Economy-Wide Decarbonization

A Global R&D Perspective

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EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Advancing safe, reliable, affordable, and environmentally responsible electricity for society through global collaboration, thought leadership, and science and technology innovation.

Together…Shaping the Future of

KEY ASPECTS

Nonprofit

Chartered to serve the public benefit, with guidance from an independent advisory council.

Thought Leadership

Systematically and imaginatively looking ahead to identify issues, technology gaps, and broader needs that can be addressed by the electricity sector.

Independent

Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

Scientific and Industry Expertise

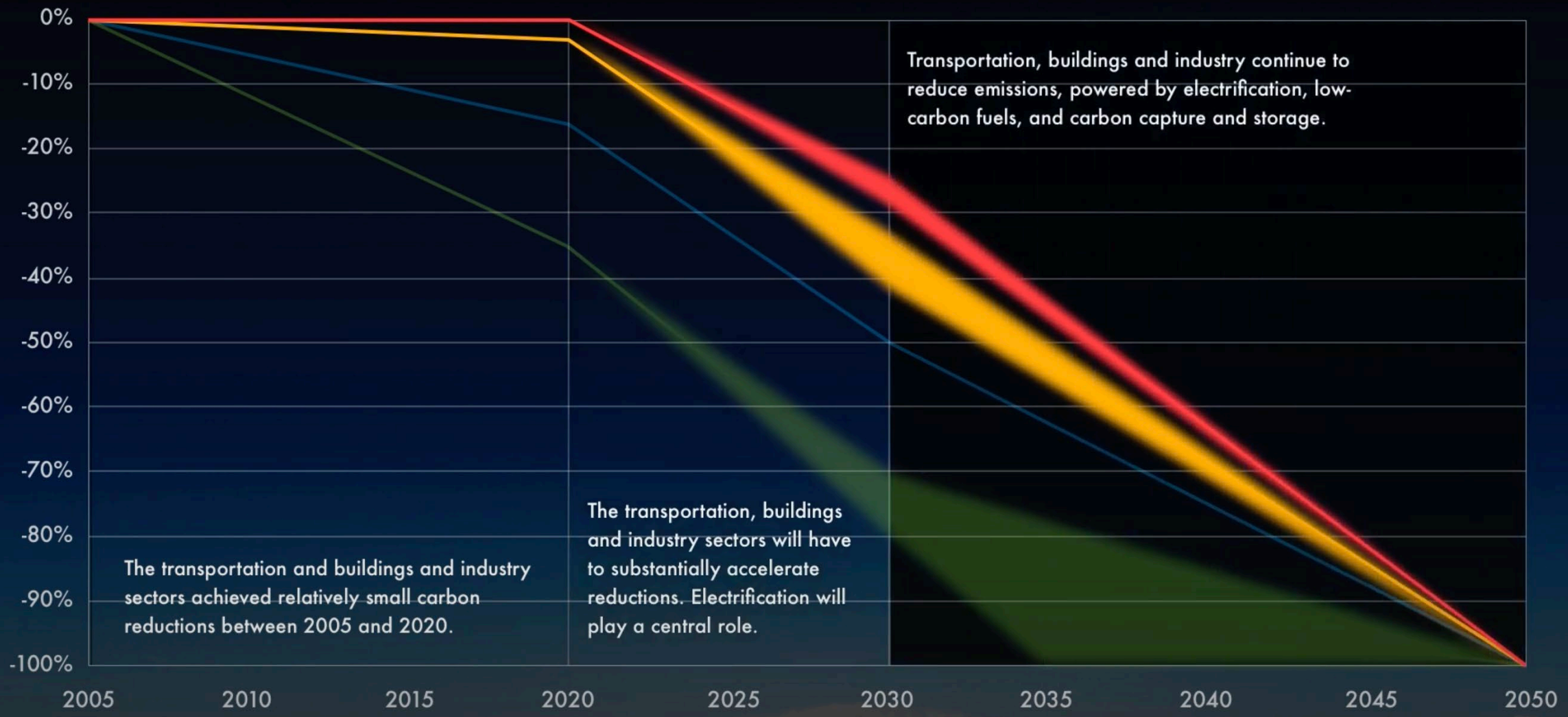
Provide expertise in technical disciplines that bring answers and solutions to electricity generation, transmission, distribution, and end use.

Collaborative Value

Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

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

Collaborative innovation essential to an affordable and reliable energy future



STRATEGIC IMPERATIVES

NEW THINKING, NEW APPROACHES

Accelerate Clean Energy Innovation

Enhance System Resilience and Adaptability

Reimagine our communities

Reimagining the Future Energy System

Decarbonization

Near-term ~10-15 years

Accelerate economy-wide, low-carbon solutions

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

Long-term ~15-30 years

Net-zero clean energy system

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

Transformation

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

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

Resiliency

Near-term ~10-15 years

Mitigate climate impacts and cyber/physical risks

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

Long-term ~15-30 years

Future proof energy system design basis

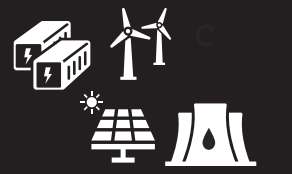
- Resilient power system design
- Advanced asset design and strategic undergrounding
- Smart integration of energy carriers

Making Energy More

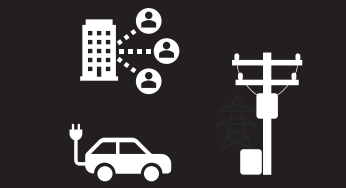
Clean | **Affordable** | **Reliable**

STRATEGIC IMPERATIVES

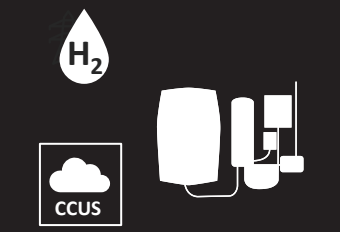
CLEAN ENERGY INNOVATION



Clean energy



Electrification



And Beyond

Decarbonization Pathways Enabled by Innovation

Decarbonization

Accelerate economy-wide, low-carbon solutions

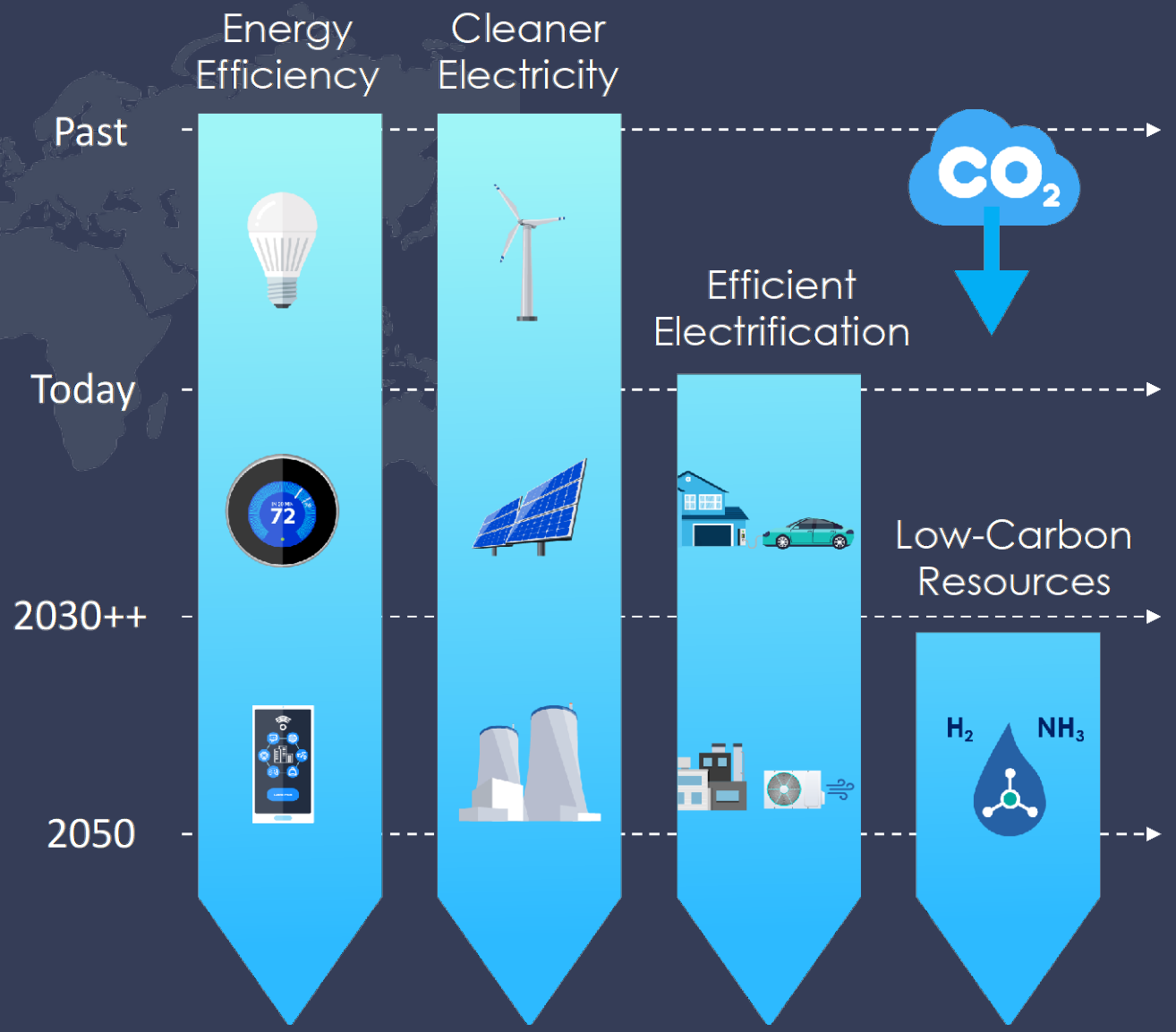
- Electric sector decarbonization
- Transmission and grid flexibility: storage, demand, EVs
- Efficient electrification

Achieve a net-zero clean energy system

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

~10-15 years

~15-30 years



DECADES OF CHANGE

WHAT DOES 2050 LOOK LIKE?

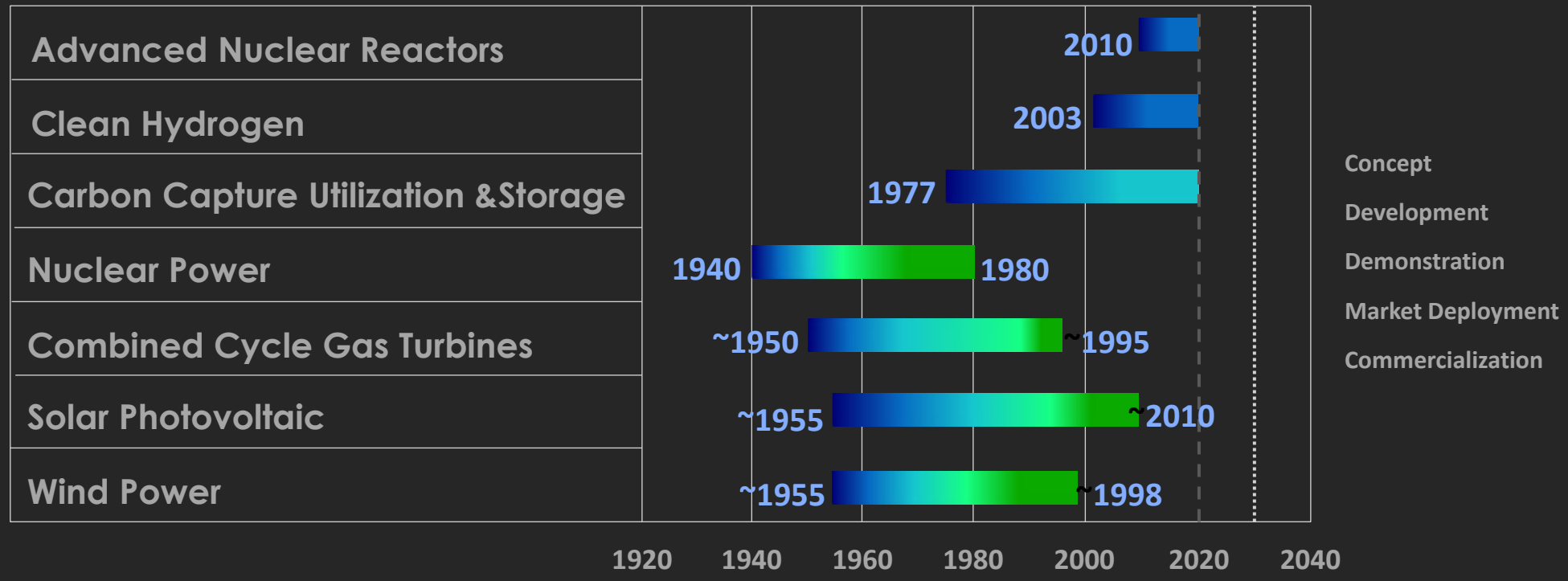
What are the technologies?

What will they cost?

What value do they provide?

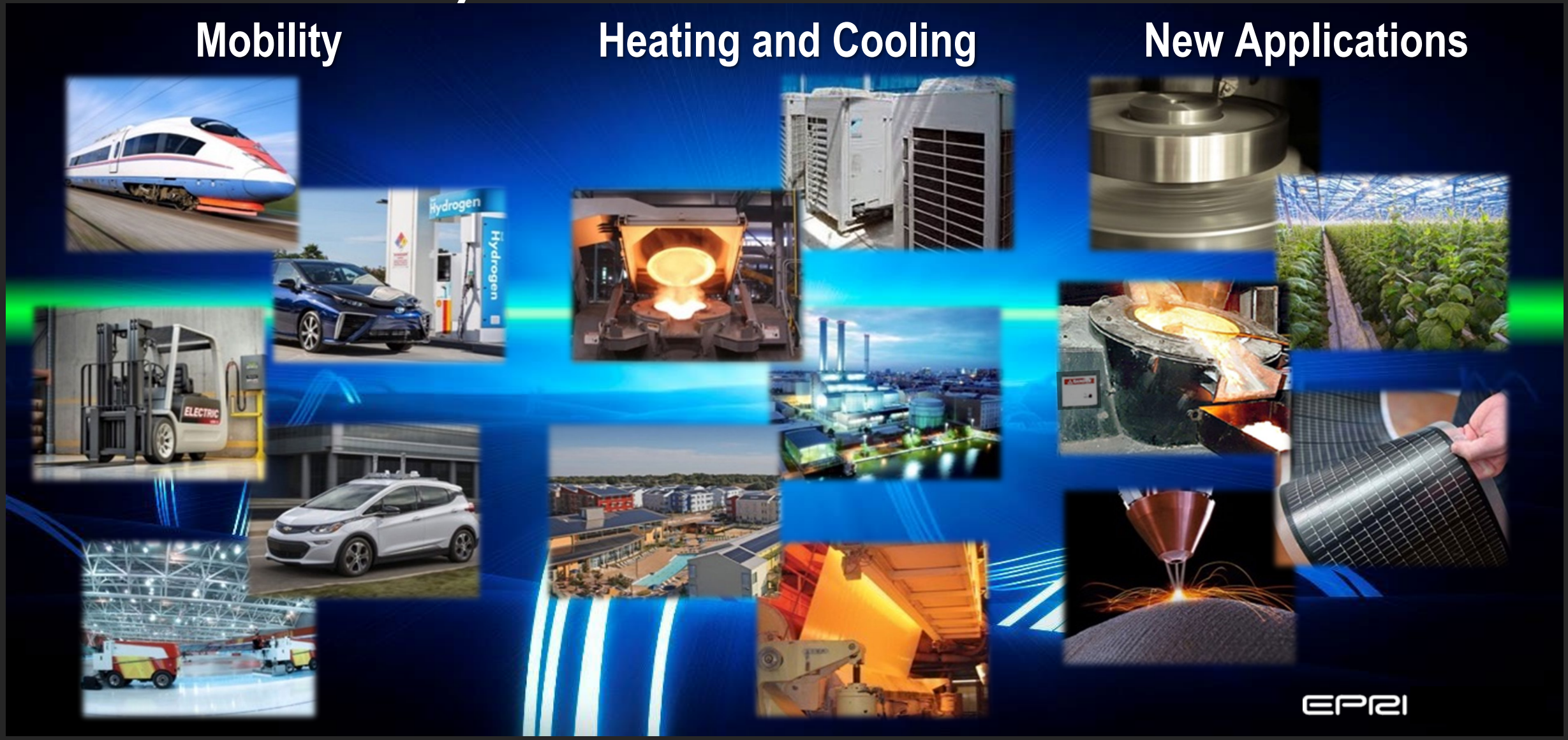
How will they perform?

What are the barriers to overcome?



Notional timelines

Key to Lower Carbon:
Cleaner Electricity That Leads to Efficient Electrification



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

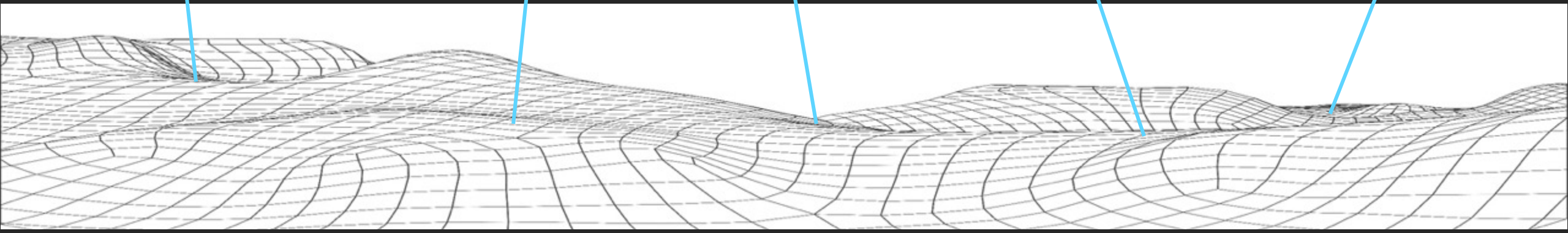
Smart and Fast EV Charging

Higher Penetration of EV/Solar/DER

Grid-Integrated Energy Storage

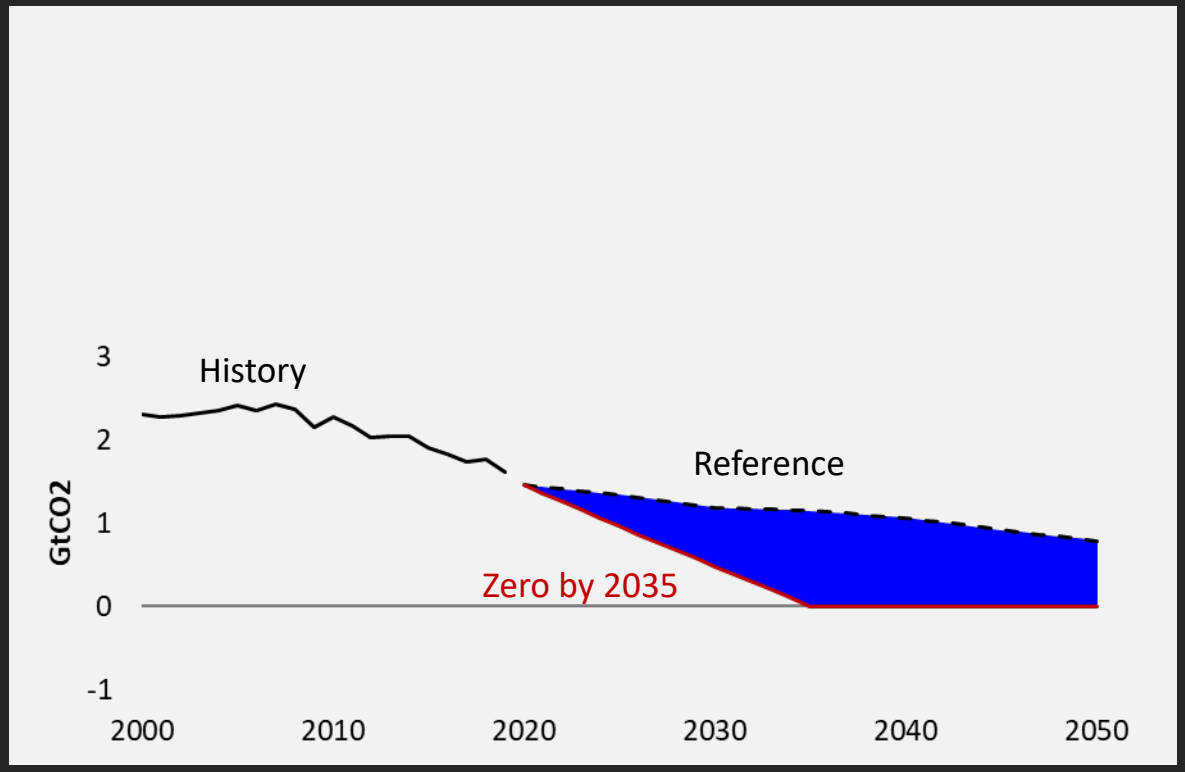
Vehicle-to-Grid System Resources

Connected, Smart, Demand-Responsive Load



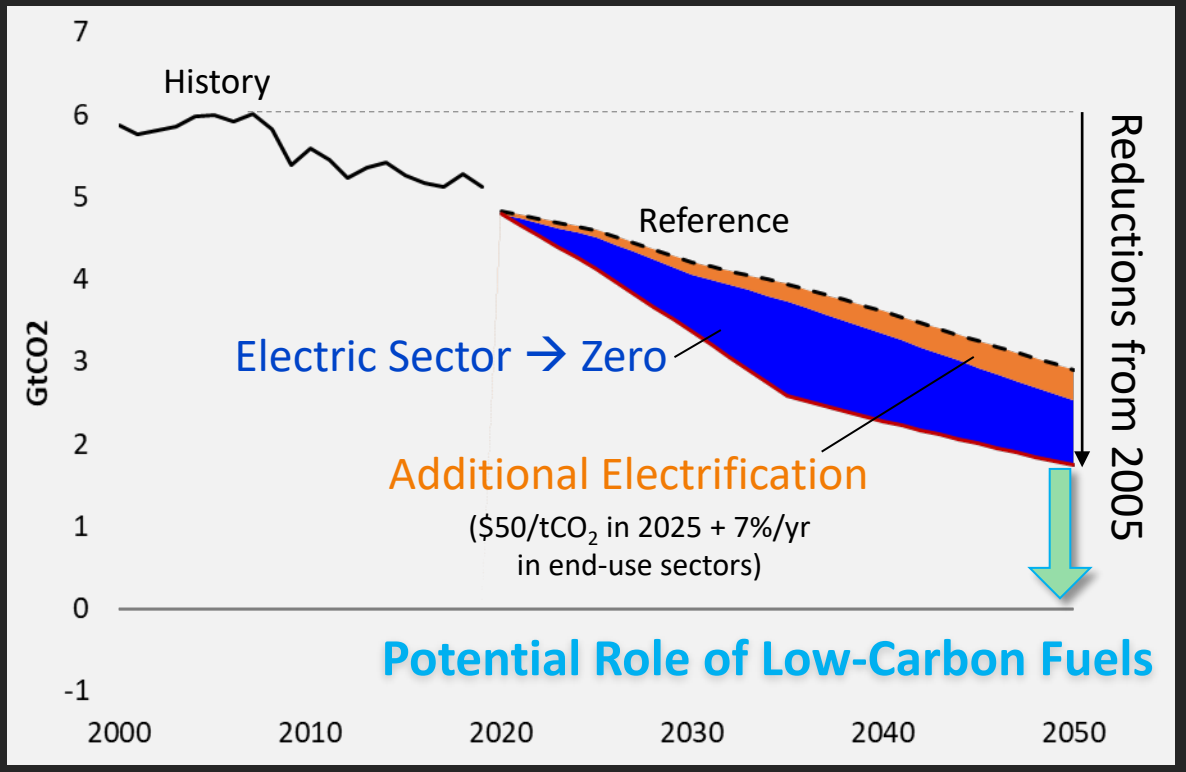
Key to Lower Carbon: Decarbonizing the "Rest" of the Economy

Electric Sector CO_2 Emissions



Electric sector emissions are reduced to zero

Economy-Wide CO_2 Emissions

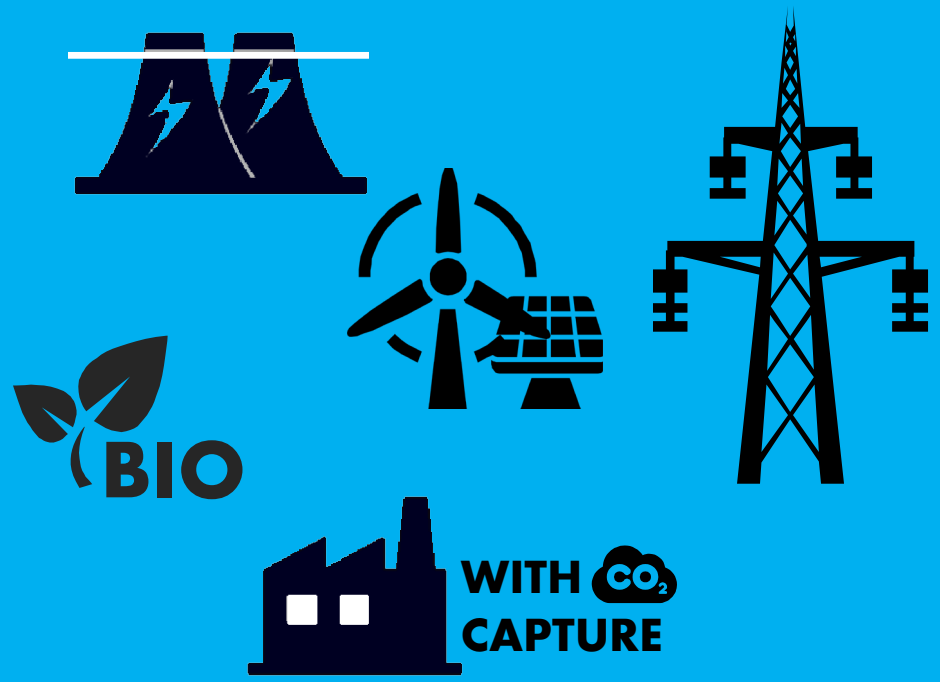


Economy-wide emissions fall to ~70% below 2005 with electric sector decarbonization plus additional electrification from CO_2 price in end-use sectors

EPRI Report 3002020700

Low-Carbon Fuels Pathway from the Electric Sector

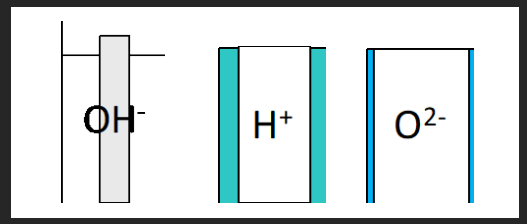
Low-Carbon Generation, Transmission & Distribution



→ **Direct Electrification** →

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

Electrolysis →



- Hydrogen
- Ammonia
- Synthetic Hydrocarbons

**Representative of one of several pathways*

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

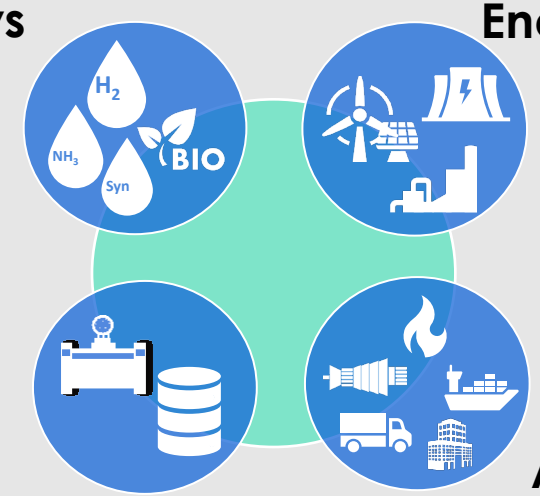
Affordable, reliable, and resilient integrated energy systems for the future

RESEARCH AREAS

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

Production Pathways

Integrated Energy Systems



Storage & Delivery

End Use Applications

VALUE

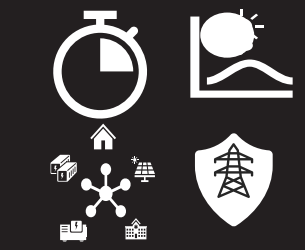
Independent, objective research leveraged by global engagement and collaboration

Comprehensive value chain approach across adjacent sectors

High-impact results that accelerate technology time to market

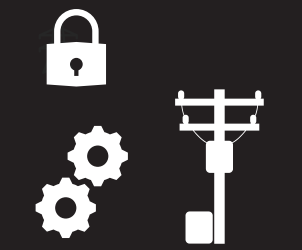
STRATEGIC IMPERATIVES

RESILIENCE AND ADAPTATION



Reliability and Resilience

Greater Understanding of Risks



Greater Understanding of infrastructure needs

Reliability and Resiliency
Challenges Through the Transition

Resource Adequacy
Additional resources to meet energy needs for resiliency to extreme future scenarios.

Balancing and Flexibility
Flexibility resources and operating reserves to manage variability and uncertainty.

Delivery Adequacy
Regional T&D capacity to integrate renewables and DER and meet increased electrification demand.

Grid Stability
Resources and controls to maintain frequency and voltage for much faster dynamic system

Additional grid resources and capabilities are required for a reliable and resilient decarbonized grid.

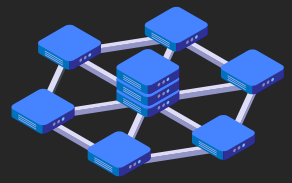
Pre-Requisites for a Reliable, Resilient Decarbonized Grid

New Grid Operation Capabilities

New protection, control, and other technologies to reliably and resiliently operate the grid

Revised Market Designs

Markets must incent investment and properly compensate resources for grid services provided

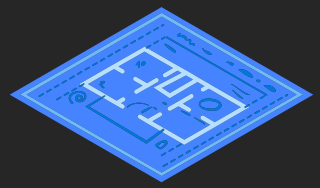


Grid Investment and Development

Adequate investment, supply chain, and workforce to develop extensive new supply, demand, and T&D resources

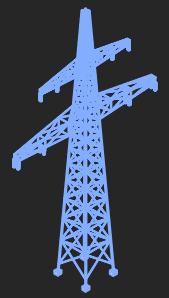
Efficient Regulation and Collaboration

Faster timelines for siting, permitting, and building new infrastructure and developing and deploying new technology



Integrated Planning for Reliability and Resiliency

Tools and processes for regional investment plans across electric and other energy systems in context of changing climate and other hazards



Resilience and Adaptation

Future Weather Predictions

- Wind
- Precipitation
- Temperature
- Ice

Impact on Asset Vulnerability & Performance

- Failure
- Ratings
- Life Expectancy
- Maintenance

- Planning & Investment Prioritization
- Design Approaches & Standards

Multiple Roles for Energy Storage

Low-Carbon Energy Supply

Enable greater deployment of renewables and direct low-carbon energy supply to customers

Dispatchable Resource

Provide reliability and grid stability with multiple options for output and duration

Customizable Options

Support scaled deployment in response to energy transformation

EPRI Energy Storage Roadmap: Vision for 2025





SAFETY	ELECTRICITY RELIABILITY	ECONOMICS	ENVIRONMENTAL RESPONSIBILITY	INNOVATION
Safety practices established	Energy storage asset reliability characterized and enhanced	Planning and operational modeling validated and applied	Reduced emissions with energy storage applications	Cross-industry disruption awareness and integration
Asset hazards characterized and minimized	Energy storage controls integrated and interoperable	Multi-use applications enabled	Sustainable life cycle implemented	Future workforce available and trained
Community resilience and public safety applications viable	Energy storage integrated into grid planning and portfolio management	Total cost of ownership reduced	End-of-life impacts minimized	Technology advancements accelerated

Source: 3002019722

Examples EPRI Support

- Value of storage
- Technical assessments
- Best-practices
  safety, reliability, siting, procurement, installation and operation of storage systems

2015
- "Grid-ready storage"
- Kicking the tires

2020
- "Storage Anywhere"
- Pilot projects in real world conditions

2025
- "Storage Everywhere"
- Deployment programs widespread

2030
- "New Landscape"
- Beyond lithium and current planning

STRATEGIC IMPERATIVES

EQUITY, ENVIRÓNMENTAL JUSTICE AND BROAD STAKEHOLDER COLLABORATION

Equitable Decarbonization

Enhanced collaboration