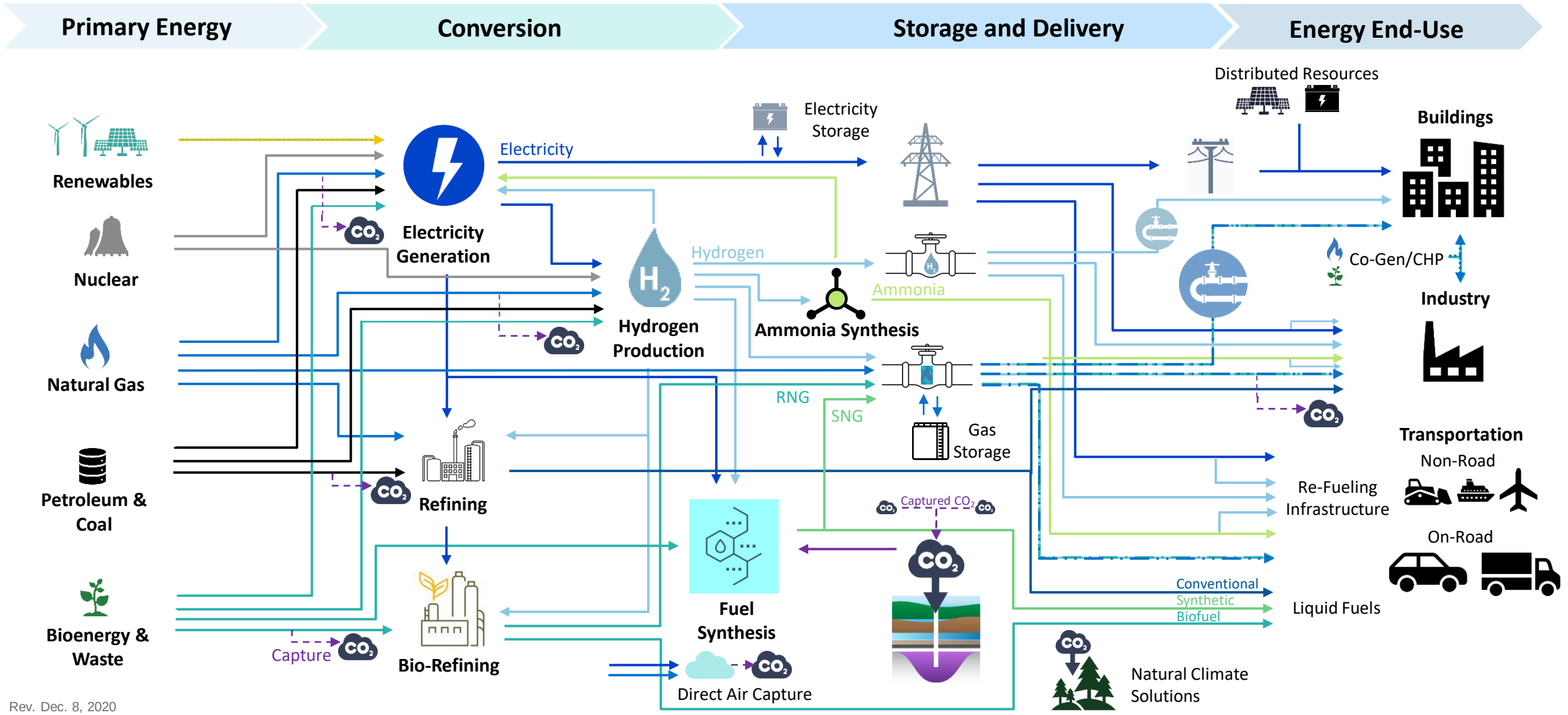
VALUE

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

Low-Carbon Energy Ecosystem



Rev. Dec. 8, 2020

LCRI Technical Subcommittees

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 Sponsorship | Expanding the Collaboration

Current Status

46 Sponsors

Electric & Gas Utilities

Energy Producers

Equipment Manufacturers

$124M Funding

80:1
Avg Sponsor Leverage

14
Active R&D Projects

40+
Technology Reports & Assessments

20+
Preliminary Techno-Economic Cases

Sponsorship Goals

50 Sponsors

Value Chain Diversity

Global Perspectives

Relationship Expansion

LCRI Research Vision

Low-Carbon Resources Initiative Research Vision

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

Living Document

annual updates

real-time learnings

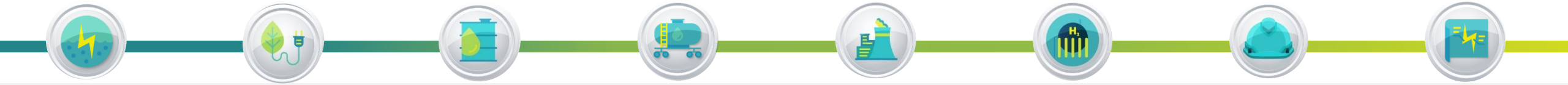
Focused on technologies that will be commercially deployed beyond 2030 to scale through 2050

Input & Development

- 500+ 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

Technology Spectrum

TRACK	PARTICIPATE	LEAD
		
TECHNOLOGY WATCH	**PROJECT ENGAGEMENT**	**PROJECT LEADERSHIP**
Substantial efforts underway outside of LCRI, early stage and/or unlikely to make scaled impact by 2050 No significant funding commitments are anticipated Opportunistic project participation only	High interest to LCRI with shorter term impacts and established engagement across the global R&D community Engagement through R&D activities either designed by LCRI or through contribution to other efforts	Substantial interest to LCRI and of critical importance to the initiative's goals/targets LCRI intends to lead efforts and design R&D activities that align to the initiative's goals/targets
Up to 10% **Project Cost Share Guidelines**	**Up to 20%** **Project Cost Share Guidelines**	**Up to 25%+** **Project Cost Share Guidelines**

Work To-Date

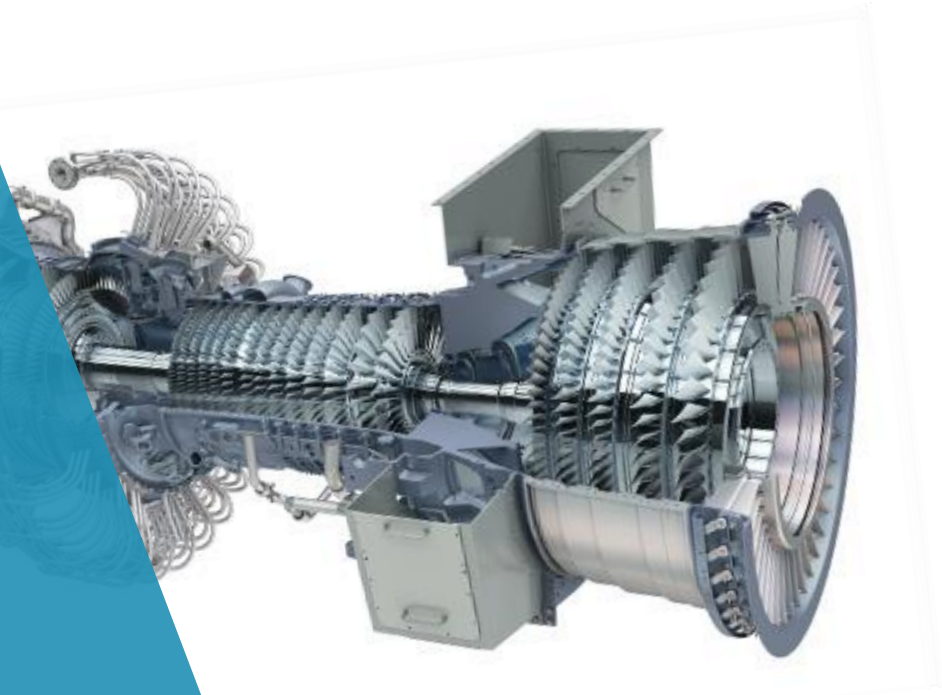
Integrated Hydrogen, Battery, and Gas Turbine Feasibility Study

- Evaluate on-site electrolysis process integrated with grid and battery storage
- Investigate modifications of aeroderivative gas turbine to support 30%v hydrogen blend
- Perform feasibility study to develop conceptual design and budgetary cost estimates

Study Complete, Final Report Pending

Gas Turbine Operational Flexibility Using Hydrogen Fuel Mixtures

- Blend up to 35%v H2 in aeroderivative gas turbine
- Evaluate gas turbine performance and operational flexibility
- Investigate impacts on NOx emissions



Anticipate completion by December 2021

Government Awards

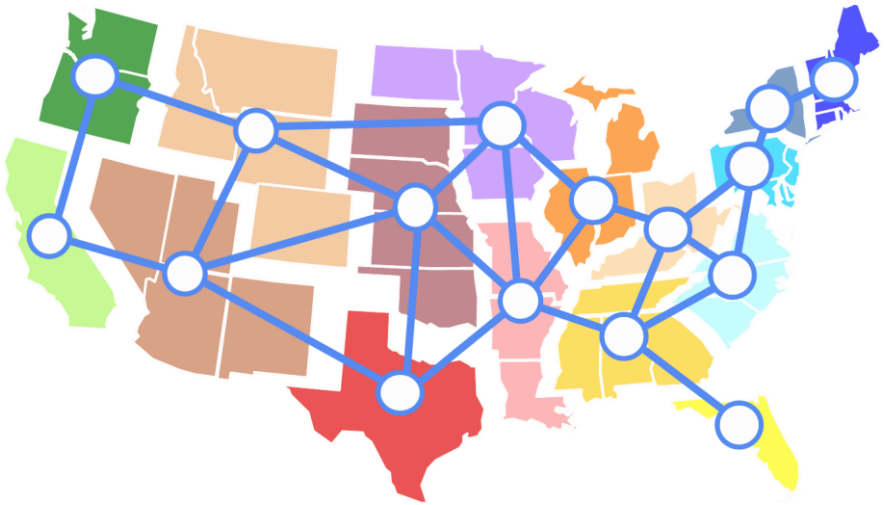
- HyBlend Collaborative Research Partnership: **Blending hydrogen into the natural gas infrastructure** ($15.3M)
- Integrated **Hydrogen Energy Storage System** (IHESS) for Power Generation (DOE FOA 2332)
- **Hydrogen Storage** for Load-Following and Clean Power (DOE FOA 2332)
- **Hydrogen Storage** for Flexible Fossil Fuel Power Generation (DOE FOA 2332)
- Sierra Northern **Hydrogen Locomotive**
- Characterizing Emissions from **Biomethane Facilities**: Quantitative pre- and post-implementation
- Developing a **Workforce for a Hydrogen Technology** Economy DOE FOA 2229 – ($2.65M)
- Flexible Gasification to **Generate Electric Power and a** Carbon-Free Hydrogen Co-Product ($11.7M) DOE FOA 2180
- Engineering-Scale Test of a **Water-Lean Solvent** for Post-Combustion Capture ($5.2M) DOE FOA-2187
- Wabash **Hydrogen Negative Emissions** Technology Demonstration ($55M) DOE FOA 2180 –
- Texas **Hydrogen Demonstration** Project H2@Scale
- UK Demo of **Compact Hydrogen** Generator HYPER*
- Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends to Generate **White Hydrogen**, DOE FOA-2376 ($625k)
- Carbon Capture R&D: Bench Scale Testing of **Direct Air Capture** (DE-FOA-0002402) – 2 separate awards for novel direct air capture technology with Silicon Kingdom and University of Kentucky)

Integrated Energy System Analysis | Evaluating pathways to decarbonization

LCRI LOW-CARBON RESOURCES INITIATIVE

Framework for understanding drivers of change across the energy ecosystem

Energy-Economy Model
US-REGEN



More information at https://esca.epri.com

MODEL FEATURES

- Integrated modeling of electric generation, fuels production, infrastructure, & energy end-use
- Spatial, temporal, sectoral, & technology detail
- State & federal policy targets
- Economic trade-offs

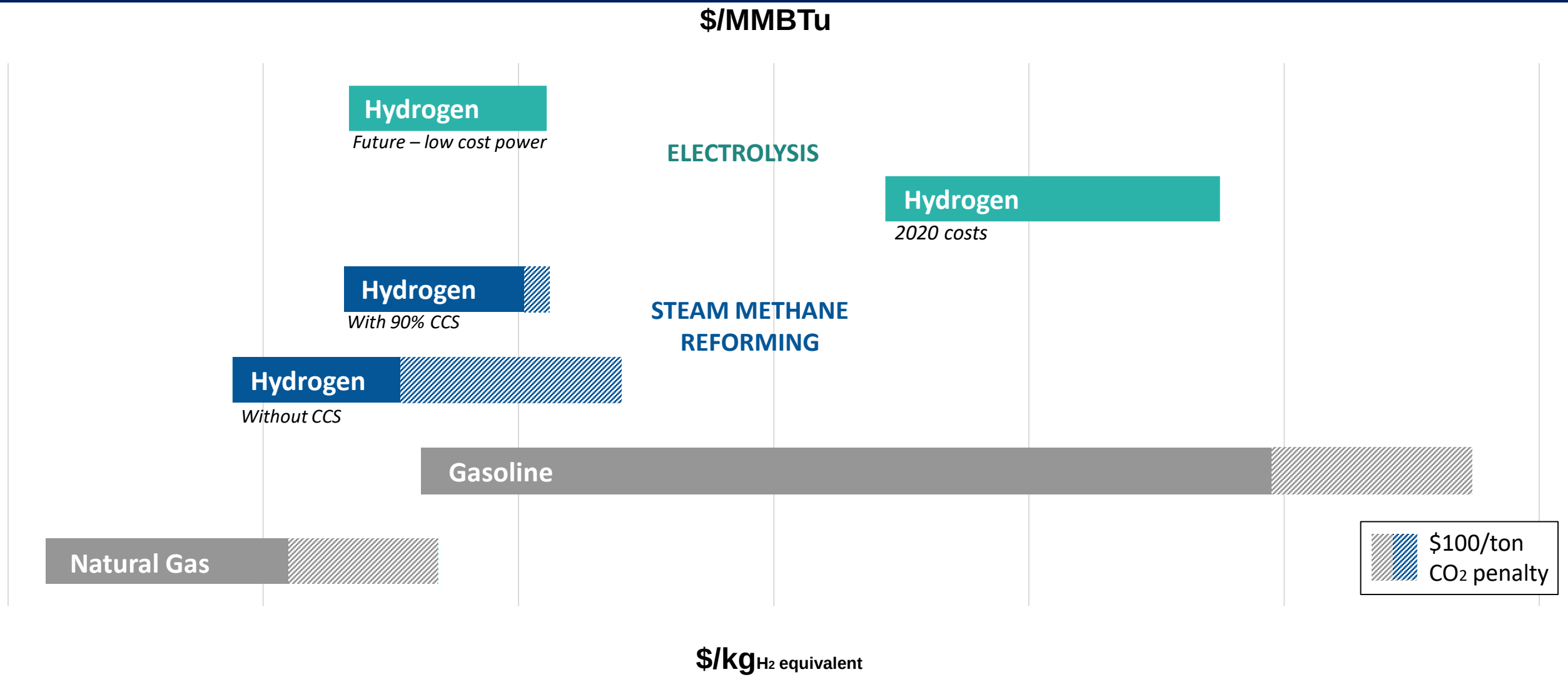
Model Outputs

- Economic equilibrium for energy production, capacity, & end-use
- Emissions (GHG, CO2, etc.), air quality, water & land use
- Least-cost deployment mix of energy subject to inputs & constraints

Example Technology Cost Insight

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

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.

In-Progress State of Technology Reports

Low-Carbon Fuels Production

- Electrolyzer Technology
- *PUBLISHED*: Naturally Occurring Hydrogen Technology Update
- Synthetic fuels produced from green H2 and captured CO2
- Blue Hydrogen Production using natural gas feedstock
- Methane Pyrolysis
- Low-Carbon Ammonia Production using Haber-Bosch process at different scale

Transport & Storage

- Current State of Natural Gas and Hydrogen Gas Storage

Power Generation

- Fuel Cell for Utility Scale Low-Carbon Power Generation
- Gas Turbines for Carbon-Free Power Generation
- Hydrogen Fuel Conversion for Power Generation and Industrial Steam Boilers
- *PUBLISHED*: Reciprocating Internal Combustion Engines for Low-Carbon Power Generation
- Hydrogen Fuel Conversion for Heat Recovery Steam Generators

Cross-Cutting Topics

- Post and pre-combustion capture technologies applied to all energy processes
- Environmental, Health and Safety Aspects of the Introduction of Alternative Energy Carriers for Decarbonization

End-Use

- Low-Carbon Fuels for Light-Duty Transport
- Low-Carbon Fuels for Medium and Heavy-Duty Transport
- Rail Applications
- Marine Applications
- Petroleum and Chemical Sector Applications
- Residential and Commercial Space Heating & Cooling Primary Metals
- Warehousing, Logistics, Construction and Agriculture Applications

Technology Insights

- Technology Insights: The Role of Water in Hydrogen Production
- Technology Insights: Critical Aspects of Hydrogen Blending in Gas Transmission and Distribution
- Technology Insights: Ammonia and Hydrogen Fuel Blends for Gas Turbines
- Technology Insights: Cost Considerations for Low-Carbon Resources

Executive Summary

- *PUBLISHED*: Executive Summary: Naturally Occurring Hydrogen
- *PUBLISHED*: Executive Summary: Reciprocating Internal Combustion Engines for Low-Carbon Power Generation

Other Deliverables

***PUBLISHED*: Electrolysis Technology Assessments**

- Low-Carbon Technology Assessment: Electrolysis – ThyssenKrupp
- Low-Carbon Technology Assessment: Electrolysis – Haldor Topsoe
- Low-Carbon Technology Assessment: Electrolysis – Sunfire
- Low-Carbon Technology Assessment: Electrolysis – Siemens
- Low-Carbon Technology Assessment: Electrolysis – Nel
- Low-Carbon Technology Assessment: Electrolysis – McPhy
- Low-Carbon Technology Assessment: Electrolysis – ITM Power
- Low-Carbon Technology Assessment: Electrolysis – Fuel Cell Energy

***In Progress:* Technology Insight Briefs**

- Technology Insights: The Role of Water in Hydrogen Production
- Technology Insights: Critical Aspects of Hydrogen Blending in Gas Transmission and Distribution
- Technology Insights: Cost Considerations for Low-Carbon Resources
- Technology Insights: Evaluation of High Removal Rate for CO2 Capture Using Aqueous MEA
- *PUBLISHED*: Technology Insights: Ammonia and Hydrogen Fuel Blends for Today's Gas Turbines – Combustion Considerations

***In Progress*: Global Insights**

- European Alternative Fuels Landscape
- Australian Alternative Fuels Landscape
- Japanese Alternative Fuels Landscape

***In Progress*: Carbon Negative Technology Assessments**

- Low-Carbon Technology Assessment: Carbon Negative Technology – Climeworks
- Low-Carbon Technology Assessment: Carbon Negative Technology – Carbon Engineering
- Low-Carbon Technology Assessment: Carbon Negative Technology – Svante
- Low-Carbon Technology Assessment: Carbon Negative Technology – Newlight
- Low-Carbon Technology Assessment: Carbon Negative Technology – Blue Planet
- Low-Carbon Technology Assessment: Carbon Negative Technology – Ecoera
- Low-Carbon Technology Assessment: Carbon Negative Technology – Skytree

Other

- An Introduction to Low-Carbon Fuels
- LCRI Research Vision: An Outline for Research, Development, and Demonstration Activities to Enable Economy-Wide Decarbonization by Midcentury
- LCRI Research Vision: Executive Summary — An outline for research, development, and demonstration activities to enable economy-wide decarbonization by midcentury
- LCRI Digital Portal
- Low-Carbon Resources Initiative: Enabling the Pathway to Economy-Wide Decarbonization
- Low-Carbon Resources Initiative: Advancing Technologies that Enable a Low-Carbon Future
- Low Carbon Resource Initiative: Accelerating Technologies that Enable Deep Carbon Reductions
- *In Progress*: U.S. Low-Carbon Resources Assessment (Integrated Energy System Analysis Report)
- *In Progress: 4* Alternative Fuels Briefings: Hydrogen, Ammonia, Synthetic Fuels, Biofuels
- *In Progress:* Design Considerations for Co-Firing Hydrogen in an Aeroderivative Gas Turbine

Visit the LCRI Digital Library to view all publications or subscribe to LCRI's monthly newsletter to stay up-to-date

Important LCRI Dates

2021 Remaining Calendar

June to September

LCRI Sponsors allocate funding to Technical Subcommittees

Members direct funding to TSCs

July

Integrated Energy System Analysis released

Technical Subcommittees begin prioritization discussions

October

Technical Subcommittees finalize research prioritization

Begin planning 2022 projects

Global Collaboration

Strategic and Technical Engagement

Industry Consortia

Hydrogen Council | Green Ammonia Consortium | World Energy Council – Hydrogen Global Initiative | Fuel Cell and Hydrogen Energy Association

Global Research Community

Universities – MIT Energy Institute, GT Strategic Energy Institute | National Labs | Research Institutes – GTI, Fraunhofer Institute

Part of LCRI Technical Collaboration Network

Leveraging Knowledge through Strategic and Technical Engagement

Regional and National Networks

Hydrogen Europe | Australian Hydrogen Council | Hypos East Germany | Fuel Cells and Hydrogen Joint Undertaking (EU)

Other Stakeholder Groups

EUTurbines | European Turbine Network | HYBRIT | SALCOS

LCRI Technical Collaboration Network

Establishing connections with laboratory communities, other research organizations, academia, federal/stat/local government agencies, international energy ministries, and non-governmental organizations

Knowledge sharing through technical meetings

Journal publication opportunities

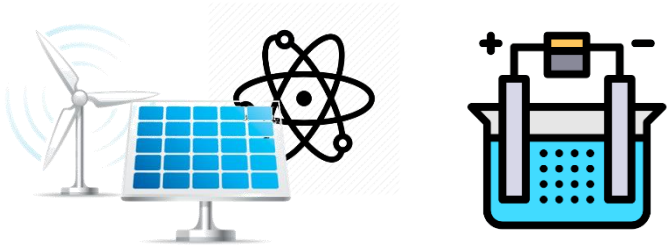
Future LCRI conference participation

Learn more about the LCRI TCN here, formal relaunch webcast will be Tuesday, Oct. 26th @ 11AM ET.

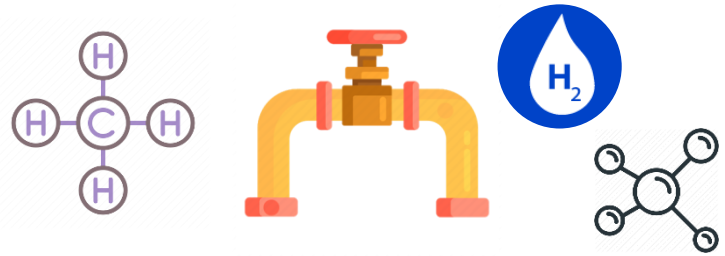
Building a network of broad, diverse set of expertise for idea sharing and collaboration

Potential Pilot & Demonstration Projects

"Green" Hydrogen Production



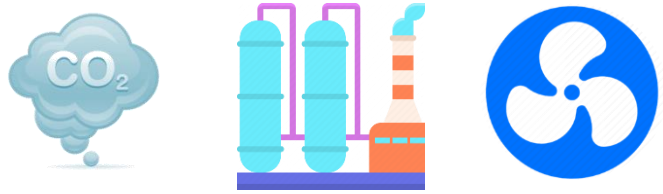
Natural Gas Pipeline Integration/Conversion



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

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

https://lcri-vision.epri.com

LCRI Research Vision

LCRI@epri.com

Email

www.LowCarbonLCRI.com

Public Webpage

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

LCRI References

LCRI Launch Document

Low-Carbon Fuels White Paper

LCRI

LOW-CARBON RESOURCES INITIATIVE

Enabling the Pathway to Economy-Wide Decarbonization

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

www.lowcarbonLCRI.com

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LCRI Sponsorship

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DTE
Duke Energy
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Exelon
FirstEnergy
Fortis Inc.
GE
Hawaiian Electric
Intermountain Gas Company
LES
LA DWP Los Angeles Department of Water & Power
Missouri River Energy Services
Mitsubishi Power
National Fuel
nationalgrid
Nebraska Public Power District
New York State of Opportunity. NY Power Authority
MISource
NOMAC
NW Natural
OglethorpePower
OPPD Omaha Public Power District
Portland General Electric
PowerSouth Energy Cooperative
ppl
SRP
Southern California Edison
SoCalGas
Southern Company
TVA Tennessee Valley Authority
TEPCO
Tri-State
WEC Energy Group
Xcel Energy

EPRI Electric Power Research Institute gti

Low-Carbon Resources Initiative Governance

LCRI Advisory Structure

Governance & Oversight

Executive Council

Technical Scope & Execution

Technical Advisory Group

Technical Subcommittees

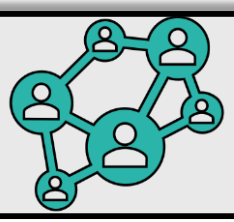
- Electrolytic Processes
- Hydrocarbon-Based Processes
- Renewable Fuels
- Storage & Delivery
- Power Generation
- Transportation, Industrial, & Buildings
- Integrated Energy Systems Analysis
- Safety and Environmental Aspects

Strategic Guidance

EPRI BOARD WORKING GROUP

gti BOARD OF DIRECTORS

Technical Input



TECHNICAL COLLABORATION NETWORK