Low-Carbon Fuels and the Energy Transformation

Affordable – Reliable – Resilient

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EPRI

Leading Global Collaborative Energy R&D

EPRI is advancing energy technologies and informing decision-making through ~$450M in collaborative annual research with more than 450 entities in 45 countries – spanning the production, delivery, and use of energy.

Independent

Non-Profit

Collaborative

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The Future of Energy

Decarbonization

~5-15 years

Accelerate economy-wide, low-carbon solutions

- Electric sector decarbonization
- Electric transmission and grid flexibility: storage, demand, EVs
- Efficient electrification and natural gas, hybrid systems
- Mitigate methane emissions

~15-30 years

Achieve a net-zero clean energy system

- Ubiquitous clean electricity: renewables, advanced nuclear, CCS
- 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

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

Resilience

~5-15 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 system design
- Advanced asset design and strategic undergrounding
- Smart integration of energy carriers

The Future Energy System must be…

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

Decarbonization Pathways Enabled by Innovation

Decarbonization

Accelerate economy-wide, low-carbon solutions

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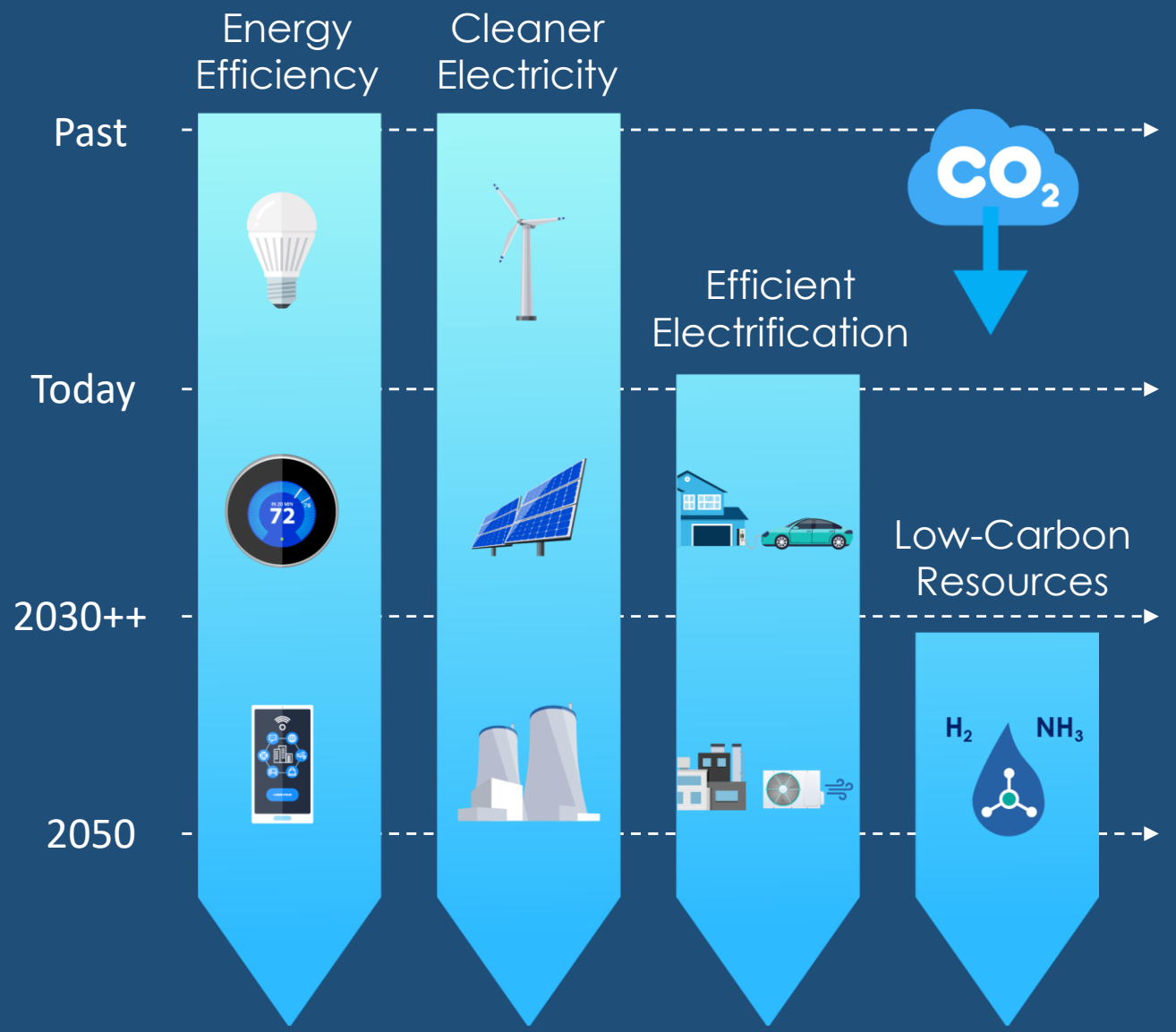
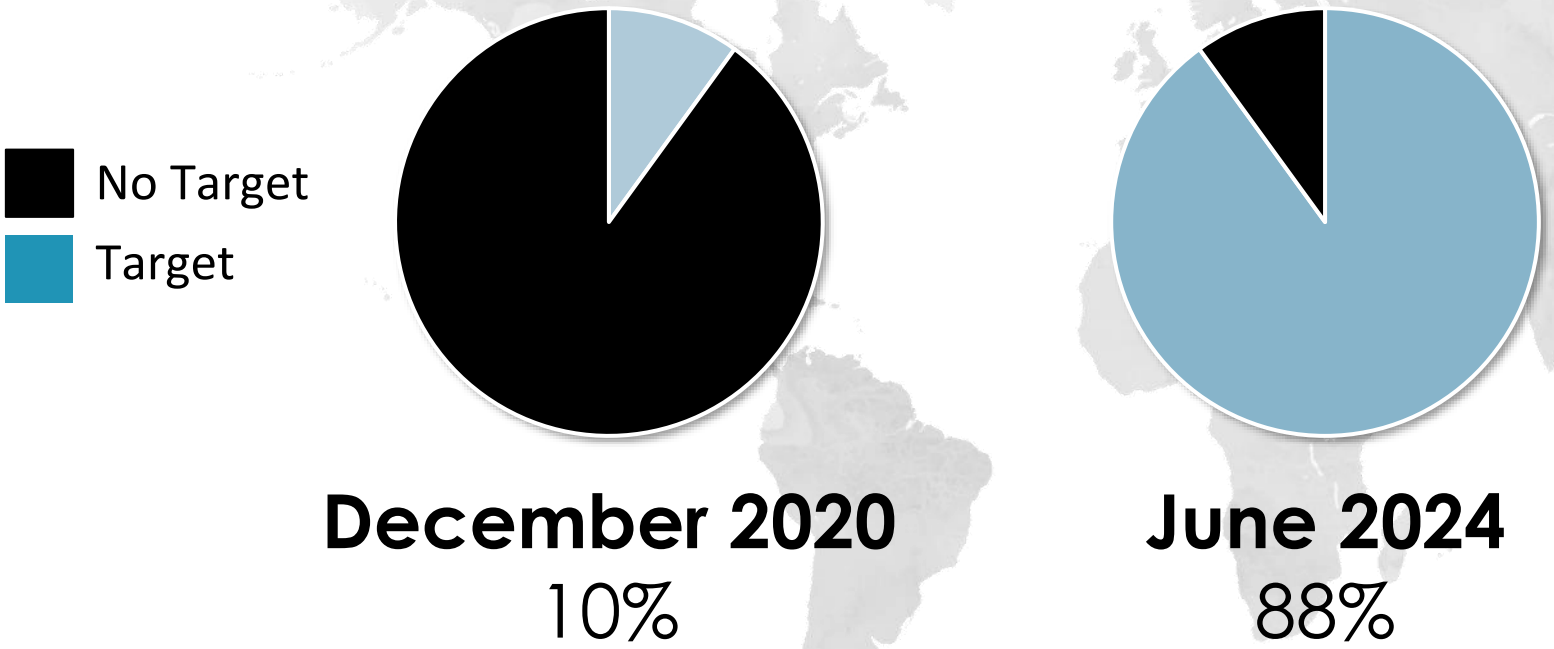
~5-15 years

~15-30 years



Net-Zero Targets

Global GHG Emissions Covered in National Targets



December 2020
10%

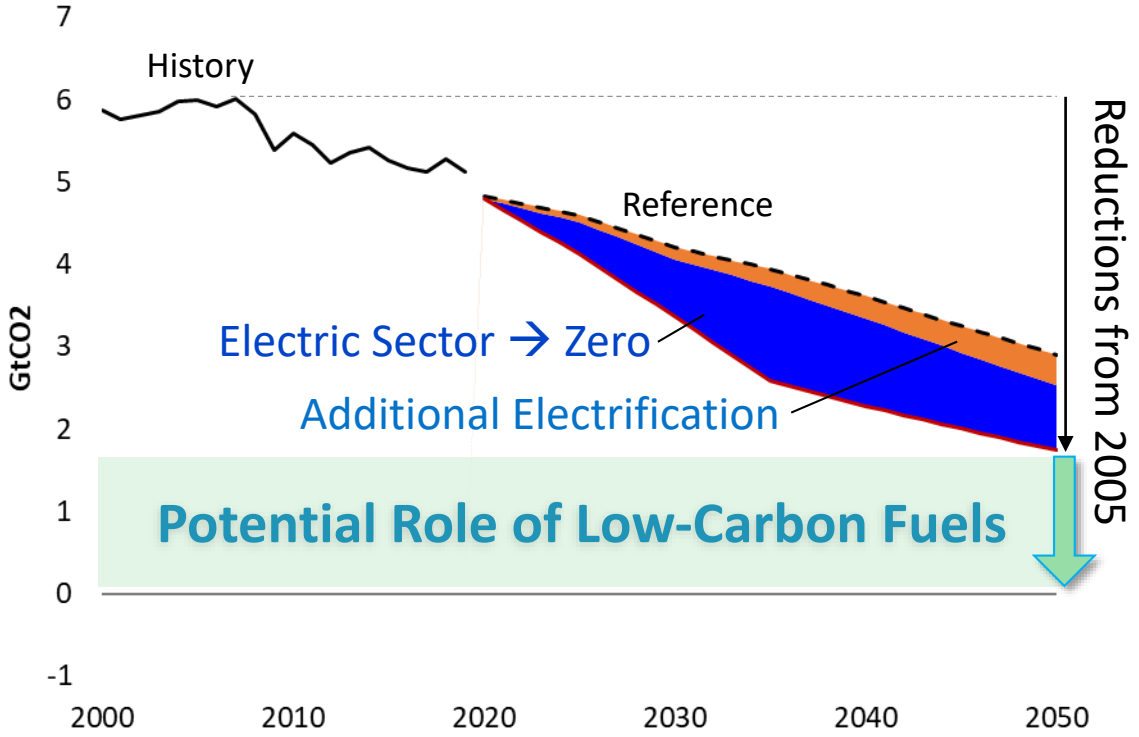
June 2024
88%

15%	Law
60%	Policy
25%	Pledged/Proposed

Data Source: Net Zero Tracker

Integrated Energy System Approach to Decarbonization

Economy-Wide CO_2 Emissions



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

Evaluating the Potential Role of Low-Carbon Fuels

- Various pathways exist to support carbon reductions across the energy-economy (e.g., efficiency improvements, electrification)
- Commercial options are currently limited for hard-to-abate areas and deep carbon reduction targets
- Significant need and opportunity to support the transition to low-carbon fuels using an integrated energy system approach

EPRI Report 3002020700

Phases of Developing a Net Zero Plan

What is “Net Zero”

What is the status of new low-carbon technologies (CO_2, H_2, Ammonia, e-methane)

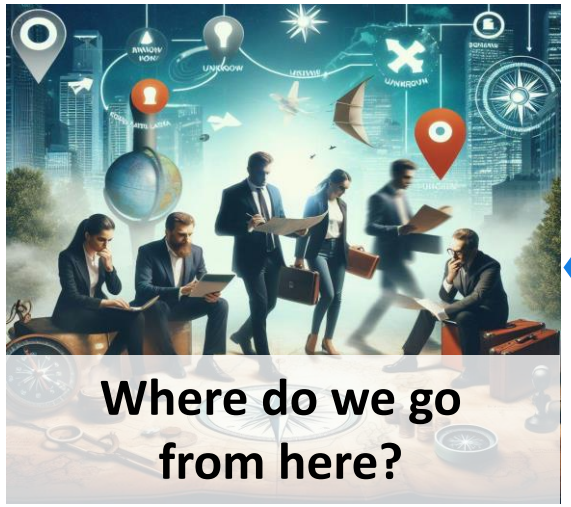
Can existing assets use low-carbon fuels…How can we prove it at specific sites

Where will the low-carbon fuels come from…How much will they cost…What are the risks (cost availability, reliability)

What other industries could use low-carbon fuels / CO_2 storage and could we share the risks for deployment

What are the global conditions impacting use of low-carbon fuels / CCS

What is a reasonable timeline and cost for deploying large-scale technologies



Phases of Developing a Net Zero Plan

What is “Net Zero”

What is the status of potential power generation technologies (CCS, H2, ammonia)

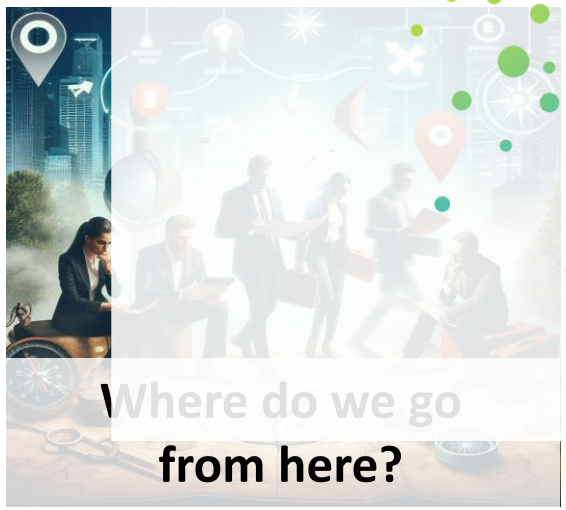
Can existing assets use low-carbon fuels (H2, NH3)…How can we improve [illegible] specific sites

Where will the low-carbon fuels come from…How much will they cost…What are the risks (cost availability, reliability)

What other industries could use low-carbon fuels / CCS and could we share the risks for deployment

What are the conditions impacting use of low-carbon fuels / CCS

What is a reasonable timeline and cost for deploying large-scale technologies



LCRI
LOW-CARBON
RESOURCES INITIATIVE

The Low-Carbon Resources Initiative (LCRI) was created by EPRI and GTI Energy to help accelerate the development and demonstration of low-carbon energy carriers

Beyond 2030 – Integration of Low-Carbon Energy Carriers

LCRI Focus: Hydrogen Ammonia Synthetic/ Derivative Fuels Biofuels

Production Sources

Next Gen Technologies

Integrated Clean Electricity

Integrated Nuclear (Current & Advanced)

Natural Gas with CCS

Delivery & Storage

Existing Natural Gas Pipeline through Blending and/or New Infrastructure

Shipping, Trucking, and Conversion/Intermediates

Aboveground and Underground Storage

End Use Applications

Combustion

Heavy Duty Transportation

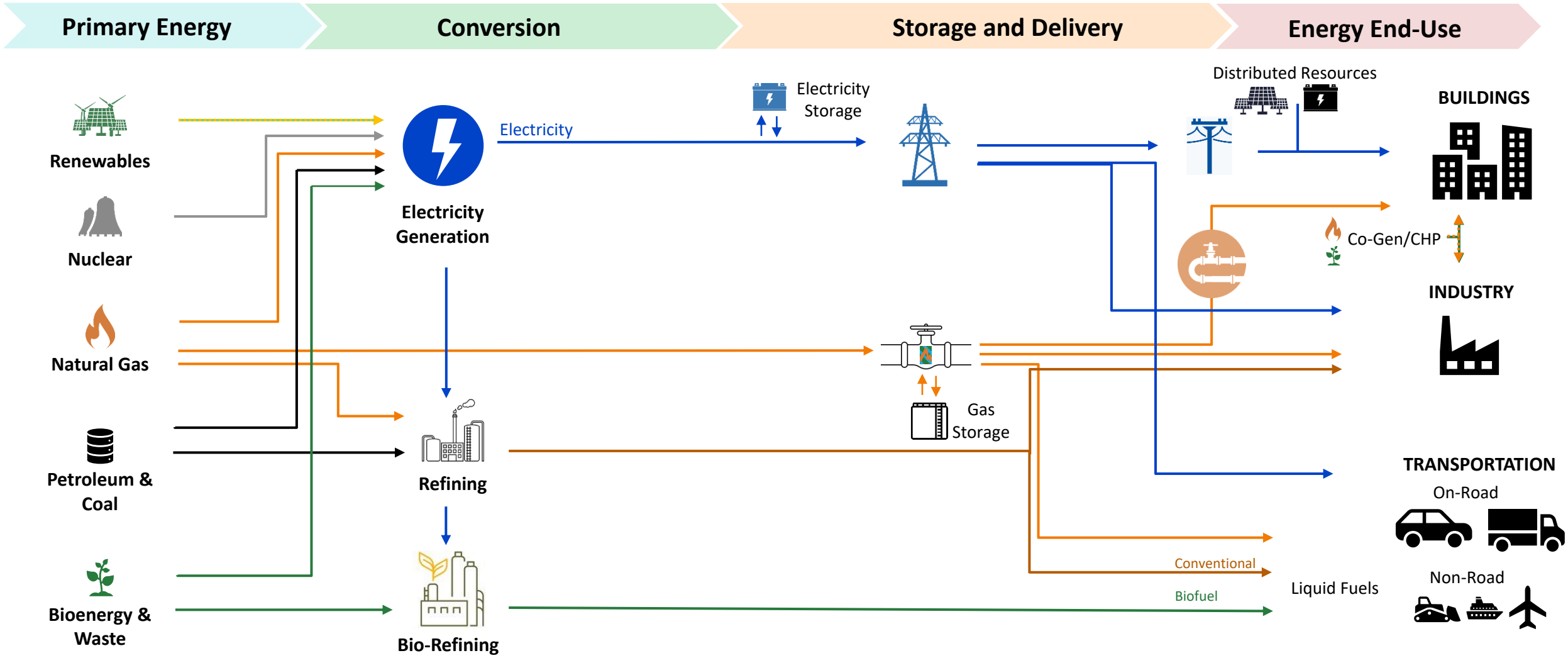
Electricity Generation

Advanced Fuel Cell

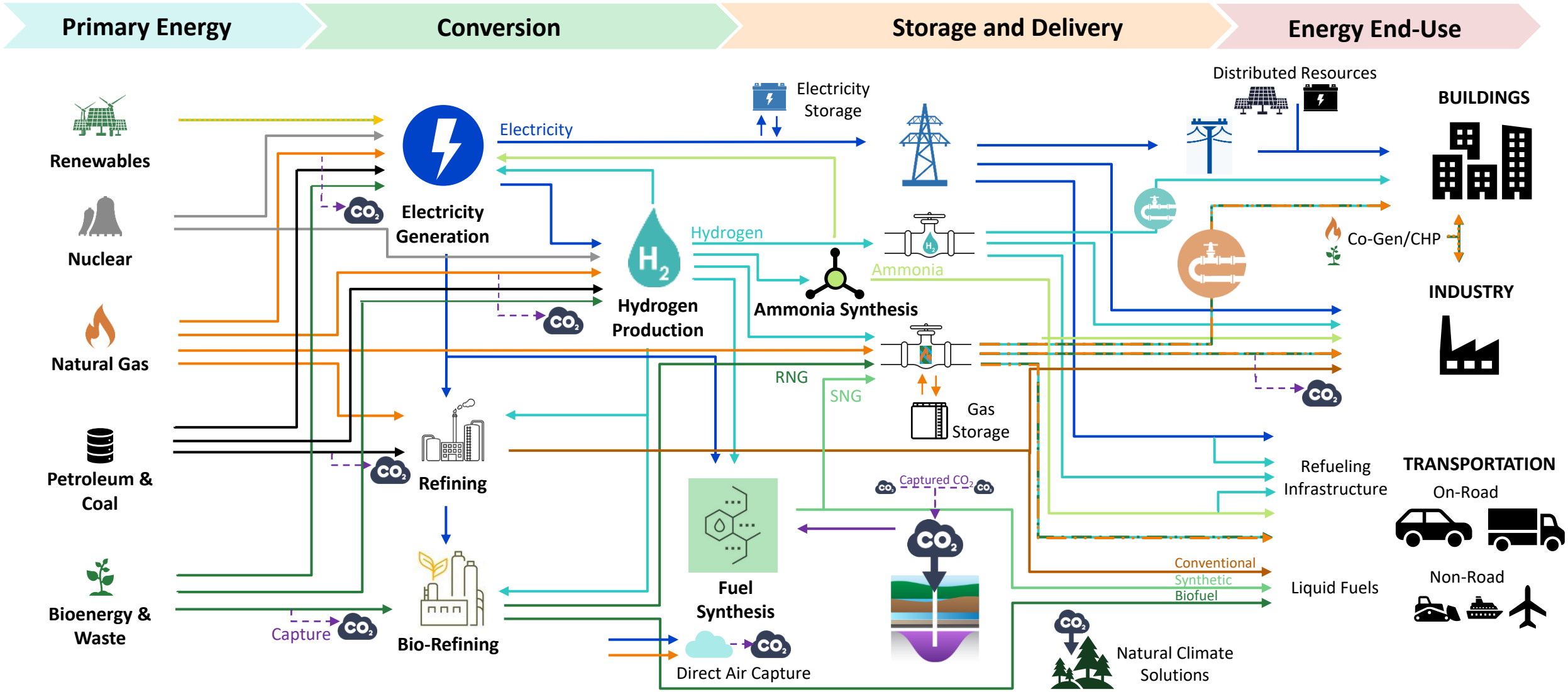
Large Industry

Chemical Processes

Energy System is Becoming More Integrated



Energy System is Becoming More Integrated



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RESOURCES INITIATIVE

EPRI

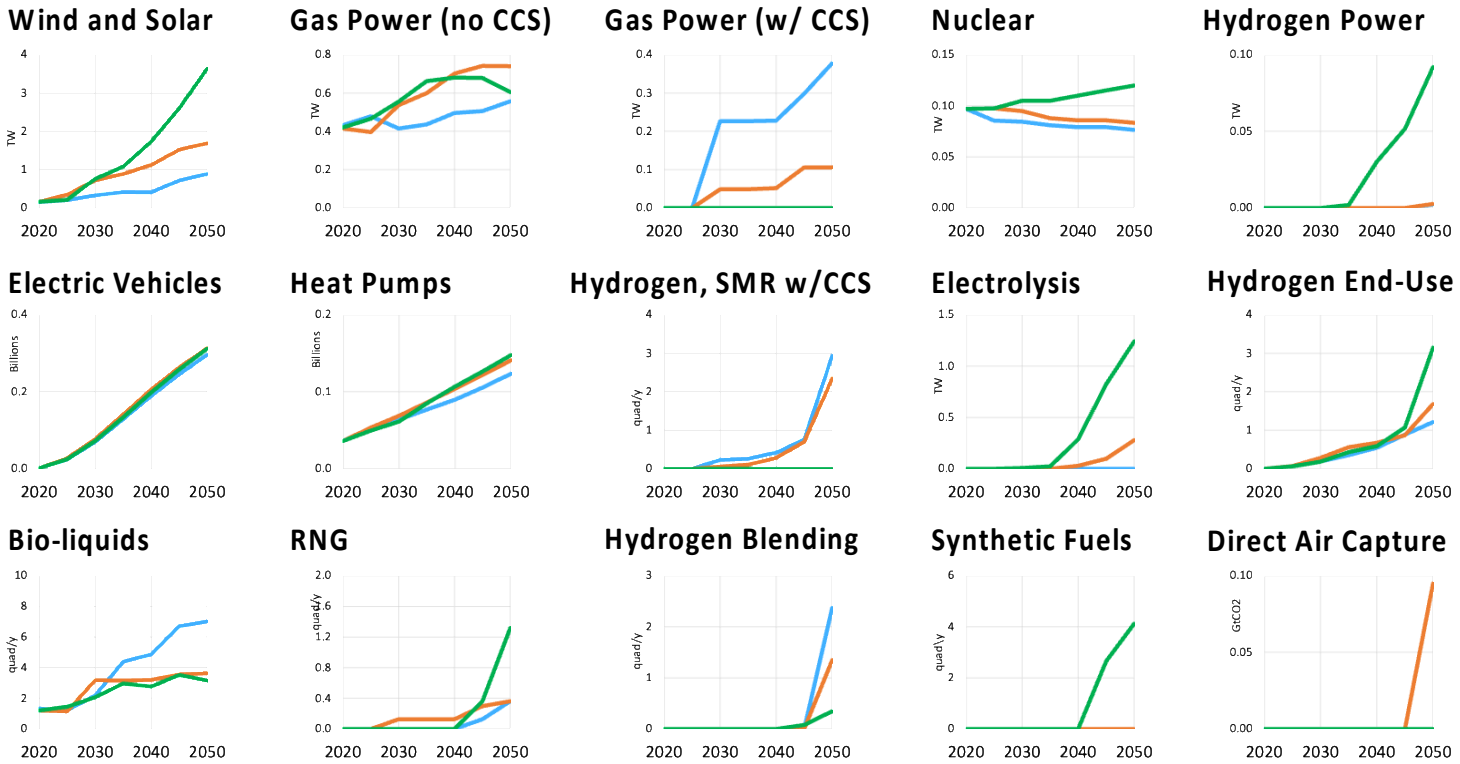
GTI ENERGY

Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

www.lowcarbonLCRI.com/netzero

U.S. Technology Trends over Time to Net-Zero in 2050

- There is no one-size-fits-all solution; viable strategies will differ by region
- Many different technologies will be needed to support decarbonization
- Technology deployment (types & timelines) impacted by complex energy system scenarios



U.S. 2050 Net Zero Scenarios

All Options

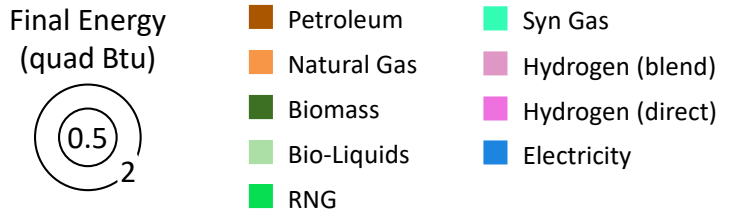
Higher Fuel Costs

Limited Options

www.lowcarbonLCRI.com/netzero

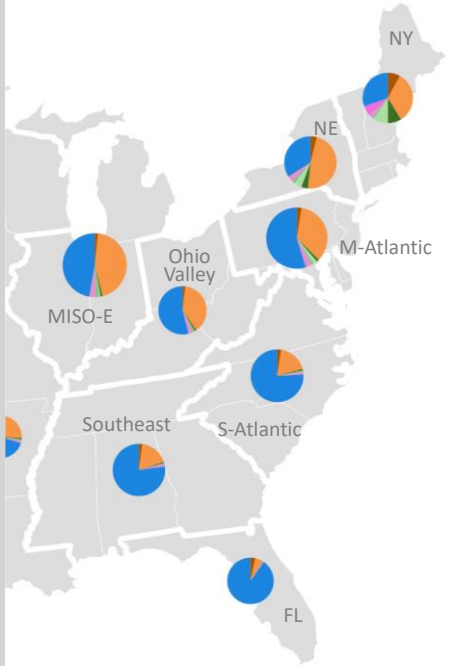
2050 Net-Zero Analysis

Final Energy by Fuel for Buildings



"All Options"

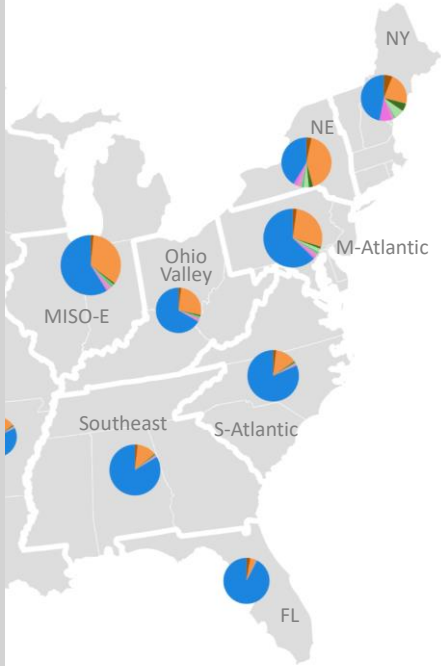
The availability of gas CCS makes the use of hybrid heat pumps with gas backup and low-carbon fuels competitive with all-electric configurations, especially in colder climates.



$165/tCO$_2$

"Higher Fuel Costs"

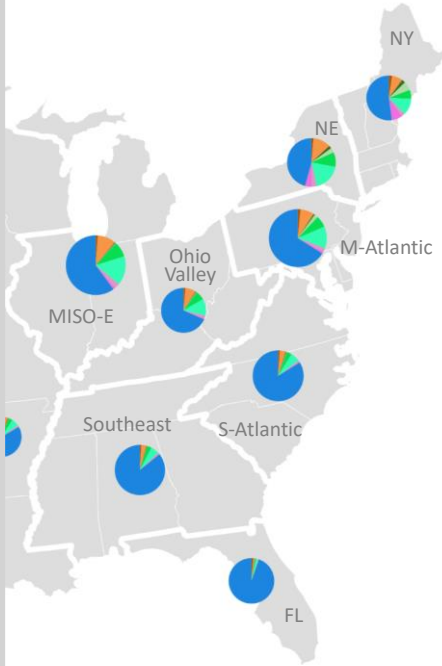
Higher costs of gas, CCS, and biomass result in faster shifts towards electricity in all regions, with electricity well over 60% of final energy consumption in some regions.



$260/tCO$_2$

"No CCS, Less Bioenergy"

The absence of CCS and constraints on biomass result in even faster shifts towards electricity in all regions, with increased reliance on low-carbon fuels as well.



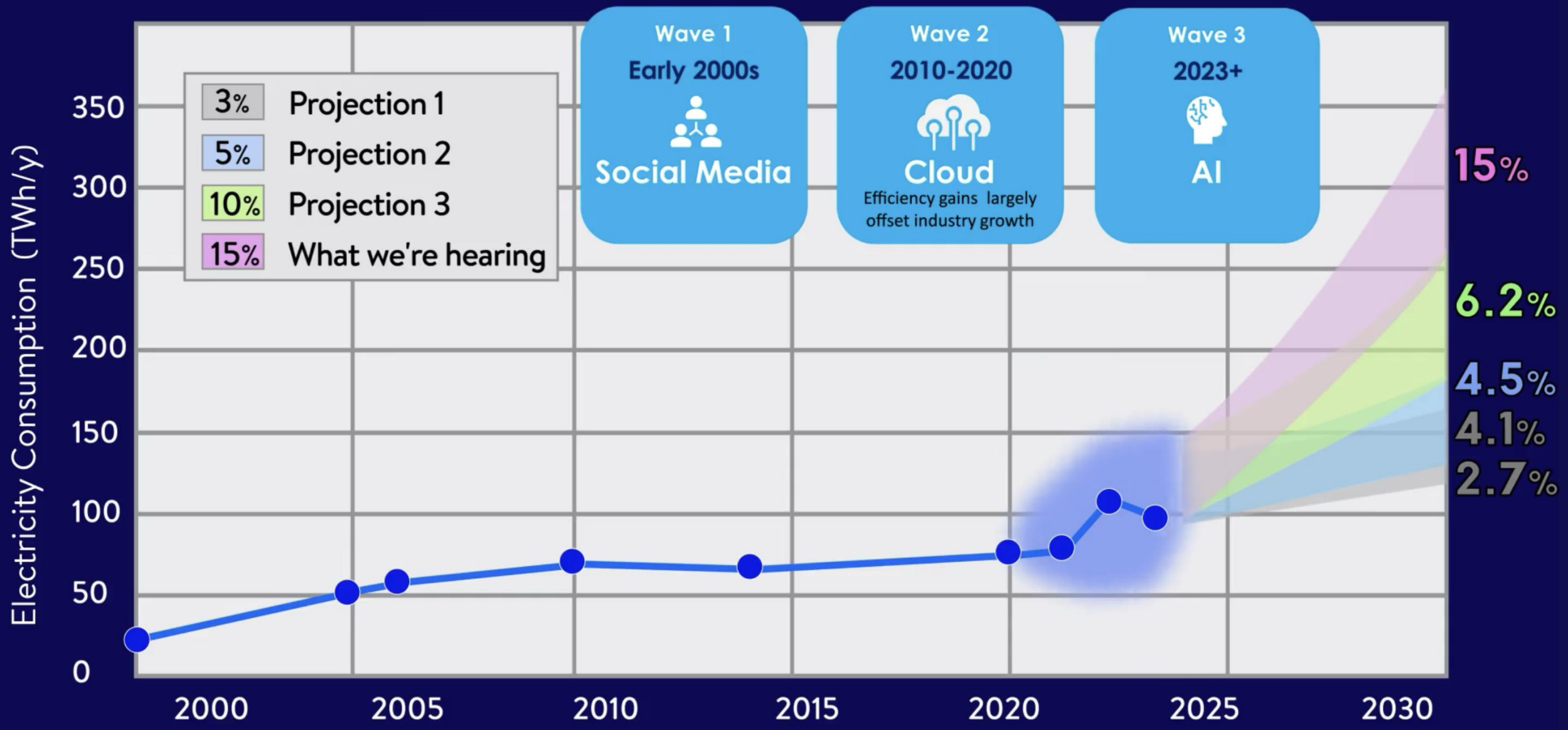
$1,200/tCO$_2$

Source: LCRI Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

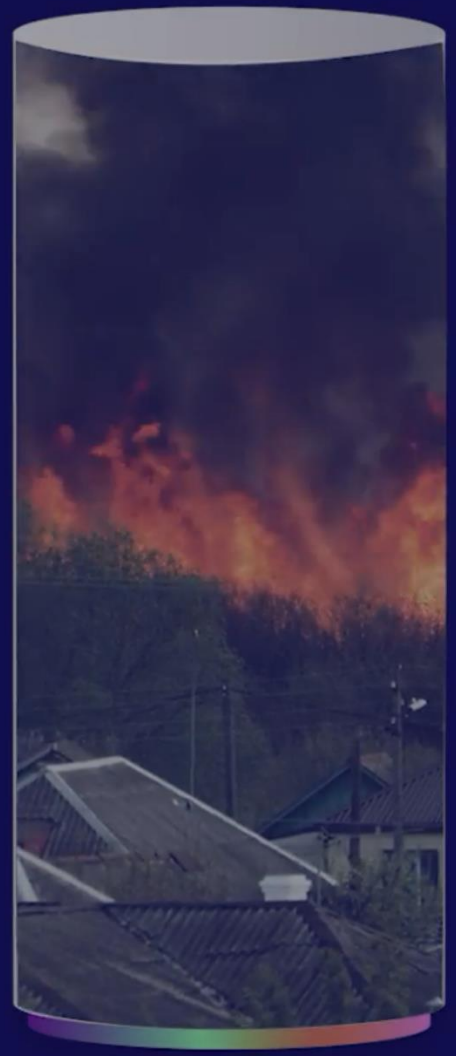
Urgency to Keep the Energy Flowing, Affordably and Reliably

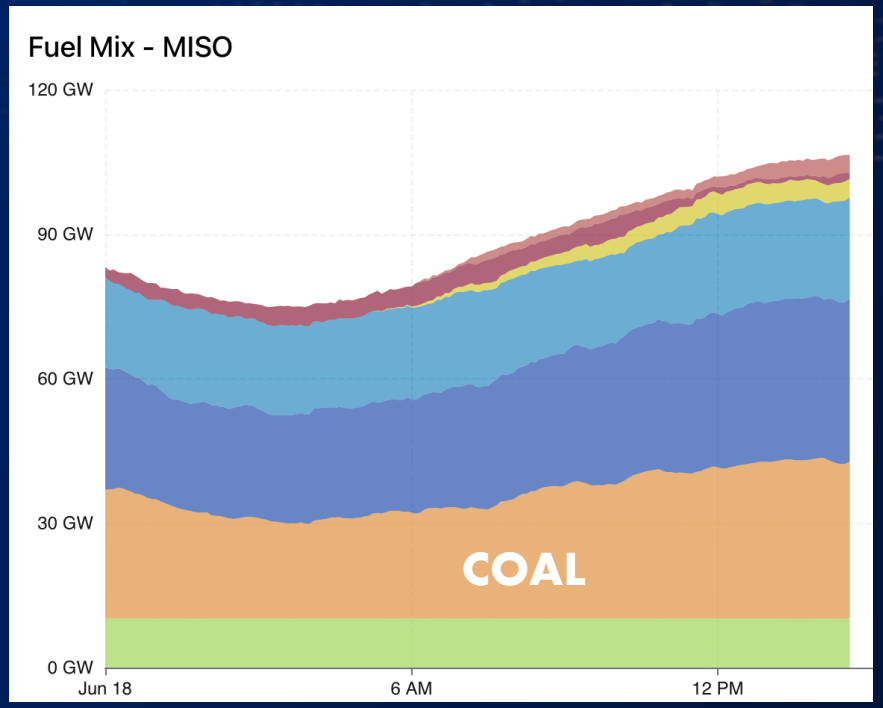
Inflection Point: Energy Transition becomes a Transformation

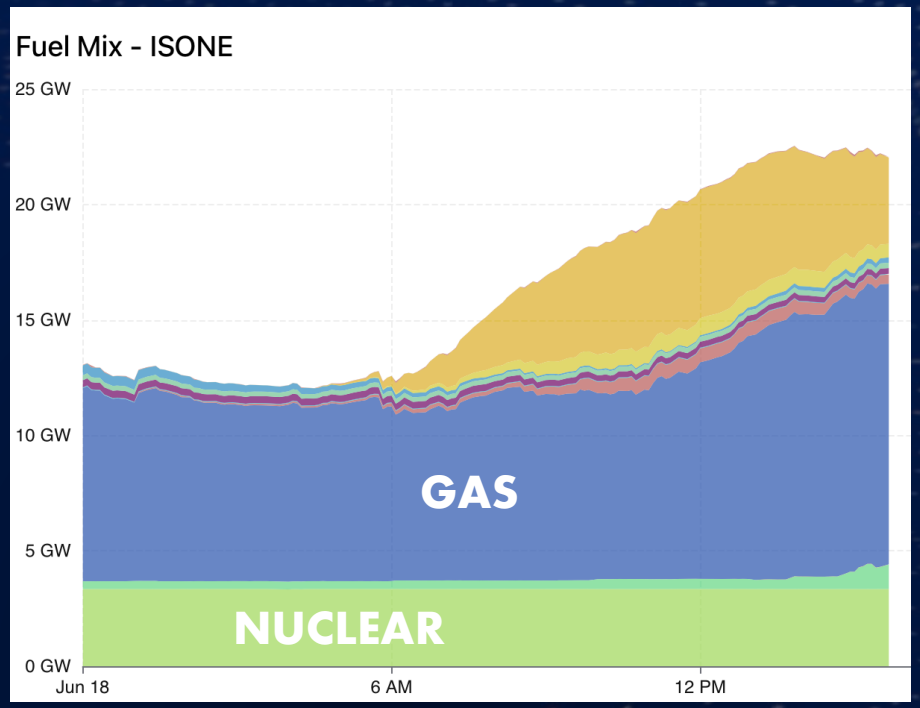
AI is Driving a Third Wave of Data Center Growth



Supply

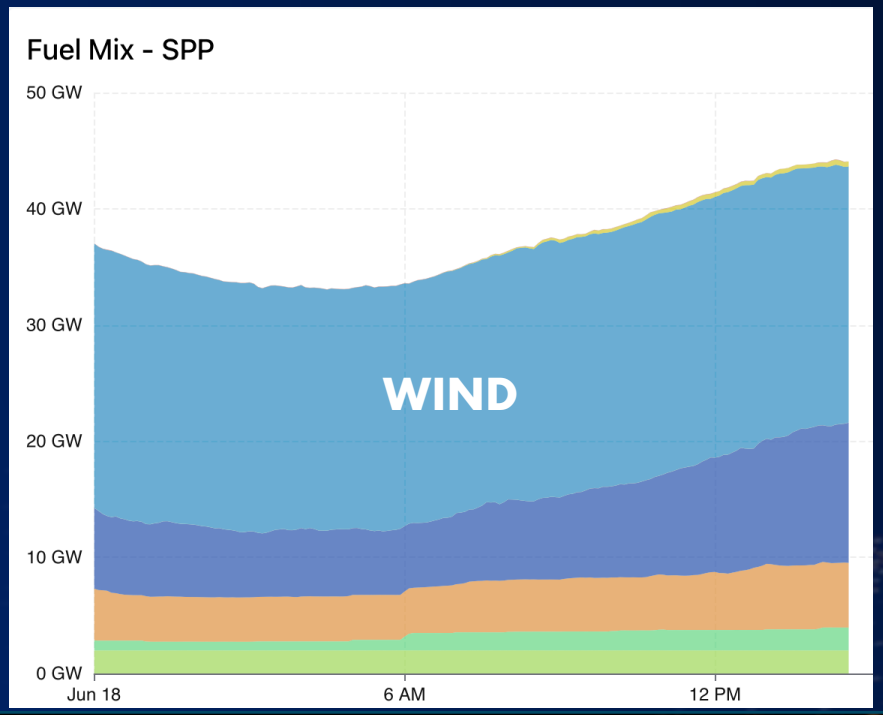


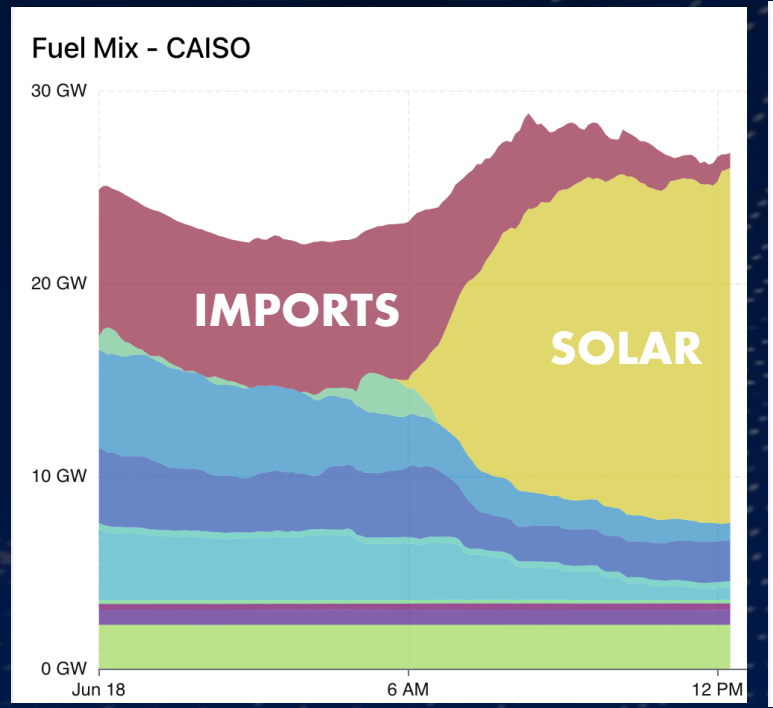


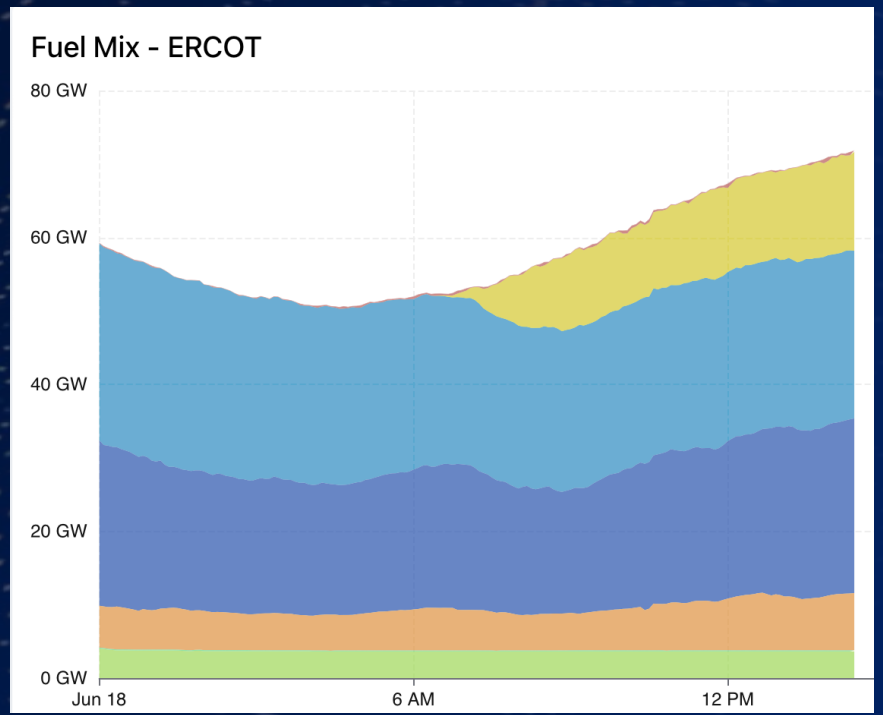


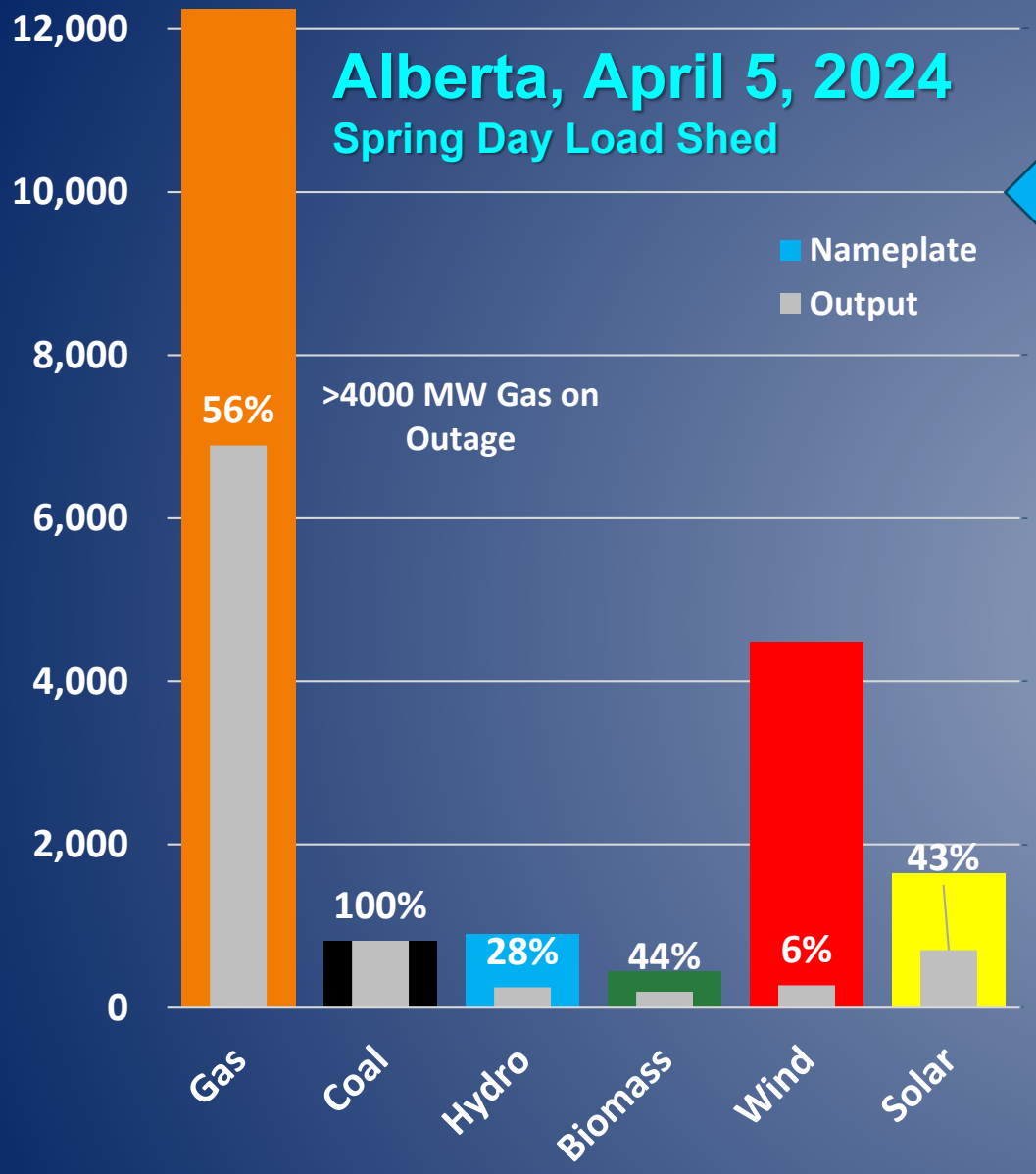
No One Size Fits All

data from June 18, 2024

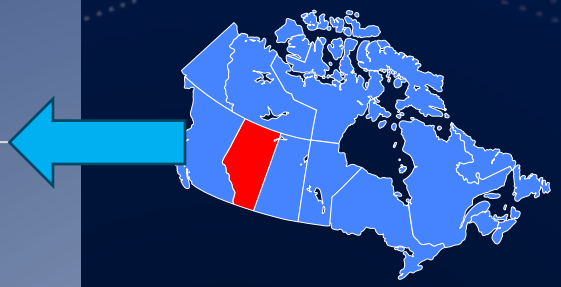






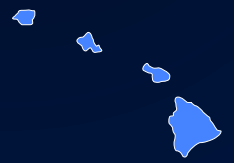


Alberta Electricity System Operator's (AESO) media briefing (https://lnkd.in/eer2822U)



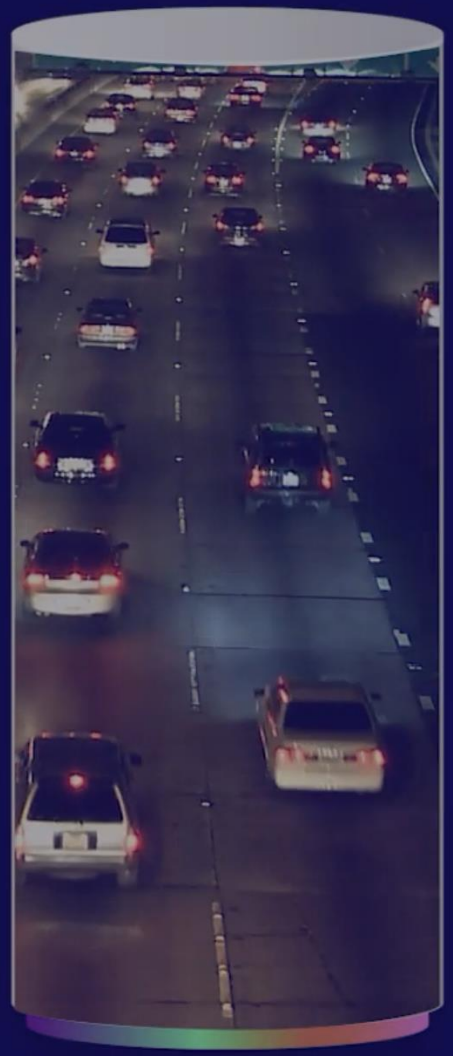
CANADA April 5, 2024
Load shedding of approximately 250 MW for 20 minutes to stabilize the supply-demand balance

TEXAS April 30, 2024
ERCOT warns of deficient power reserves and potential load shedding

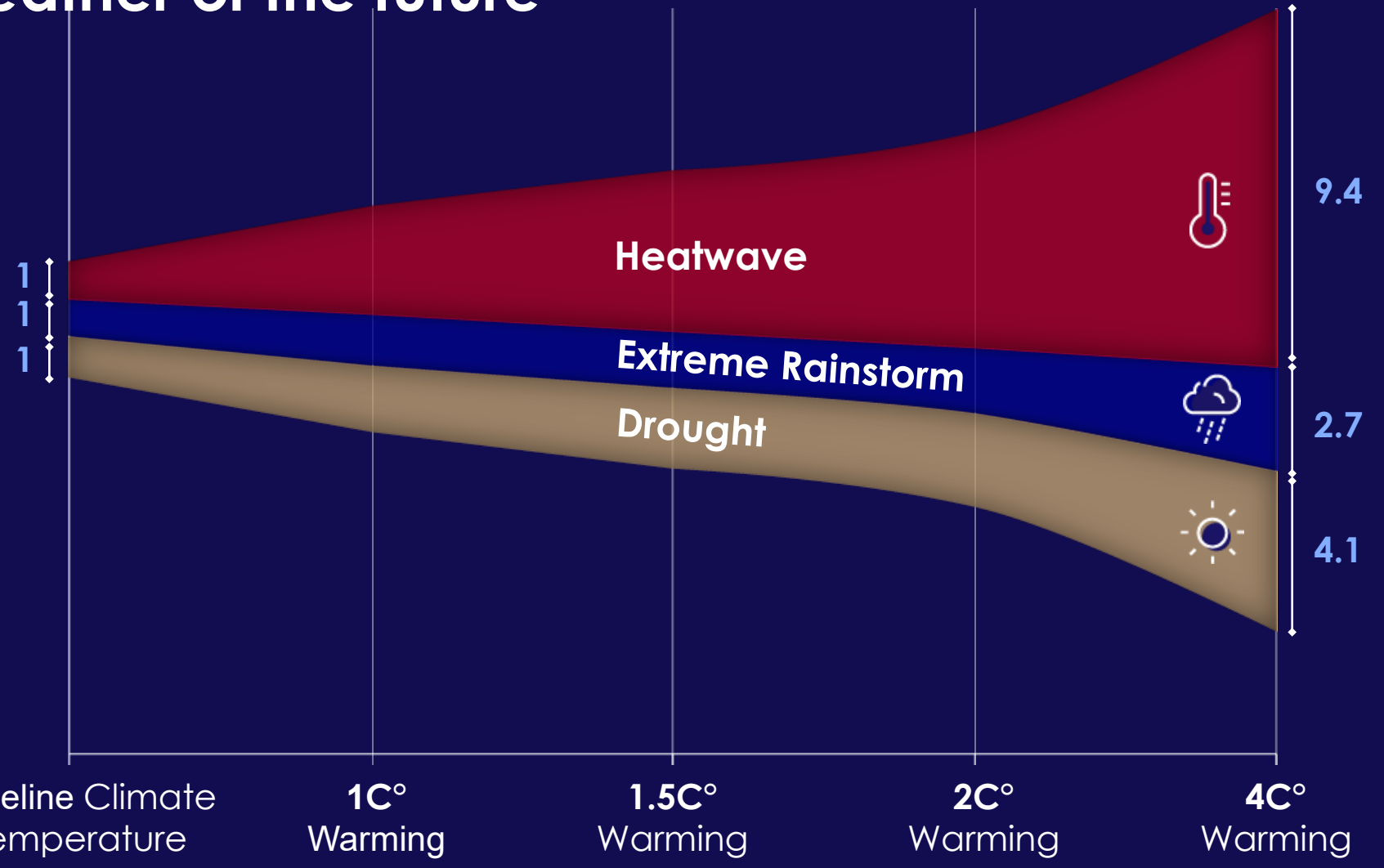


HAWAII April 15, 2024
Hawaii prepared to initiate rolling blackouts due to decreased wind and solar

Weather



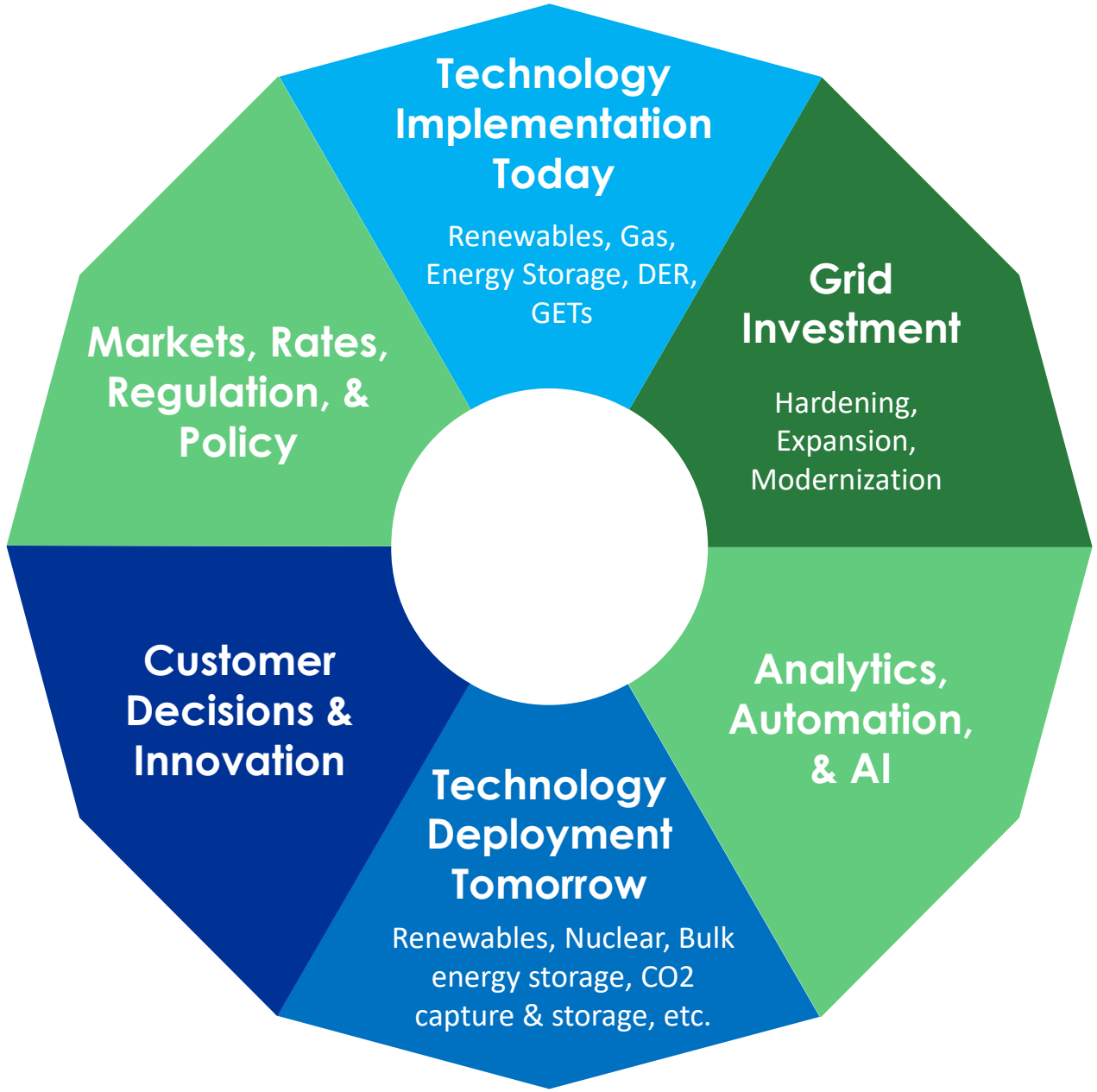
Grid of the future will need to be ready for the weather of the future



…weather of the future depends on how fast we decarbonize

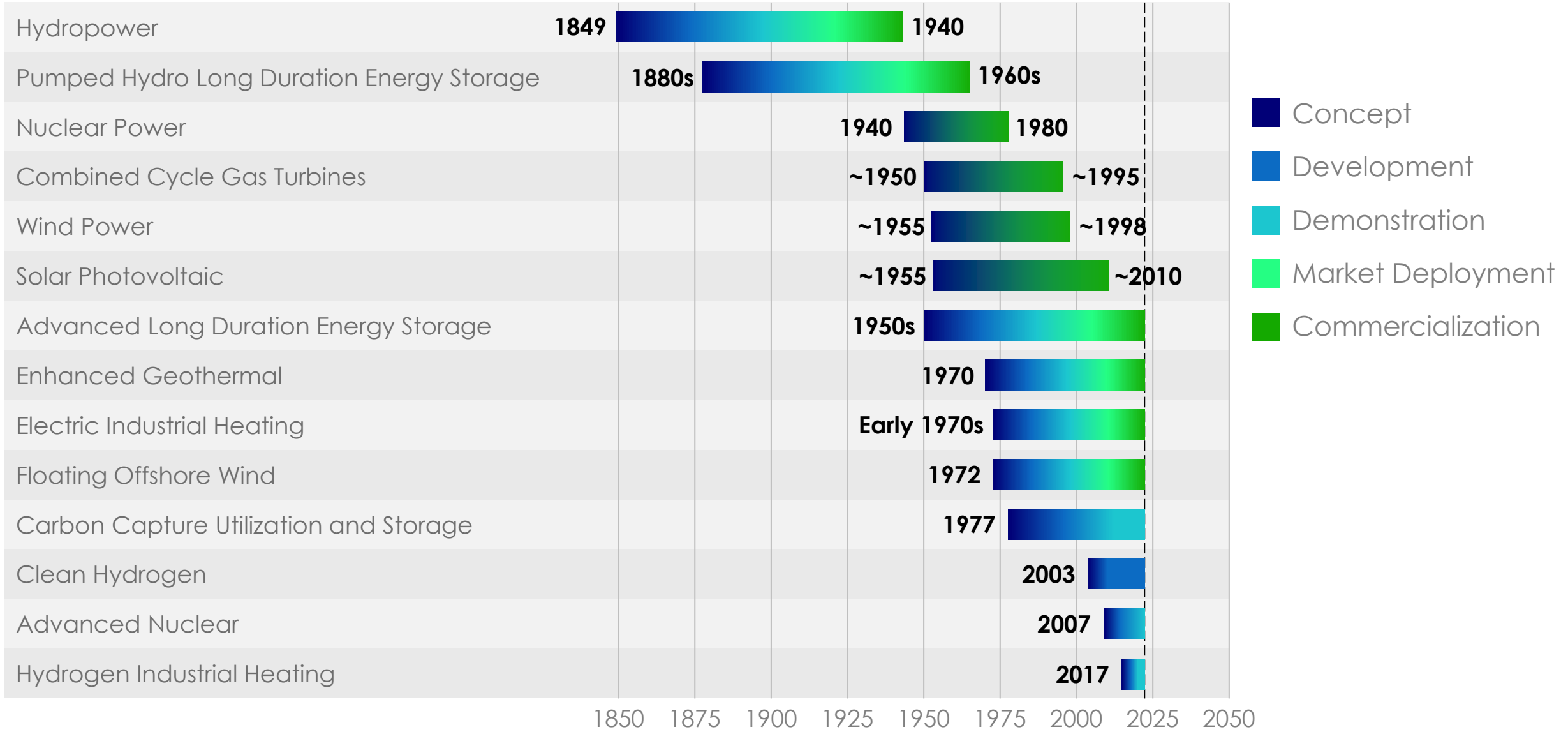
No Single Solution

Many critical pathways
to enable an
AFFORDABLE and RELIABLE
energy transformation



TECHNOLOGY

Decades of Effort
From concept to commercialization

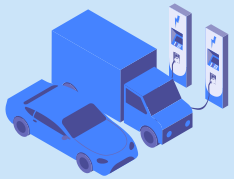


Decarbonization Options by Industry

Technology Options are Valuable

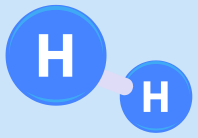
Clean Electricity


Buildings


Transportation


Industrial Processes

Short and Medium Duration Energy Storage

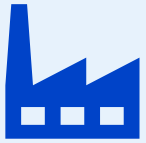


Electrolytic Hydrogen

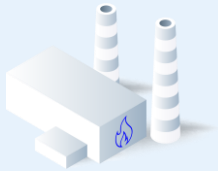
Hydrogen Direct


Refining & Chemicals


Ammonia

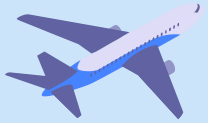

Steel


High Temp Process Heating


Power Generation & Seasonal Storage

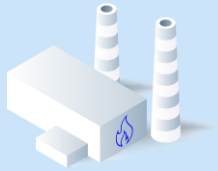

MD/HD Vehicles

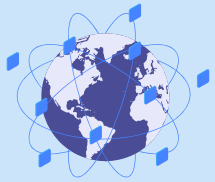
Hydrogen Derivatives & Biofuels


Aviation

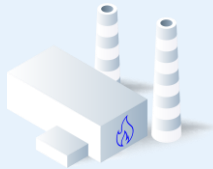

Marine Shipping


MD/HD Vehicles


Power Generation & Seasonal Storage


Bulk Import / Export

Carbon Capture


Power Generation

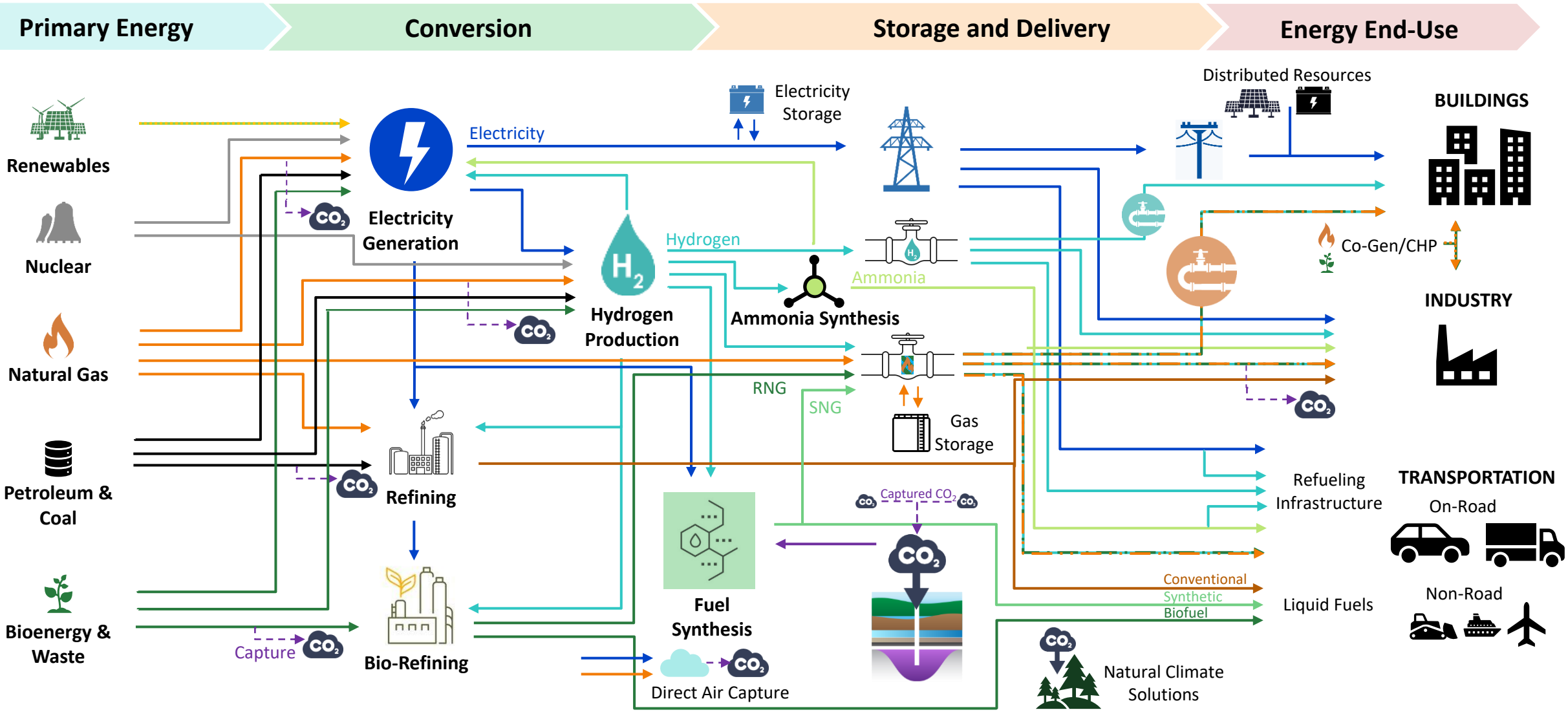

Cement & Concrete


Ammonia


Industrial Process Heating


Carbon Offset Technologies

Energy System is Becoming More Integrated



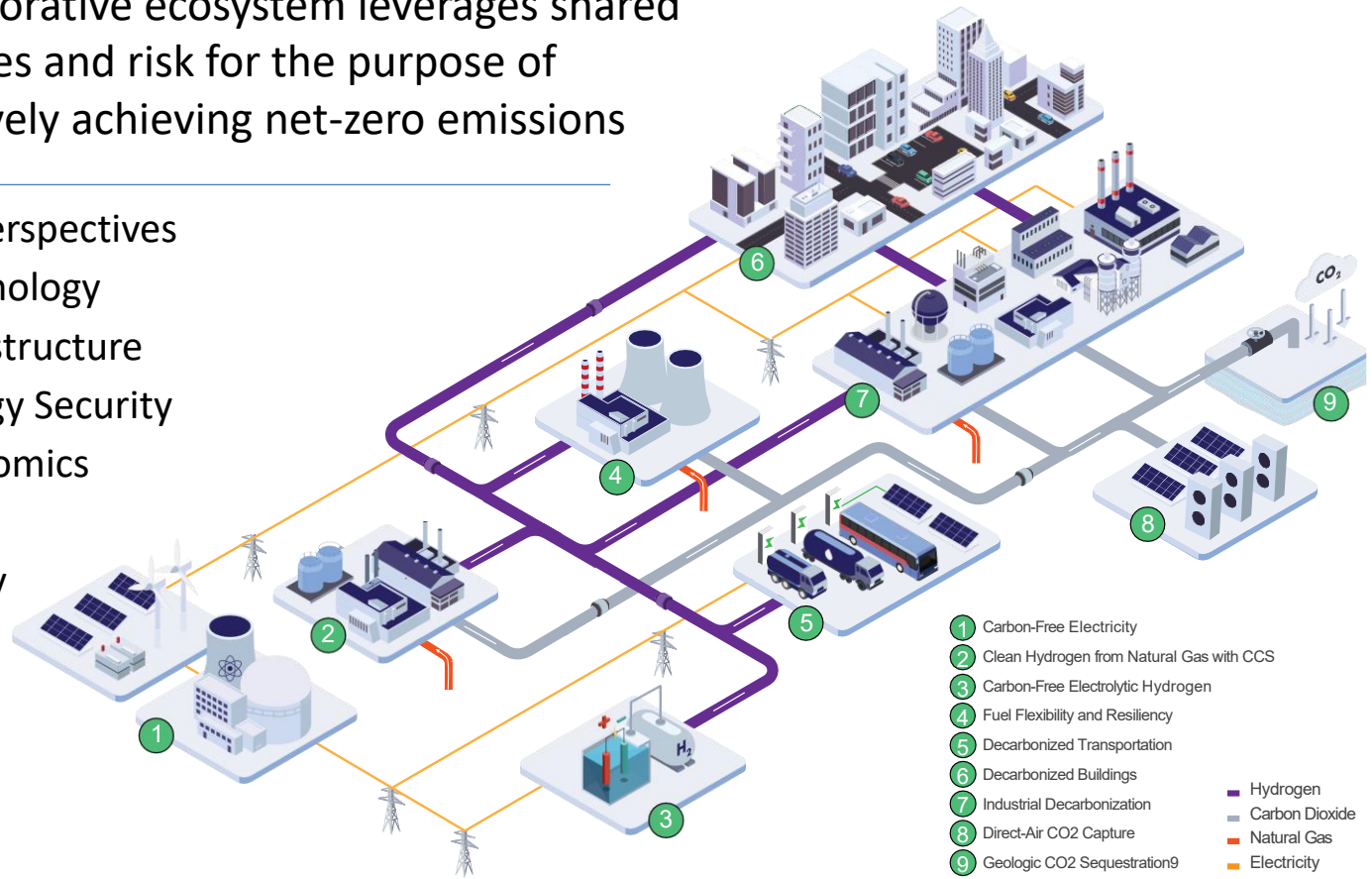
Integrated approach to decarbonization

LCRI is focused on reducing risks and maximizing impact while prioritizing safety, reliability, and affordability

A collaborative ecosystem leverages shared resources and risk for the purpose of collectively achieving net-zero emissions

Value Perspectives

- Technology
- Infrastructure
- Energy Security
- Economics
- Jobs
- Policy



Maximize Emissions Reductions

Enhance Economic Efficiency

Reduce Technology Risks

Enable Energy Flexibility & Resilience

Align Policies and Regulations

Realize Environmental and Social Benefits

Develop Long-Term Sustainability

Accelerating Low-carbon Fuel Deployment

From concept to commercialization

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Foundational Knowledge. Value-based applied research evaluating the feasibility of new technologies.

Demonstrations. Pilot-scale deployments to demonstrate capabilities and scalability.

Environmental Aspects. Independent evaluations of technologies and methods.

Infrastructure Readiness. Understanding potential use of existing vs. new infrastructure.

Commercialization. Pathways to adopt new technologies and infrastructure.

Global collaboration	Addressing common challenges & transferring lessons learned
Technical research	Independent, objective, and technical rigor
Technology demonstration	Validation, scaling, and communicating
Resources and tools	Applying research at the company-level

LCRI Timeline & Progression

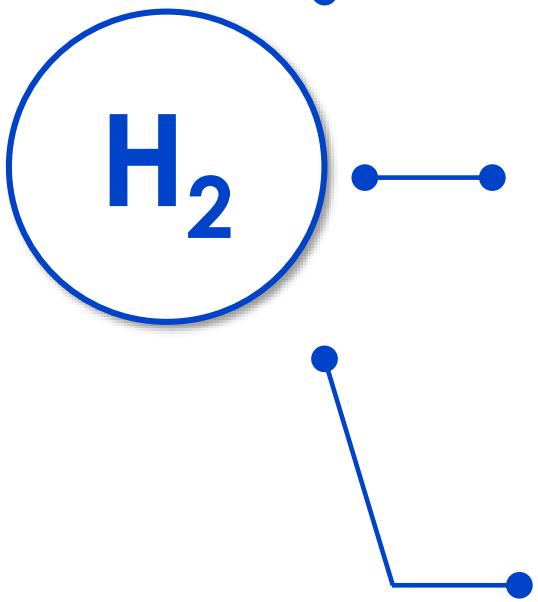
High-impact research driving towards economy-wide decarbonization

Foundational Knowledge & Initial Testing

Integrated Analysis and Technology Demonstrations

Demonstrating Integrated Pathways

Key Aspects for Accelerating Deployment of Hydrogen



Clarifying Hydrogen's Role

- Decarbonization objectives
- Consumer adoption priorities
- Policy and regulatory impacts

Supporting Regional Engagement

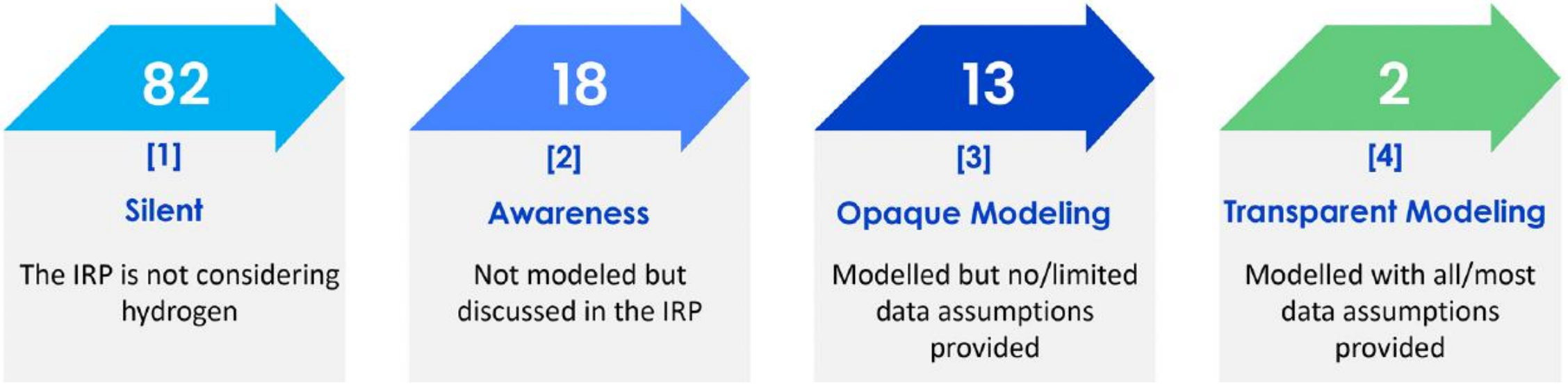
- Stakeholder education
- Workforce development and training
- Community and environmental priorities

Advancing Technology Adoption

- Demonstrations on production, storage, delivery, and use
- Expanded infrastructure for storage and delivery
- Best practices for design and operations

hydrogen.epri.com

State of Hydrogen Modeling in Electric Company Integrated Resource Planning



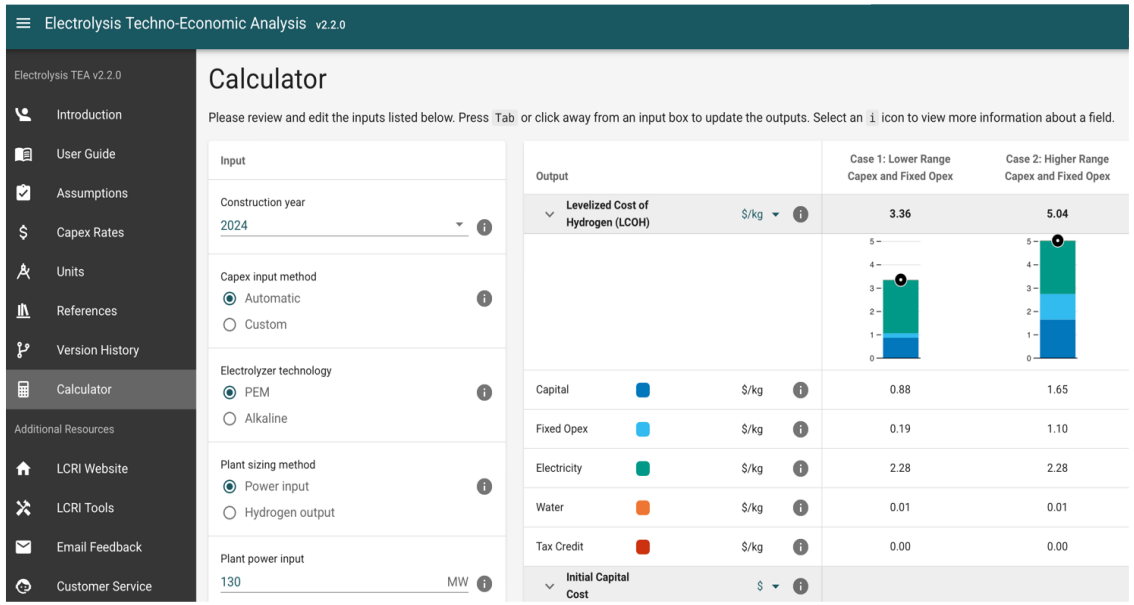
EPRI's review of 115 IRPs in regulated states in the U.S. found that the level of transparency and completeness of the models varied, with the majority silent on hydrogen.

EPRI 3002026595

Hydrogen + Renewables

Plant Design & Optimization

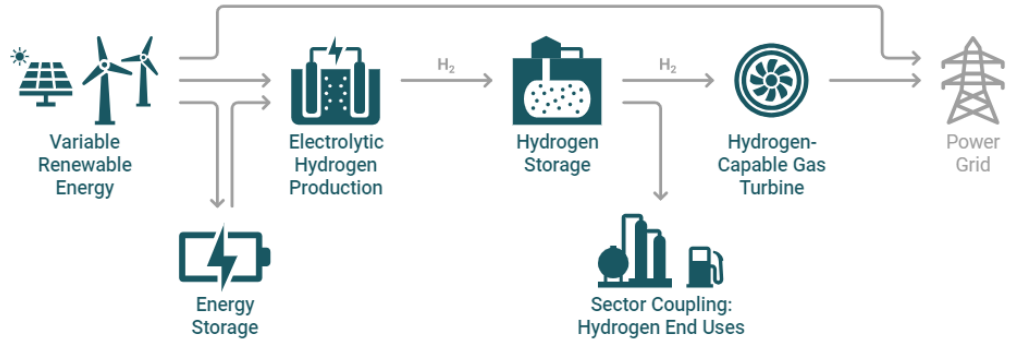
Hydrogen Electrolysis Techno-Economic Analysis

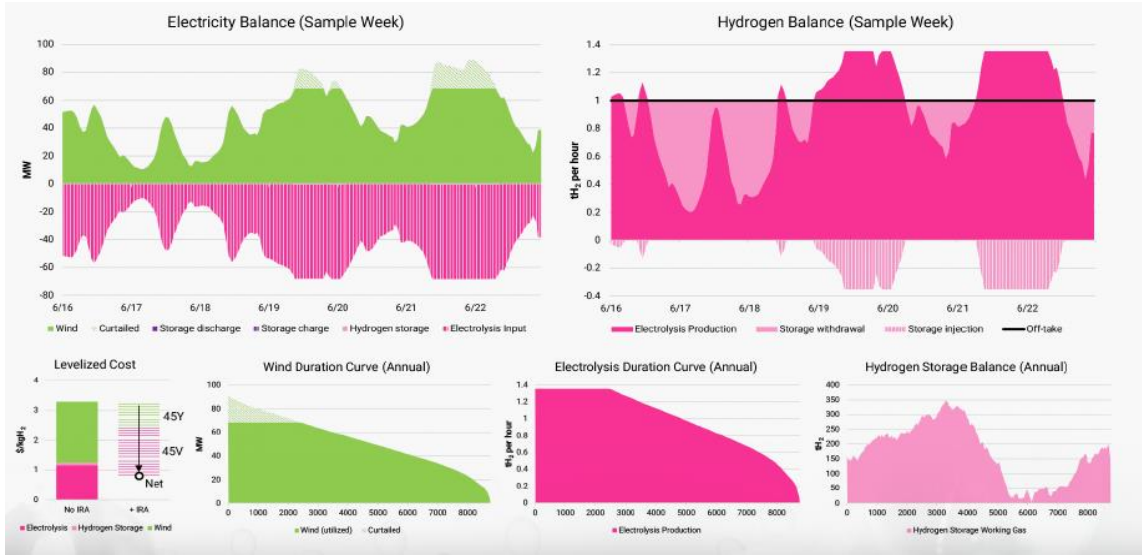


Provides levelized cost of hydrogen based on the electrolysis plant design, operation mode, and economic considerations

https://lcri-tools.epri.com/tea-electrolysis/calculator

Impacts of IRA 45V Clean Hydrogen Production Tax Credit

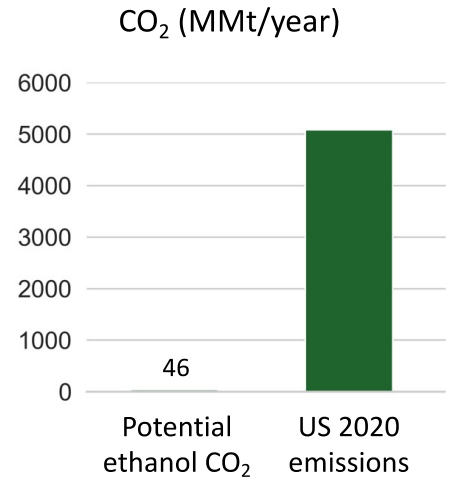


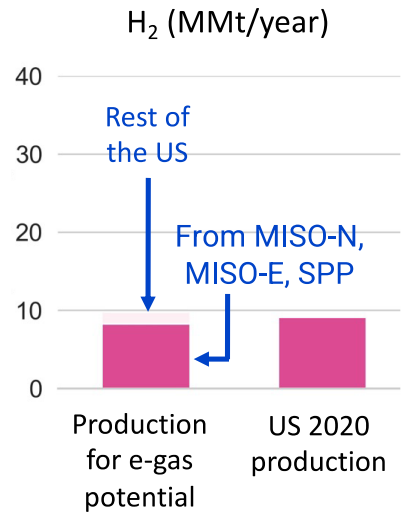


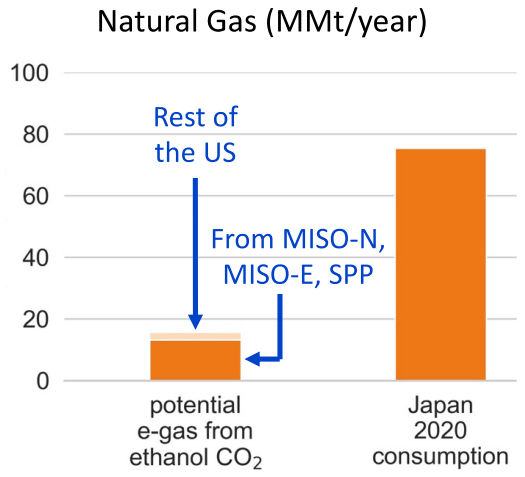
EPRI 3002028407

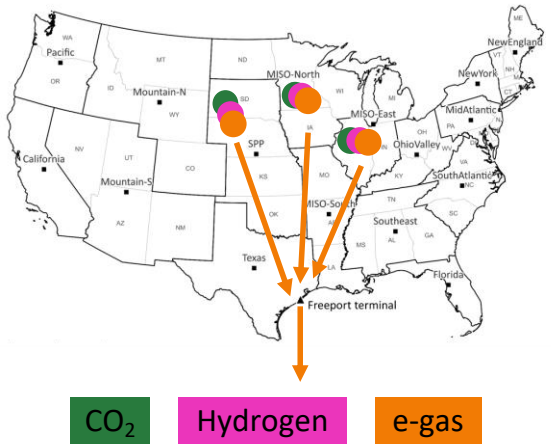
US Potential for e-Fuels Production and Export

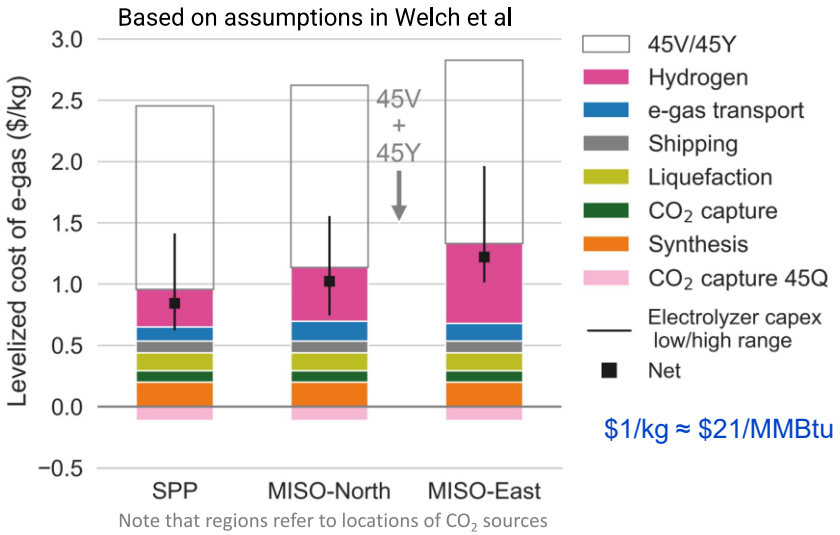
CO_2 captured from existing ethanol facilities and e-gas produced may be small compared to current levels of production in the US, but hydrogen requirements may be significant











With maximum IRA tax credits, 1.1-1.5 $/kg e-gas ($23 - $30 per MMBtu) from three scenarios analyzed with electrolyzer costs of 1,440 $/kWe

Source: Feasibility Assessment of U.S. E-gas Exports to Japan

Hydrogen Education for a Decarbonized Global Economy (H_2EDGE)

Primary Goal

Building a sustainable infrastructure for developing a workforce for the emerging H_2 economy as a part of the decarbonized global economy by:

- Developing course material at the university and professional level
- Creating a university network, which includes HBCUs
- Evaluating and measuring course and overall program effectiveness
- Assessing the job needs for the hydrogen economy

Key Participants

Principal Investigator: Dr. Eladio Knipping (EPRI)
Co-Investigator: Dr. Krystal York (EPRI)

- Partner Universities: Oregon State University, University of Delaware, University of Houston
- Other Major Participants: GTI Energy, Embedded Assessments, Cavendish Energy, and industry partners on an Advisory Board

Project Description

Clean H_2 technology is emerging as an option to help decarbonize our energy system, leading to new jobs across a variety of industries.

- H_2EDGE was initiated to develop a workforce for the emerging hydrogen industry.
- Content will cover in four key technical pillars that form the basis of the H_2 industry: production, delivery, storage, and end-use with safety as a foundation woven through each pillar.
- A professional short course program is being developed to cover the four key pillars and will be given through a wide variety of delivery options including in-person and virtual.
- A university network is being developed, led by Partner Universities and expanded with Affiliate Universities. Affiliate Universities are industry sponsored to build a long-term sustainable relationship.

Program Approach

	Key Milestones and Tasks
Develop	• Establish an industrial Advisory Board • Select Partner Universities and launch curriculum • Create an Affiliate University network (including HBCUs) • Develop professional course material
Deliver	• Deliver professional training and academic curriculum • Execute regional workshops and webinars to “train the trainer” (instructors/professors) for Affiliate Universities • Establish internships and capstone projects
Evaluate	• Create an academic and professional gaps assessment • Make iterative improvements to content and delivery
Sustain	• Deliver a sustainability plan for a hydrogen workforce • Establish a university network • Establish and maintain repository of materials

The hydrogen industry is expected to grow, and thus, create more jobs within the industry. H_2EDGE will increase workforce readiness within the industry and support decarbonization.

U.S. DEPARTMENT OF ENERGY

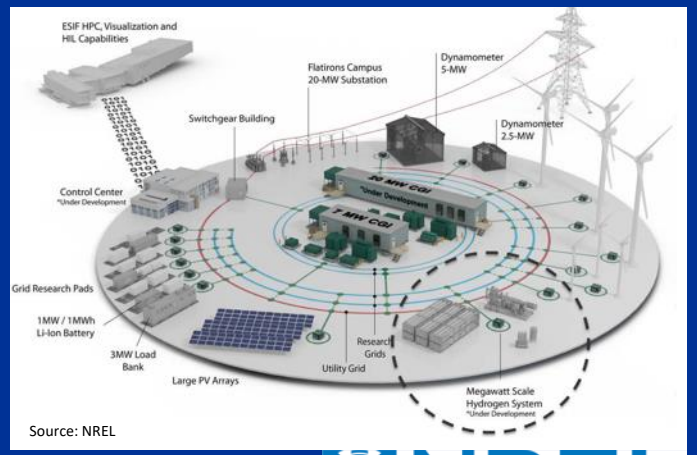
Website: https://hydrogen.epri.com/en/h2edge.html

Examples from LCRI Technology Demonstration Portfolio

PRODUCTION

Renewables + Electrolyzer Flexibility

- Operate 1.25 MW PEM electrolyzer
- Develop system characterization and monitoring guidelines



Source: NREL

NREL Transforming ENERGY

STORAGE & DELIVERY

Hydrogen Infrastructure

- Evaluate natural gas pipeline infrastructure hydrogen compatibilities
- Characterize benefits, risks, and costs of blending hydrogen

HyBlend
U.S. DEPARTMENT OF ENERGY

END USE

Technology Adoption Tests

- On-road and off-road transportation fueling
- Blending with natural gas for power generation
- Microgrid integration
- Industrial heating and processing
- Leak detection sensors

EPRI

Natural Gas Power Generation: Retrofit, Repower, or New

Increasing Complexity →

Drop-in Biofuels	Blended Low-Carbon Fuels	CO_2 Capture and Storage	100% Low-Carbon Fuels

Factors Impacting Natural Gas

Upstream Methane Emissions
(Full life cycle)

Public Acceptance, Permitting, Infrastructure

Availability
(Domestic vs. Imports)

Cost
(Supply & Demand, CO_2 tax)

Renewable Fuels Research Portfolio

Supply Chain Assessments

- Transportation & inbound logistics guidance
- Biofuel sourcing & supply considerations
- Fuels production process designs

Fuel Use Guidance

- Operations guidelines for existing and new assets (gas turbines, RICE, boilers, fuel cells, etc.)
- Fuel storage and on-site implementation support

Fuel Characterization

- Combustion analyses & emissions profiling
- Database of renewable fuels properties
- Life-cycle carbon intensity analysis

Community & Environment

- Economic impacts assessment (workforce development, direct/indirect/induced economics, etc.)
- Localized environmental impacts analysis

Renewable Fuels Research Value

Renewable Fuels Atlas

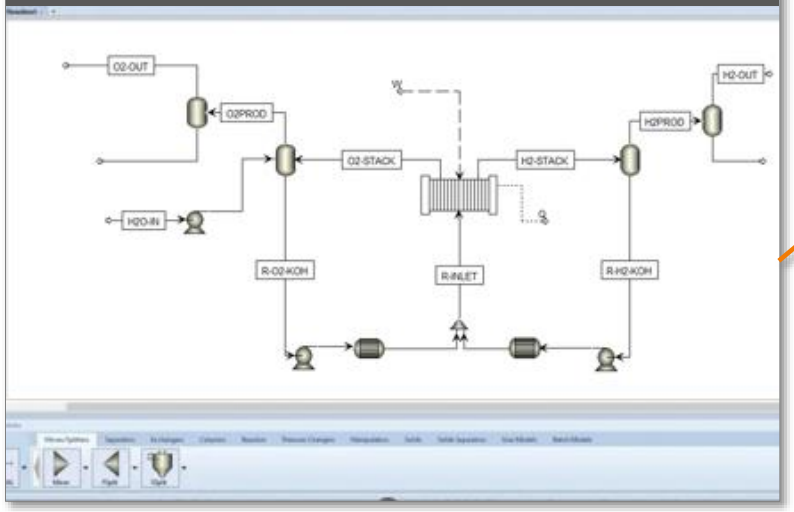
Database and Mapping
- Power generation
- Ethanol production
- Biofuels sources
- NG pipelines
- Rail lines

https://apps.epri.com/lcri-rf-atlas/en/map.html

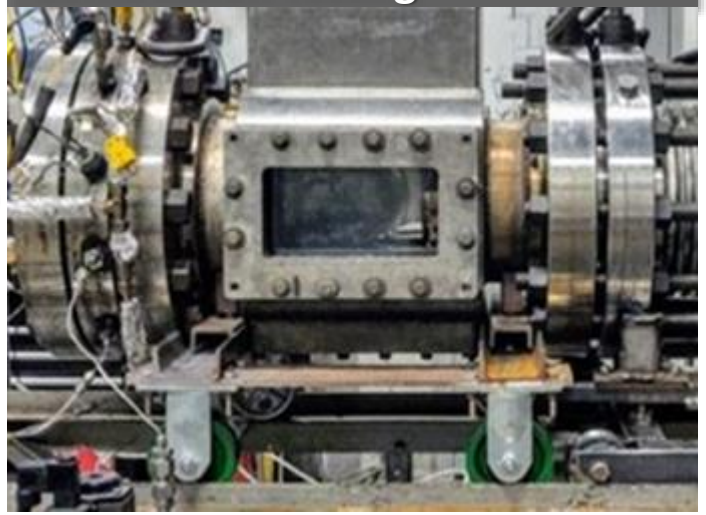
Renewable Fuels Fact Sheet

EPRI 3002028341

Process Models



Combustion Testing



EPRI Supported Testing of Hydrogen for Power Generation

Hydrogen Testing Objectives

- Operate unit without major modifications
- Measure impacts on CO_2, NOx, CO, and unit performance
- Develop best practices for hydrogen blending
- Provide input on priorities for R&D needs

NEW YORK STATE OF OPPORTUNITY. | NY Power Authority

44%v | GE LM6000
(45 MWe - Aeroderivative)

Executive Summary report

Georgia Power

20.9%v | Mitsubishi 501G
(265 MWe – Heavy Frame)

White Paper report

WEC Energy Group

25%v | Wärtsilä RICE
(18 MWe – RICE)

Executive Summary report

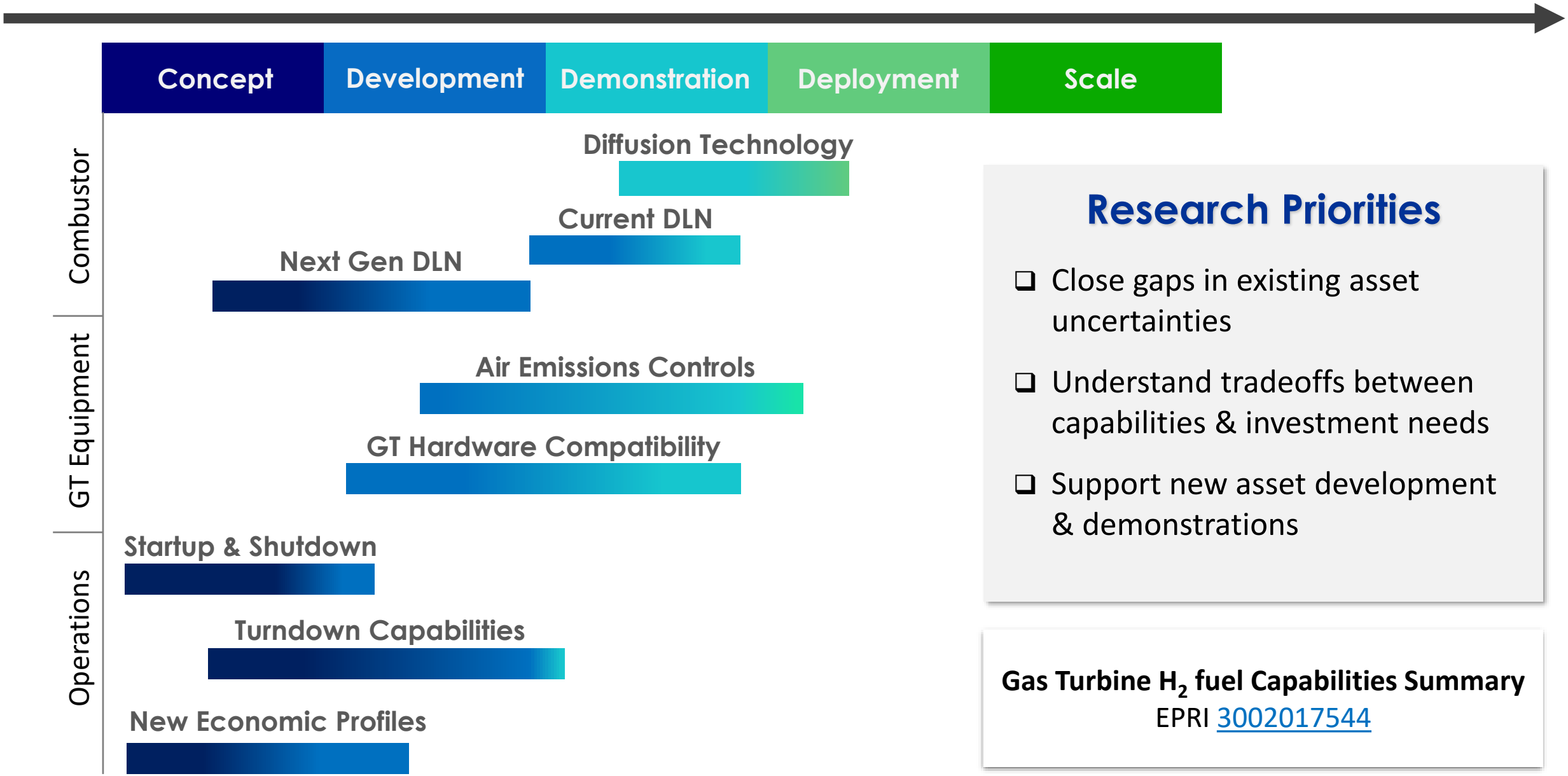
Constellation.

38%v | Siemens SGT6-6000G
(246 MWe – Heavy Frame)

Press Release

Hydrogen Blending Demonstration Synopsis: EPRI-Affiliated Testing Summary (EPRI 3002028175)

Status of Hydrogen as a Low-Carbon Fuel for Gas Turbines



Research Priorities

- ❑ Close gaps in existing asset uncertainties
- ❑ Understand tradeoffs between capabilities & investment needs
- ❑ Support new asset development & demonstrations

Gas Turbine H_2 fuel Capabilities Summary
EPRI 3002017544

LCRI Efforts to Accelerate Technology Development

Completed & Ongoing LCRI Demonstrations

3 Electrolyzer demonstrations

4 Natural gas & bio-feedstock to hydrogen related demonstrations

6 Hydrogen in power generation demonstrations (4 gas turbines, 1 reciprocating engine, 1 fuel cell)

3 Fundamental tests of ammonia combustion

3 Carbon capture / direct air capture related demonstrations

4 Commercial & industrial decarbonization demonstrations

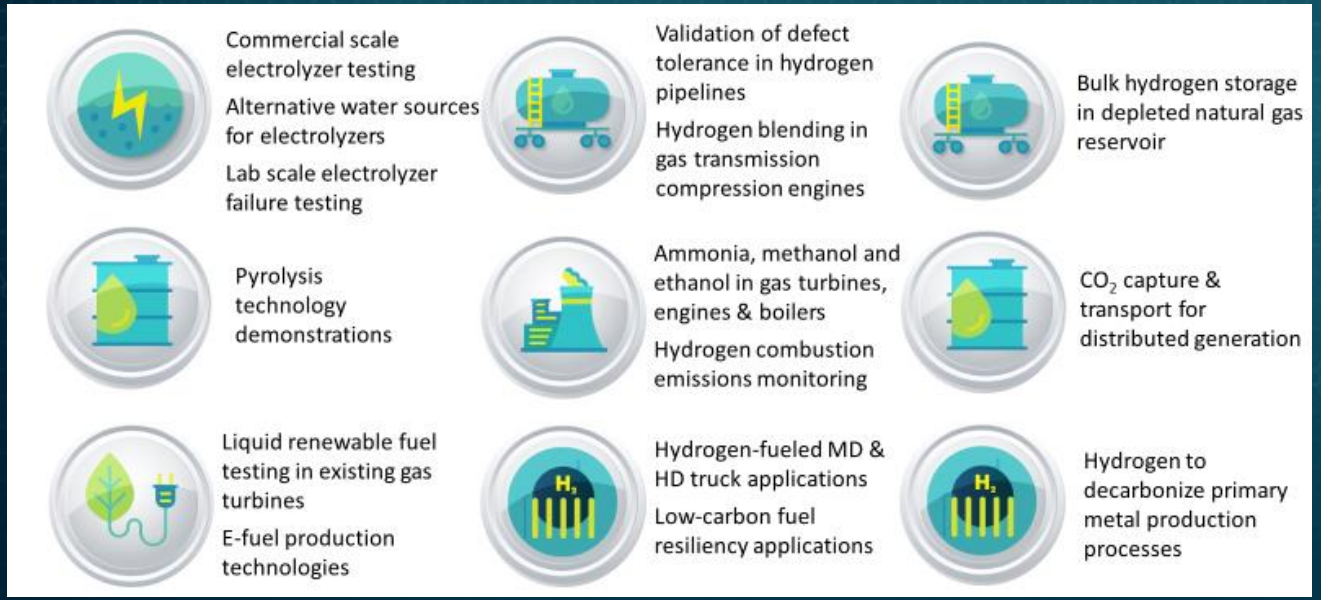
2 Transport application demonstrations

1 Jet fuel and gasoline production demonstration

3 Delivery and storage infrastructure related demonstrations

Upcoming LCRI Efforts to Accelerate Technology Commercialization

24 New Demonstration Projects Across the Low-Carbon Fuels Value Chain



H2Hub Network | Addressing Common Needs

The H2Hub Network is convened by EPRI to foster industry-wide collaboration. This technical platform facilitates the collective development and real-time exchange of insights, best practices, metrics, and other valuable information across the development, operation, and evolution of hydrogen hubs.

Information Sharing

- Designed to address the common technology, workforce, and community challenges of all H2Hubs
- Focused on the production, end use, and integration of hydrogen, workforce training, and community benefits.
- Supports growth and sustainability of the hydrogen industry as commercial projects are deployed and evolve and learnings are shared

Education and Engagement

- **Workforce Development**
  Design and deliver educational and training materials for workers and learning institutions
- **Community Leadership**
  Objective evaluation of the effectiveness of community benefits plans and opportunities for improvement plans
- **Health and Safety**
  Comprehensive reviews of health and safety plans to leverage best practices across H2Hubs

https://hydrogen.epri.com/en/h2hub-network.html

H2Hubs – LCRI Engagement

MIDWEST ALLIANCE FOR CLEAN HYDROGEN

https://machh2.com

HyVelocity Hub

https://www.hyvelocityhub.com

Coming Soon!

Updated Net-Zero Scenario Analysis

What has changed since 2022?

Inflation Reduction Act (IRA)

Wide range of incentives across electric and end-use sectors for clean energy and domestic manufacturing

New EPA Power Plant Rules 111(b) and (d)

Updated GHG performance standards for new gas and existing coal units

Data center / other load growth drivers

Emerging trends of accelerated load growth in certain regions

Pace of Change Has Intensified

AI/ Data Center

Extreme Weather

Emerging Low-Carbon, Dispatchable Technologies

Reliability

LCRI

LOW-CARBON RESOURCES INITIATIVE

Enabling the Pathway to Economy-Wide Decarbonization

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www.lowcarbonLCRI.com

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