LCRI Update
TMCES 2021
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Outline

LCRI Motivation
Research Areas
LCRI Research Vision
Work To-Date
Global Collaboration

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

Project 3X to 2030

LCRI: U.S. Low-Carbon Resources Assessment

https://www.youtube.com/watch?v=42UqxqCCYs4
Achieving economy-wide net zero emissions will require low-carbon energy resources

Two Major Decarbonization Trends are Emerging Worldwide

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
### 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 reforming, 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

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

Input & Development

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

Living Document

annual updates  real-time learnings

www.lowcarbonLCRI.com
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

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<thead>
<tr>
<th>Track</th>
<th>Participate</th>
<th>Lead</th>
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<tbody>
<tr>
<td><strong>Technology Watch</strong></td>
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<tr>
<td>Substantial efforts underway outside of LCRI, early stage and/or unlikely to make scaled impact by 2050</td>
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<td>No significant funding commitments are anticipated</td>
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<tr>
<td>Opportunistic project participation only</td>
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<td>Up to 10% Project Cost Share Guidelines</td>
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<td><strong>Project Engagement</strong></td>
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<td>High interest to LCRI with shorter term impacts and established engagement across the global R&amp;D community</td>
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<td>Engagement through R&amp;D activities either designed by LCRI or through contribution to other efforts</td>
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<td>Up to 20% Project Cost Share Guidelines</td>
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<td><strong>Project Leadership</strong></td>
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<td>Substantial interest to LCRI and of critical importance to the initiative’s goals/targets</td>
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<tr>
<td>LCRI intends to lead efforts and design R&amp;D activities that align to the initiative’s goals/targets</td>
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<td>Up to 25%+ Project Cost Share Guidelines</td>
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Work To-Date
Project Highlights

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
Project Highlights

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

Framework for understanding drivers of change across the energy ecosystem

**Energy-Economy Model**
**US-REGEN**

**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

More information at [https://esca.epri.com](https://esca.epri.com)
Example Technology Cost Insight

Energy Cost (USD/MMBTU and USD/kg H₂ eq.)

For discussion purposes only.

$/MMBTu

- **Hydrogen**
  - Future – low cost power
  - 2020 costs

- **Hydrogen**
  - With 90% CCS

- **Hydrogen**
  - Without CCS

- **ELECTROLYSIS**

- **STEAM METHANE REFORMING**

- **Gasoline**

- **Natural Gas**

$/kg \text{H}_2 \text{ equivalent}

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.

$100/ton CO₂ penalty
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**

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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

**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

**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


**In Progress: Global Insights**
- European Alternative Fuels Landscape
- Australian Alternative Fuels Landscape
- Japanese Alternative Fuels Landscape

Visit the [LCRI Digital Library](http://www.lowcarbonLCRI.com) 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


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.
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

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

https://lcri-vision.epri.com
LCRI Research Vision

LCRI@epri.com
Email

www.LowCarbonLCRI.com
Public Webpage

LCRI References
LCRI Launch Document
Low-Carbon Fuels White Paper

An Introduction to Low-Carbon Fuels
Enabling the Pathway to Economy-Wide Decarbonization
Low-Carbon Resources Initiative Governance

LCRI Advisory Structure

Governance & Oversight
- Executive Council

Technical Scope & Execution
- Technical Advisory Group
  - Technical Subcommittees:
    - Electrolytic Processes
    - Storage & Delivery
    - Power Generation
    - Transportation, Industrial, & Buildings
    - Hydrocarbon-Based Processes
    - Renewable Fuels
    - Integrated Energy Systems Analysis
    - Safety and Environmental Aspects

Strategic Guidance
- BOARD WORKING GROUP
- BOARD OF DIRECTORS

Technical Input
- TECHNICAL COLLABORATION NETWORK