Perspectives on the Future of Electric Power in the US

Presentation to the NAS Committee on "The Future of Electric Power in the US"

Tom Wilson

Principal Technical Executive,
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August 14, 2019

EPRI - Independent – Objective – Technically Based

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'S VALUE

To provide value to the public, our members, and the electricity sector

THOUGHT LEADERSHIP

INDUSTRY EXPERTISE

COLLABORATIVE MODEL

OUR MEMBERS...

- 450+ participants in more than 30 countries
- EPRI members generate approximately 90% of the electricity in the United States
- International funding – nearly 25% of EPRI's research, development, and demonstrations
- $415M Annual funding

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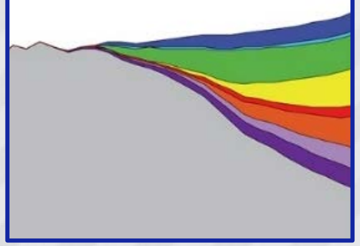
Topics for Today

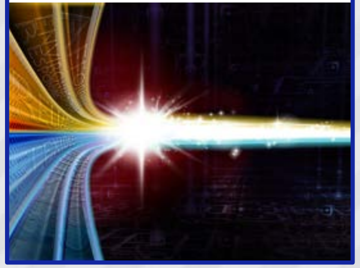
- Overview of EPRI Research/Perspectives
- Electric Sector Generation Technology and Carbon Reductions
- Electricity’s Role in Economy-wide Carbon Reduction
- T&D (the “invisible” enabler) and 10 Planning Challenges

Building on Decades of Thought Leadership

46^{th} Annual Summer Seminar: Intelligent Transformation

PRISM: Portfolio for Clean Generation	Energy Efficiency	Flexible, Resilient, and Connected Power System	Connected Customers	Integrated Grid	Integrated Energy Network	Efficient Electrification





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PROJECT 2X to 2050

Accelerating Carbon Reduction Across the Economy

U.S. Energy CO_2 Emissions

Rounded to the nearest gigaton (Gt) of remaining emissions

2005	~6 Gt CO_2
Present Day	~5
2030	~4
2050	~1

The Carbon Reduction Technology Timeline

Energy Efficiency

Cleaner Electricity

Efficient Electrification

Cleaner Transportation

Low-Carbon Resources

H_2 NH_3

U.S. CO_2 Emissions by Sector

	Electric	Transport	Industry/Buildings
2005	40%	33%	27%
Present Day	34%	37%	29%
2030	29%	36%	35%
2050	LOW TO NO CARBON		

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

Next Steps: Expanding Low-Carbon R&D

The Path to 2030: Accelerating Demonstration and Deployment

EVs account for ~20% of vehicle miles traveled by 2030

Grid-integrated battery storage reaches 30 GW

Accelerating Electric Vehicle (EV) Adoption and Infrastructure Modernization

- Renewable/EV-Ready Integrated Grid
- EV Charging Infrastructure and Customer Behavior
- Grid Energy Storage Integration
- Fleet Electrification

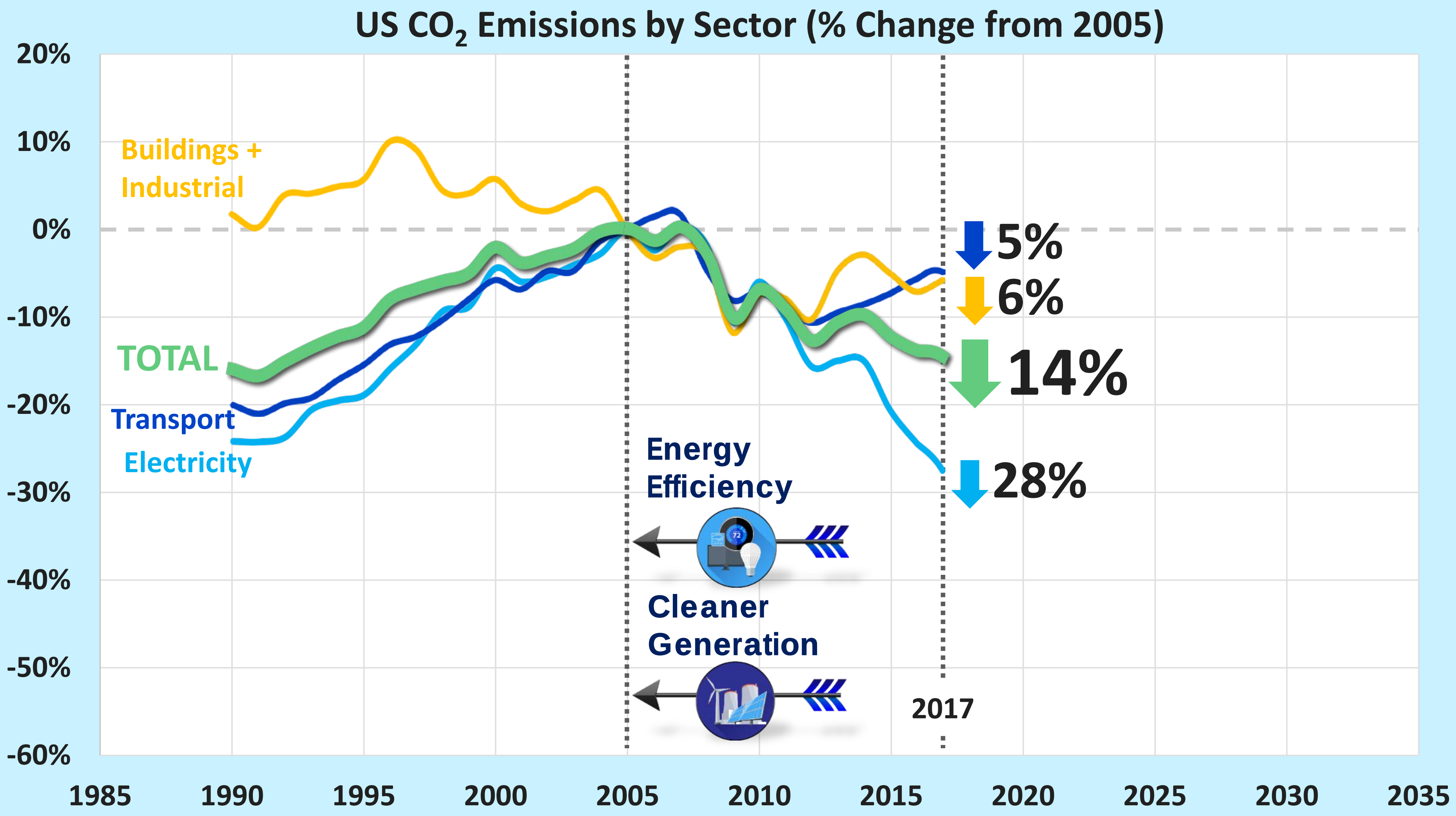
The Path to 2050: Creating Affordable, Low-Carbon Options

Hydrogen and related, low-carbon resources

Advancing Low-Carbon Resources

- Advanced Renewables
- Advanced Nuclear
- Low-Carbon Fuels and Gas Pipelines
- Carbon Capture, Utilization, and Storage

To Project Forward, Useful to Look Back

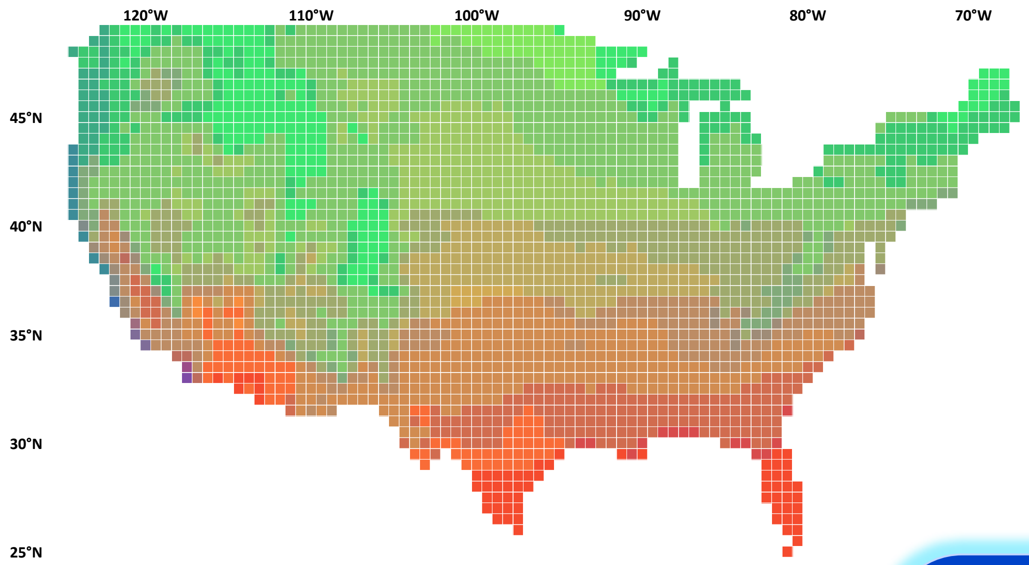


Historic data from EIA Monthly Energy Review, February 2019

US-REGEN Couples Demand Simulation with Electric Generation

U.S. Regional Economy, Greenhouse Gas, and Energy

Energy End-Use



- Climate zones
- Building types
- Household characteristics
- Industrial mix
- End-use technology detail

Synchronized

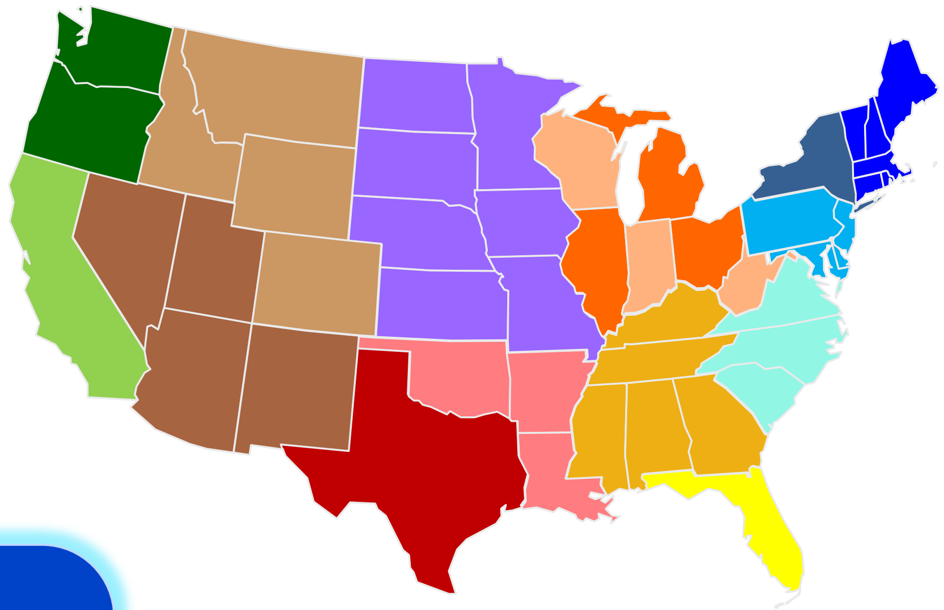
Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water use

Electric Generation



- Investment and dispatch
- Transmission
- Intermittent renewables
- Energy and capacity requirements
- State-level policies and constraints

Topics for Today

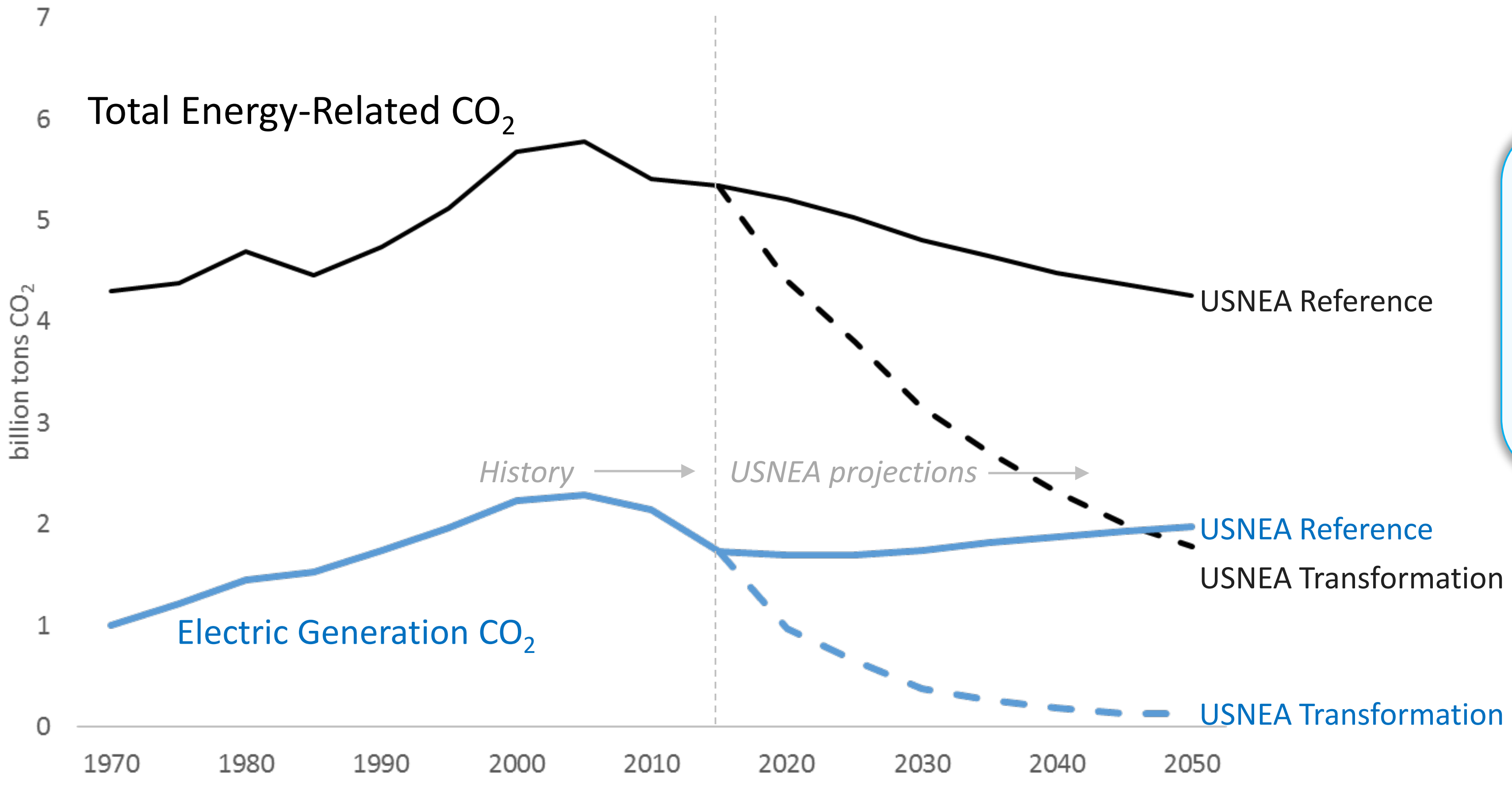
Overview of EPRI Research/Perspectives

Electric Sector Generation Technology and Carbon Reductions

Electricity’s Role in Economy-wide Carbon Reduction

T&D (the “invisible enabler”) and 10 Planning Challenges

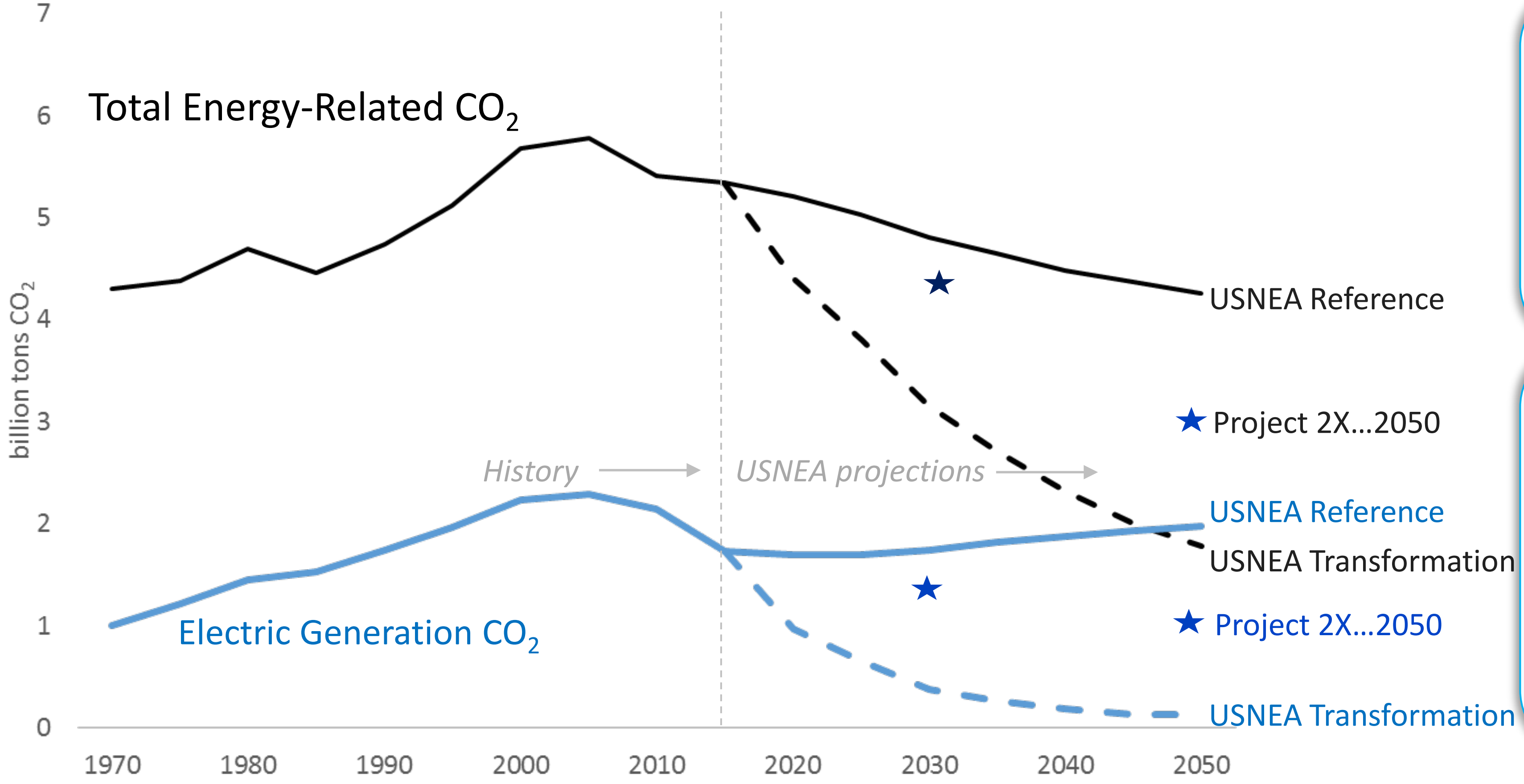
Total and Electric Generation CO_2 Emissions Projections: US National Electrification Assessment (~ 8/2017)



Increasing electrification leads to lower overall CO_2 emissions, even as emissions from electric generation increase in the USNEA Reference

Source: US National Electrification Assessment, 2018

Total and Electric Generation CO_2 Emissions Projections: USNEA (~ 8/2017) and Project 2X … 2050 (8/2019)



~~Increasing electrification leads to lower overall CO_2 emissions, even as emissions from electric generation increase in the USNEA Reference~~

Increasing electrification and continuing reductions in emissions from electric generation drive economy-wide CO2 reductions

Source: US National Electrification Assessment (2018) and Project 2X to 2050 (8/2019)

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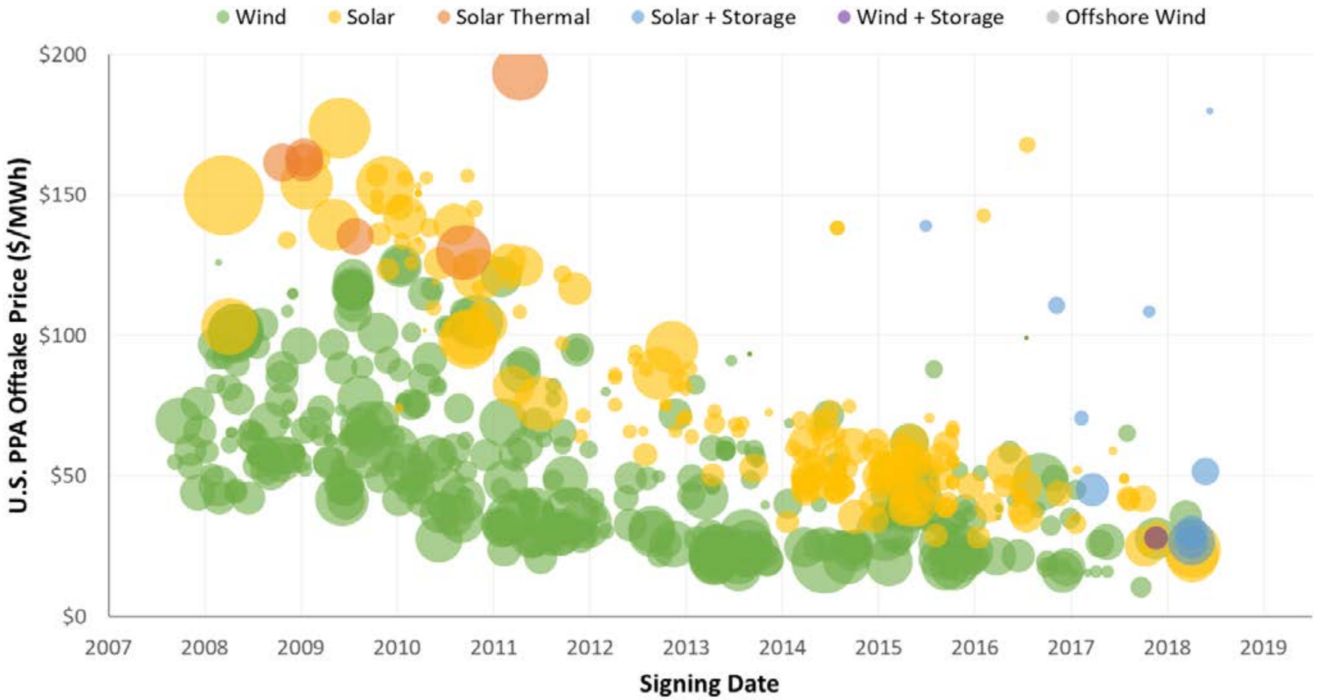
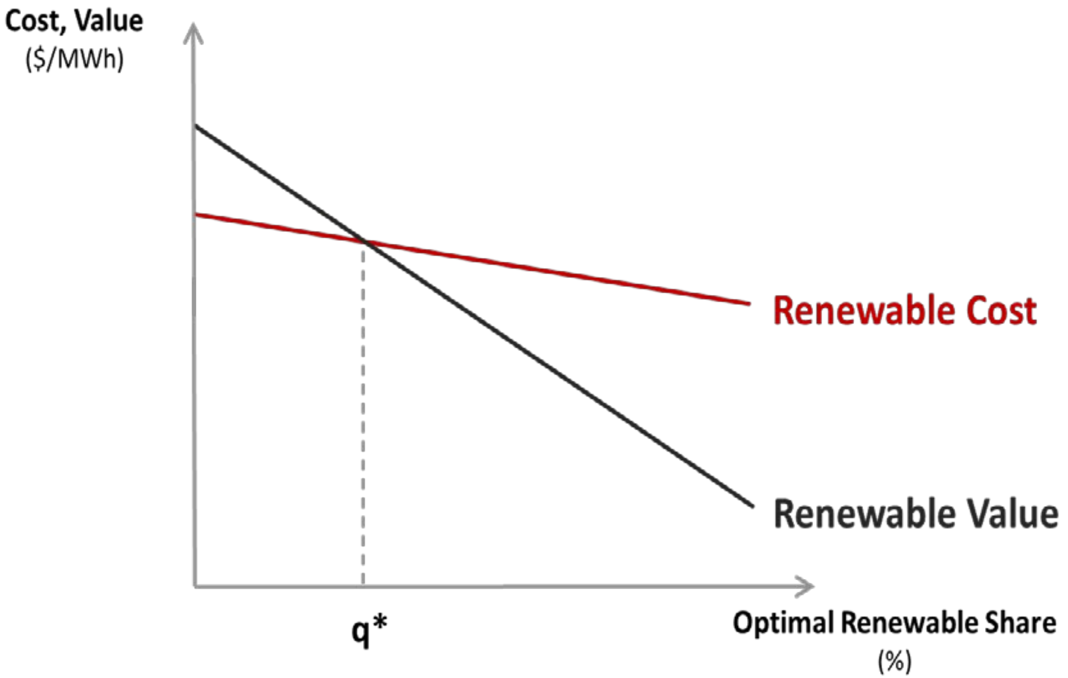
100% Renewable: Declining Wind/Solar Costs Do Not Equate to Increase Value

Wind/Solar Cost Continue to Decline

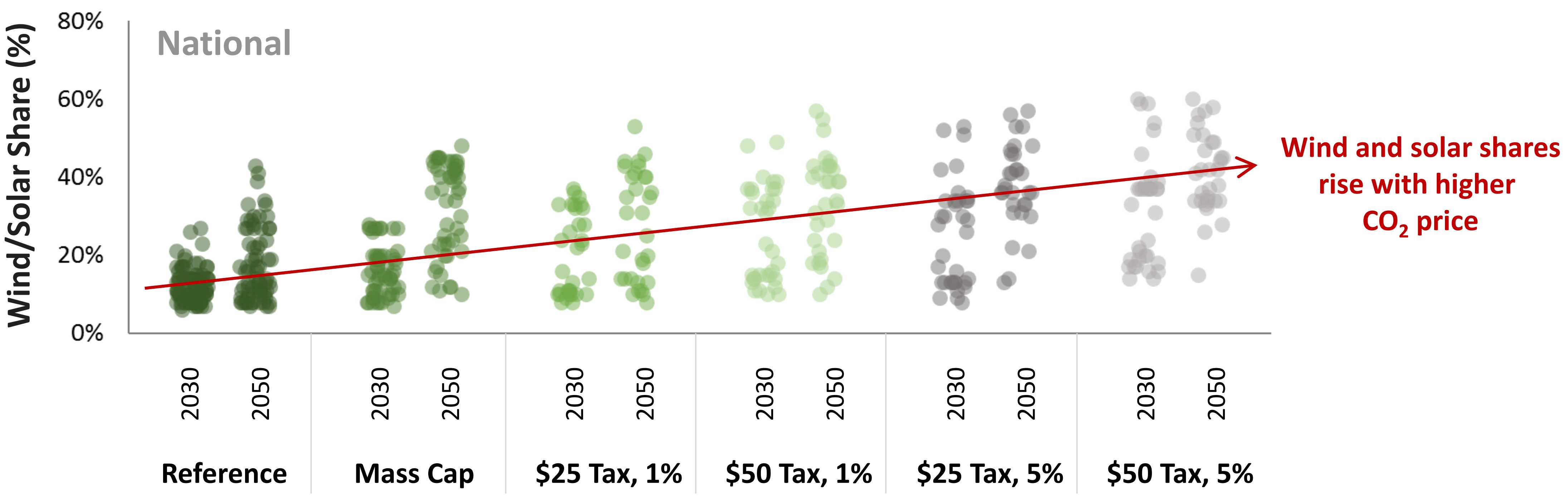


U.S. data from BloombergNEF, FERC, and DOE
Note: Prices in nominal U.S. dollars; bubbles are proportional to contract capacity; prices represent project costs not system (or integration) costs

But Value Also Declines as Penetration Increases



100% Renewables? Least-Cost Role Differs by Model/Scenario



Notes

- Results from the Energy Modeling Forum 32 study of U.S. climate policy and technological change
- Each dot is a different model (16 in the study) and technology sensitivity (8 in study)

Takeaways

- Wind and solar penetration play large roles even without policy
- National penetration is far from 100% even with low wind/solar costs and high CO_2 price

Source: Energy Modeling Forum 32, Energy Economics 2018

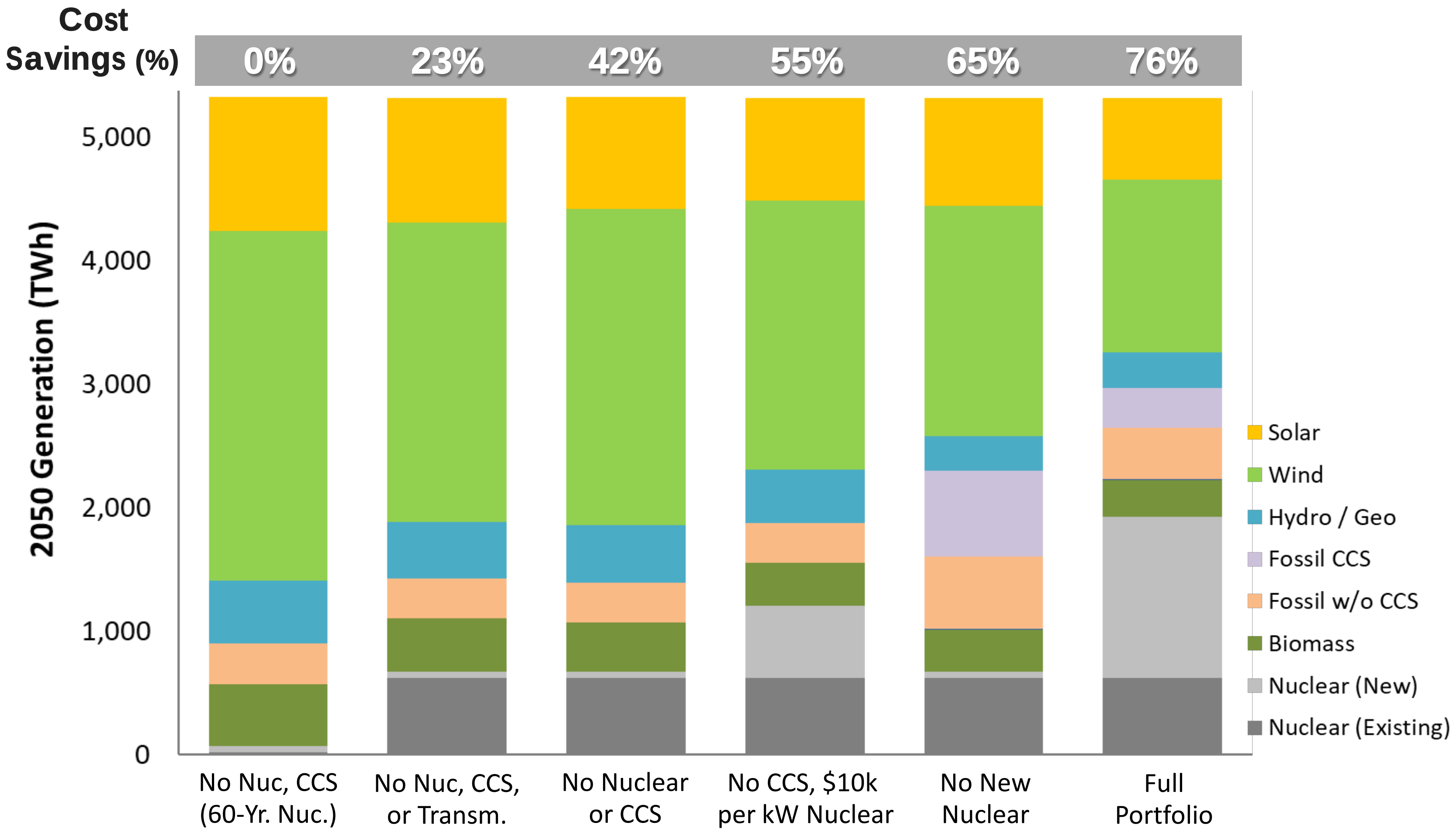
100% Renewables? Least-Cost Role Differs by Model/Scenario/Region

EMF 32 models indicate that least-cost decarbonization pathways likely entail a portfolio of generation options

Source: Energy Modeling Forum 32, Energy Economics 2018

Many Low-CO_2 Pathways, But Some Are Lower Cost Than Others

95% Cap on U.S. Power Sector CO_2 by 2050 (Results from EPRI's US-REGEN Model)



- Tradeoff between cost and technological preferences
- Important role of dispatchable low-carbon power
  - Options: Existing nuclear and hydropower, gas (without/with carbon capture), new nuclear, biomass, geothermal
  - Region-specific solutions
- Technology optionality helps to manage cost under uncertainty about the future

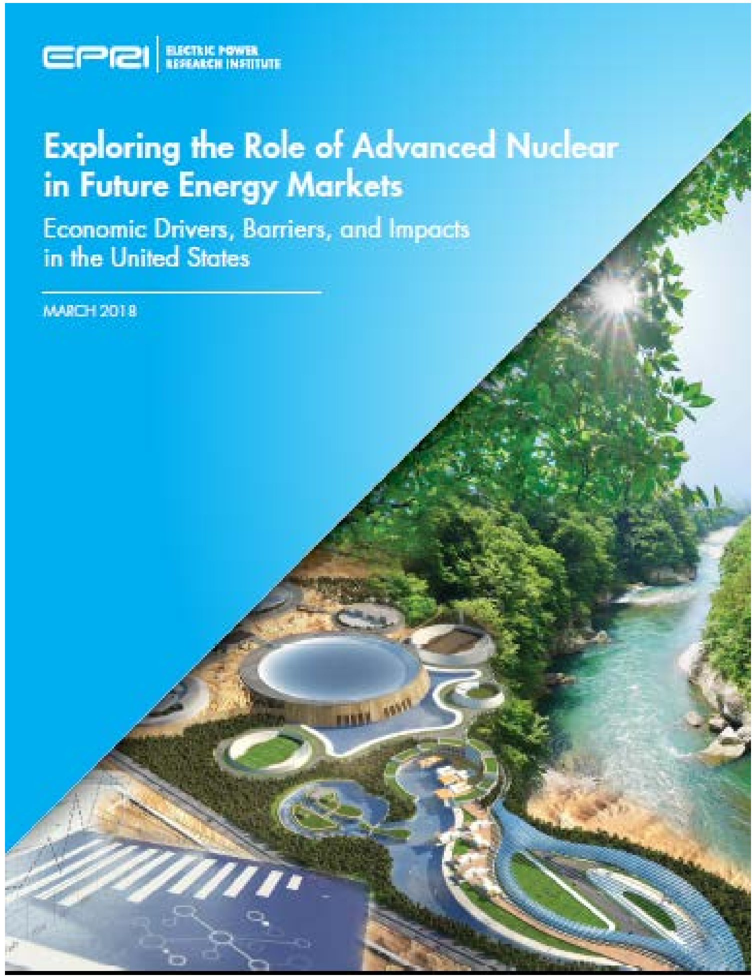
Source: Bistline and Blanford (2018)

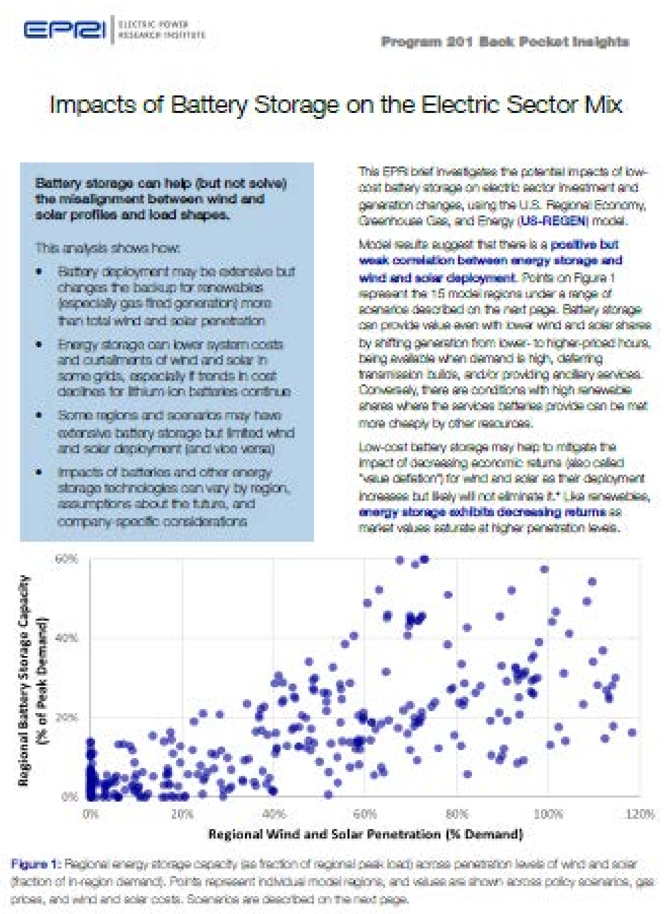
Declining marginal value and increasing system costs with high renewables mean that there are cheaper ways to decarbonize

Related Peer Literature Publications in 2018/19

Paper Title	Author(s)	Journal	Status
"Electric Sector Policy, Technological Change, and U.S. Emissions Reductions Goals: Results from the EMF 32 Model Intercomparison Project"	Bistline, Hodson, Rossmann, Creason, Murray, Barron	*Energy Economics*	In Print
"Effects of Technology Assumptions on US Power Sector Capacity, Generation and Emissions Projections: Results from EMF 32"	Creason, Bistline, Hodson, Murray, Rossmann	*Energy Economics*	In Print
"The Role of Input Assumptions and Model Structures in Projections of VRE: A Multi-Model Perspective of the U.S. Electricity System"	Mai, Bistline, Sun, Cole, Marcy, Namovicz, Young	*Energy Economics*	In Print
"Economic Drivers of Wind and Solar Penetration in the U.S."	Bistline, Young	*PNAS*	Submitted Q4 2018
"Value of Technology in the Electric Power Sector: Full Portfolios and R&D Lower Costs of Meeting Decarbonization Goals"	Bistline, Blanford	*Energy*	Submitting Q1 2019

Additional Public Reports/Publications on Nuclear, Storage, Flexible Operations, etc. at http://eea.epri.com





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Program 201 Back Pocket Insights

Impacts of Battery Storage on the Electric Sector Mix

Battery storage can help (but not solve) the misalignment between wind and solar profiles and load shapes.

This analysis shows how:

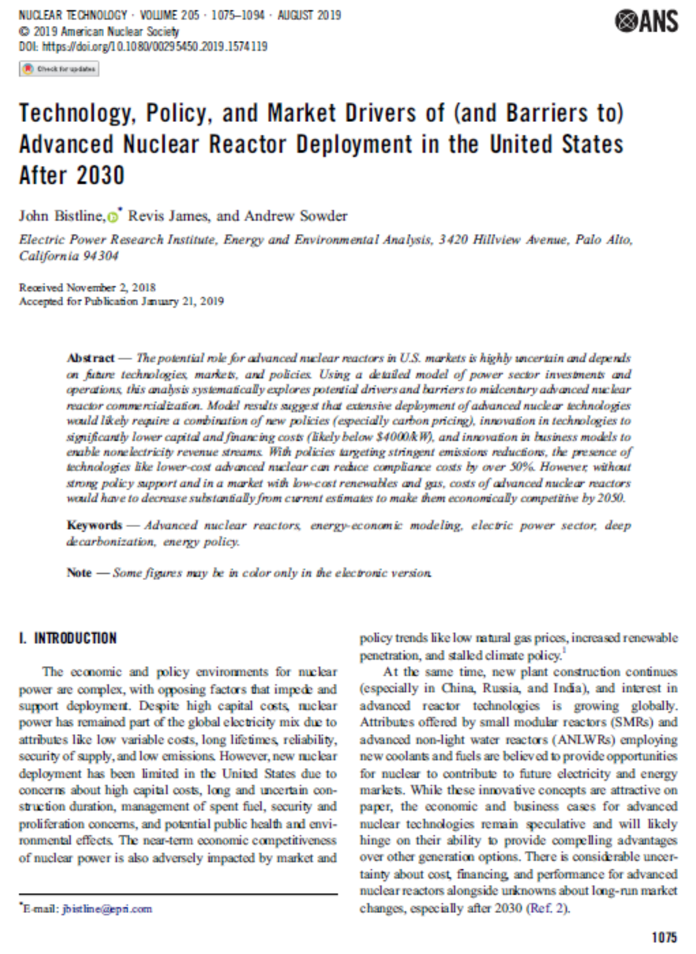
- Battery deployment may be extensive but changes the backup for renewables (especially gas-fired generation) more than total wind and solar penetration
- Energy storage can lower system costs and curtailments of wind and solar in some grids, especially if trends in cost declines for lithium-ion batteries continue
- Some regions and scenarios may have extensive battery storage but limited wind and solar deployment (and vice versa)
- Impacts of batteries and other energy storage technologies can vary by region, assumptions about the future, and company-specific considerations

This EPRI brief investigates the potential impacts of low-cost battery storage on electric sector investment and generation changes, using the U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model.

Model results suggest that there is a **positive but weak correlation between energy storage and wind and solar deployment**. Points on Figure 1 represent the 15 model regions under a range of scenarios described on the next page. Battery storage can provide value even with lower wind and solar shares by shifting generation from lower- to higher-priced hours, being available when demand is high, deferring transmission builds, and/or providing ancillary services. Conversely, there are conditions with high renewable shares where the services batteries provide can be met more cheaply by other resources.

Low-cost battery storage may help to mitigate the impact of decreasing economic returns (also called "value deflation") for wind and solar as their deployment increases but likely will not eliminate it.* Like renewables, **energy storage exhibits decreasing returns** as market values saturate at higher penetration levels.

Figure 1: Regional energy storage capacity (as fraction of regional peak load) across penetration levels of wind and solar (fraction of in-region demand). Points represent individual model regions, and values are shown across policy scenarios, gas prices, and wind and solar costs. Scenarios are described on the next page.



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ANS

Technology, Policy, and Market Drivers of (and Barriers to) Advanced Nuclear Reactor Deployment in the United States After 2030

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Abstract — *The potential role for advanced nuclear reactors in U.S. markets is highly uncertain and depends on future technologies, markets, and policies. Using a detailed model of power sector investments and operations, this analysis systematically explores potential drivers and barriers to midcentury advanced nuclear reactor commercialization. Model results suggest that extensive deployment of advanced nuclear technologies would likely require a combination of new policies (especially carbon pricing), innovation in technologies to significantly lower capital and financing costs (likely below $4000/kW), and innovation in business models to enable nonelectricity revenue streams. With policies targeting stringent emissions reductions, the presence of technologies like lower-cost advanced nuclear can reduce compliance costs by over 50%. However, without strong policy support and in a market with low-cost renewables and gas, costs of advanced nuclear reactors would have to decrease substantially from current estimates to make them economically competitive by 2050.*

Keywords — *Advanced nuclear reactors, energy-economic modeling, electric power sector, deep decarbonization, energy policy.*

Note — *Some figures may be in color only in the electronic version.*

I. INTRODUCTION

The economic and policy environments for nuclear power are complex, with opposing factors that impede and support deployment. Despite high capital costs, nuclear power has remained part of the global electricity mix due to attributes like low variable costs, long lifetimes, reliability, security of supply, and low emissions. However, new nuclear deployment has been limited in the United States due to concerns about high capital costs, long and uncertain construction duration, management of spent fuel, security and proliferation concerns, and potential public health and environmental effects. The near-term economic competitiveness of nuclear power is also adversely impacted by market and policy trends like low natural gas prices, increased renewable penetration, and stalled climate policy.[1]

At the same time, new plant construction continues (especially in China, Russia, and India), and interest in advanced reactor technologies is growing globally. Attributes offered by small modular reactors (SMRs) and advanced non-light water reactors (ANLWRs) employing new coolants and fuels are believed to provide opportunities for nuclear to contribute to future electricity and energy markets. While these innovative concepts are attractive on paper, the economic and business cases for advanced nuclear technologies remain speculative and will likely hinge on their ability to provide compelling advantages over other generation options. There is considerable uncertainty about cost, financing, and performance for advanced nuclear reactors alongside unknowns about long-run market changes, especially after 2030 (Ref. 2).

*E-mail: jbistline@epri.com

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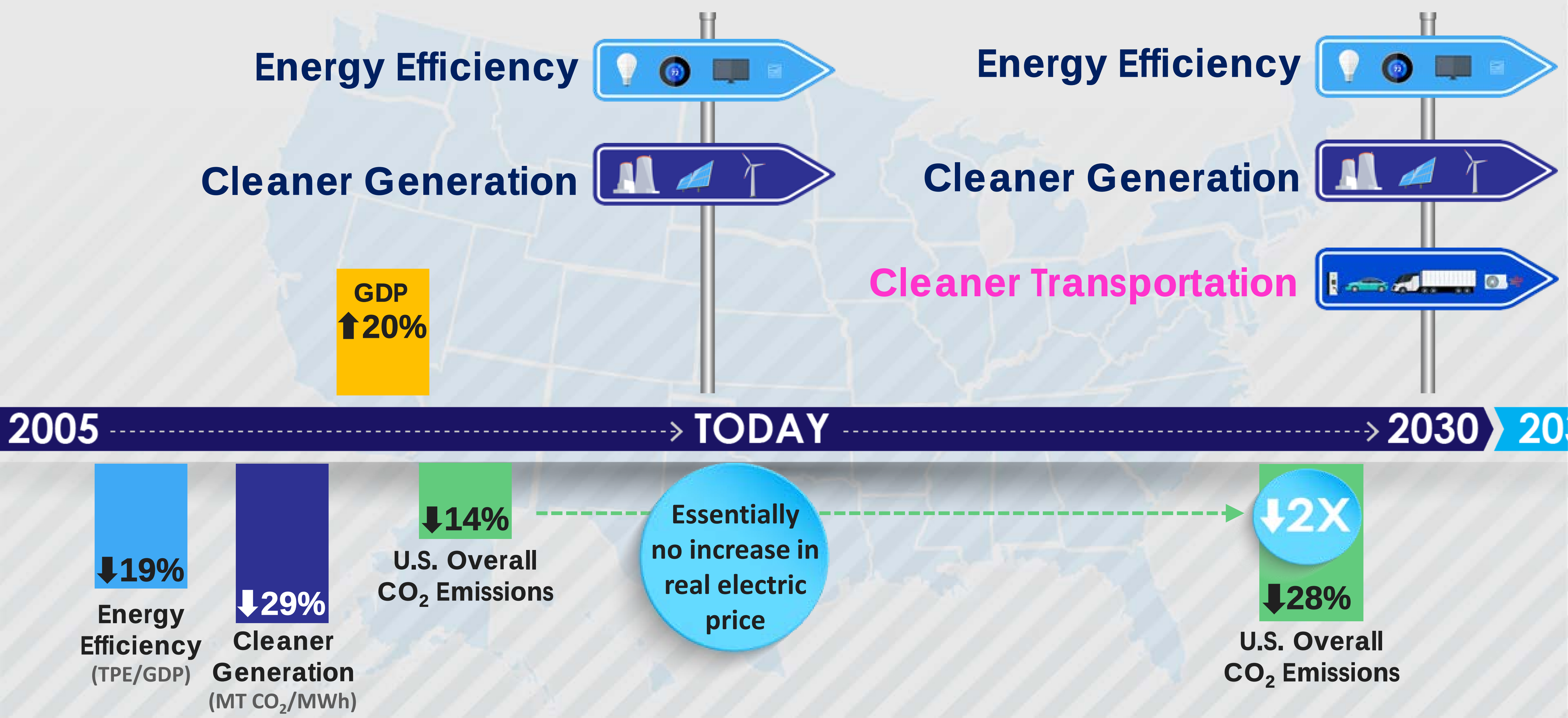
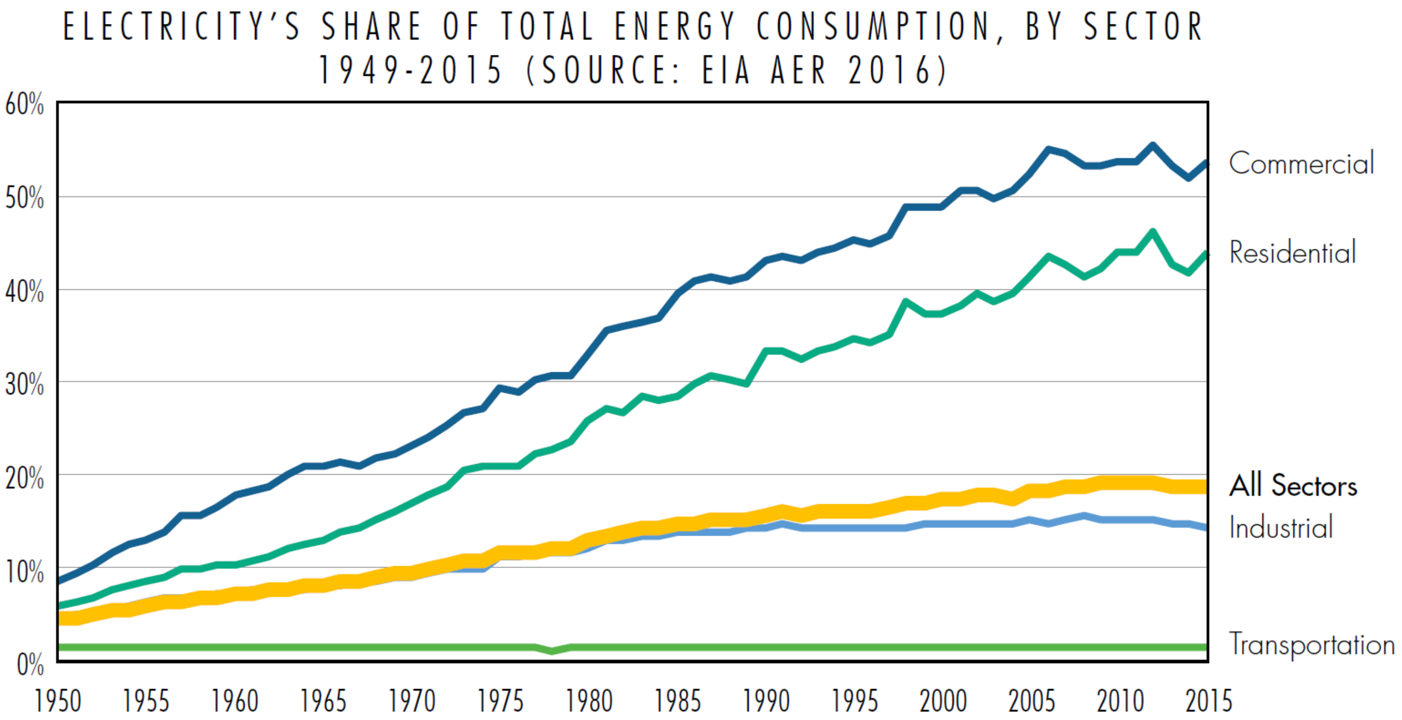
Project 2X – Examining Pathways to CO_2 Reduction

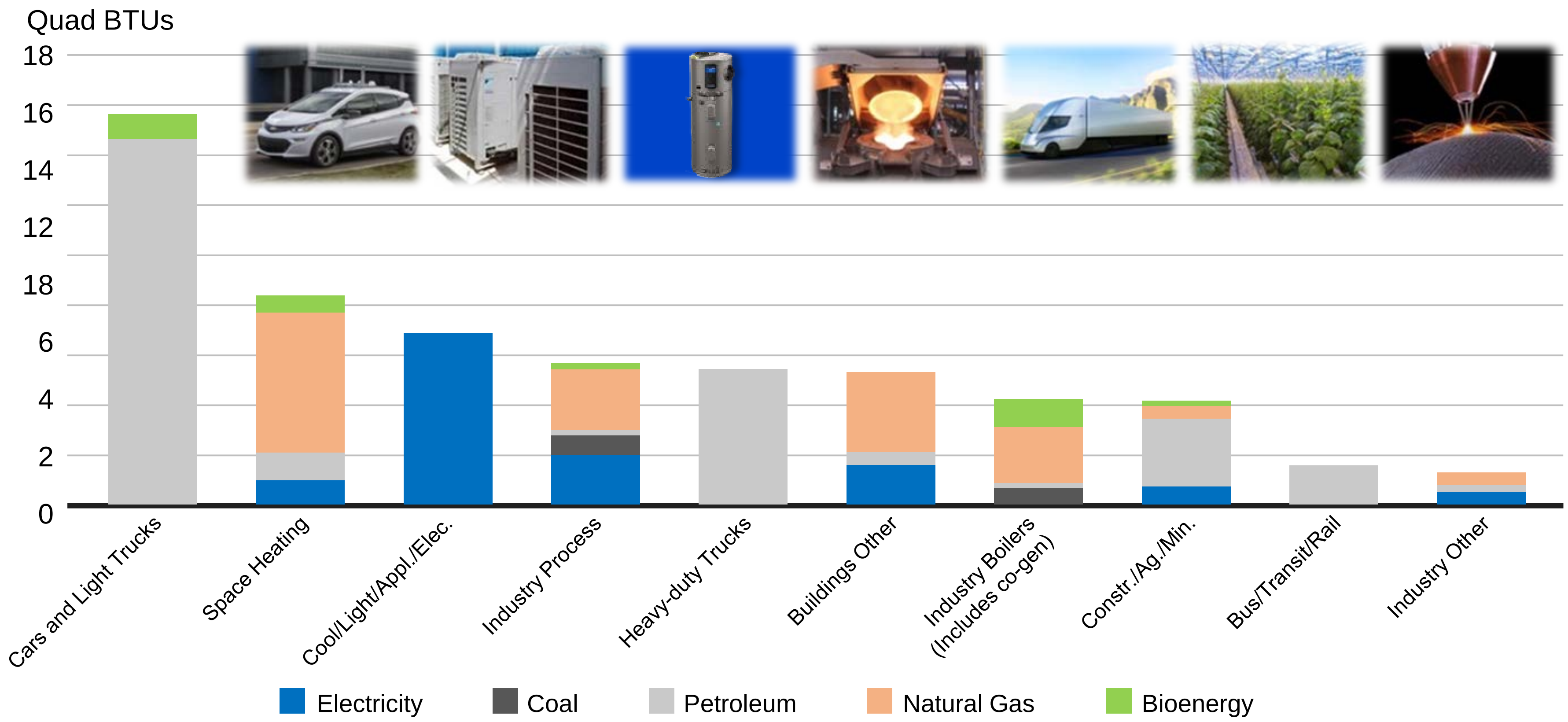


Electricity Use Has Grown Faster than Total Energy for More than A Century… What Will Happen Next? Or Could Happen?



Historic growth driven by efficiency, convenience, safety, and low cost

End Use (Final) Energy Use By Sector, 2016



- *Excludes upstream and midstream energy use, e.g., power generation, oil and gas extraction, refining, and pipelines.*

Adapted from Energy Information Administration

EPRI's U.S. National Electrification Assessment (USNEA)

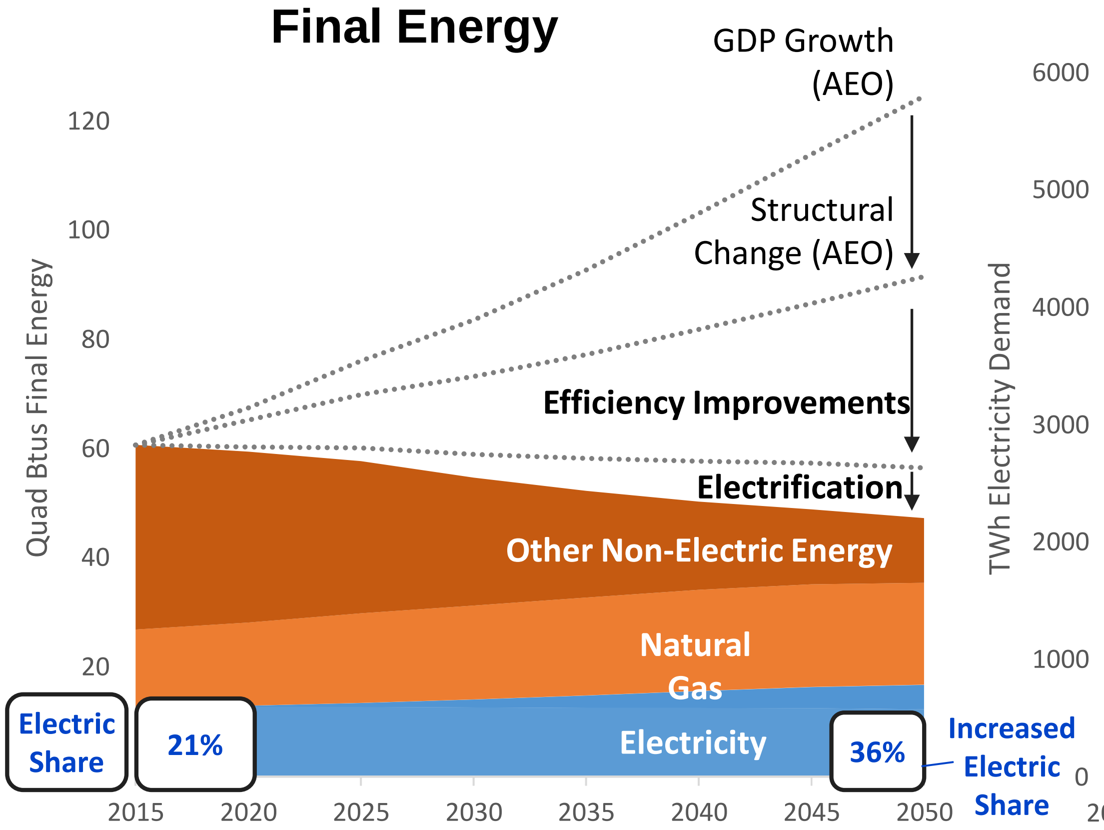
- Economy-wide assessment:
  - Residential
  - Commercial
  - Industrial
  - Transport
- Customers have broad technology choices and control
- Customer choices integrated with detailed electricity supply model

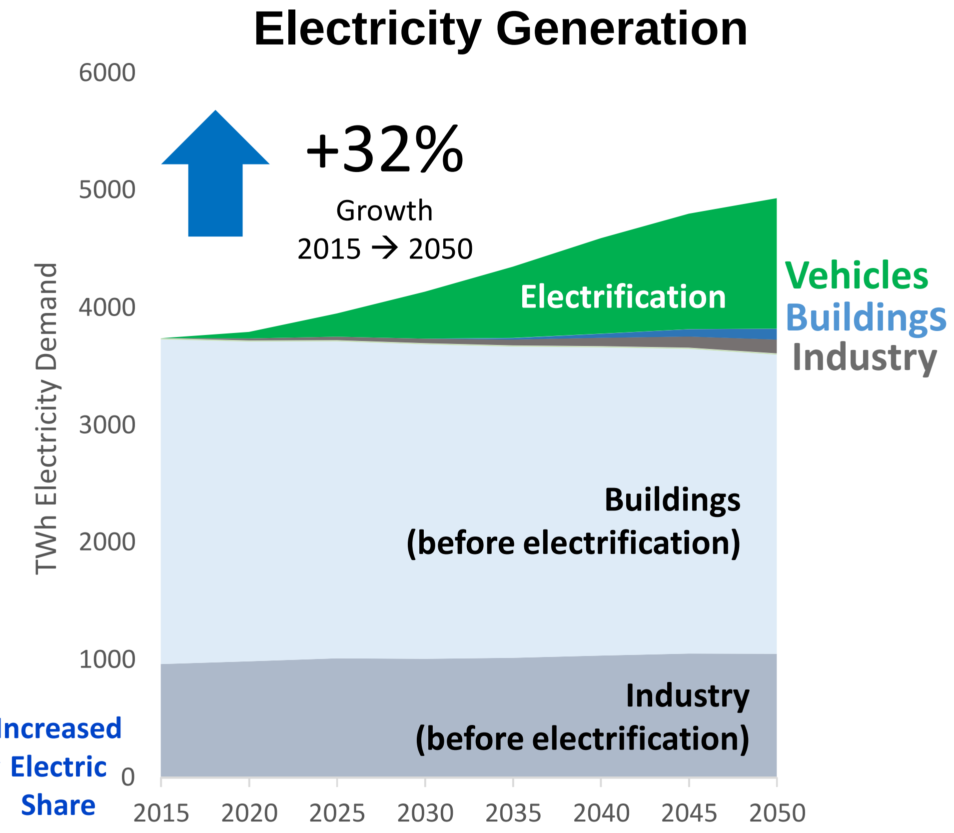
For more information on EPRI's Efficient Electrification Initiative:
https://www.epri.com/#/pages/sa/efficient-electrification?lang=en-US

Example of US National Electrification Assessment Scenarios and Assumptions

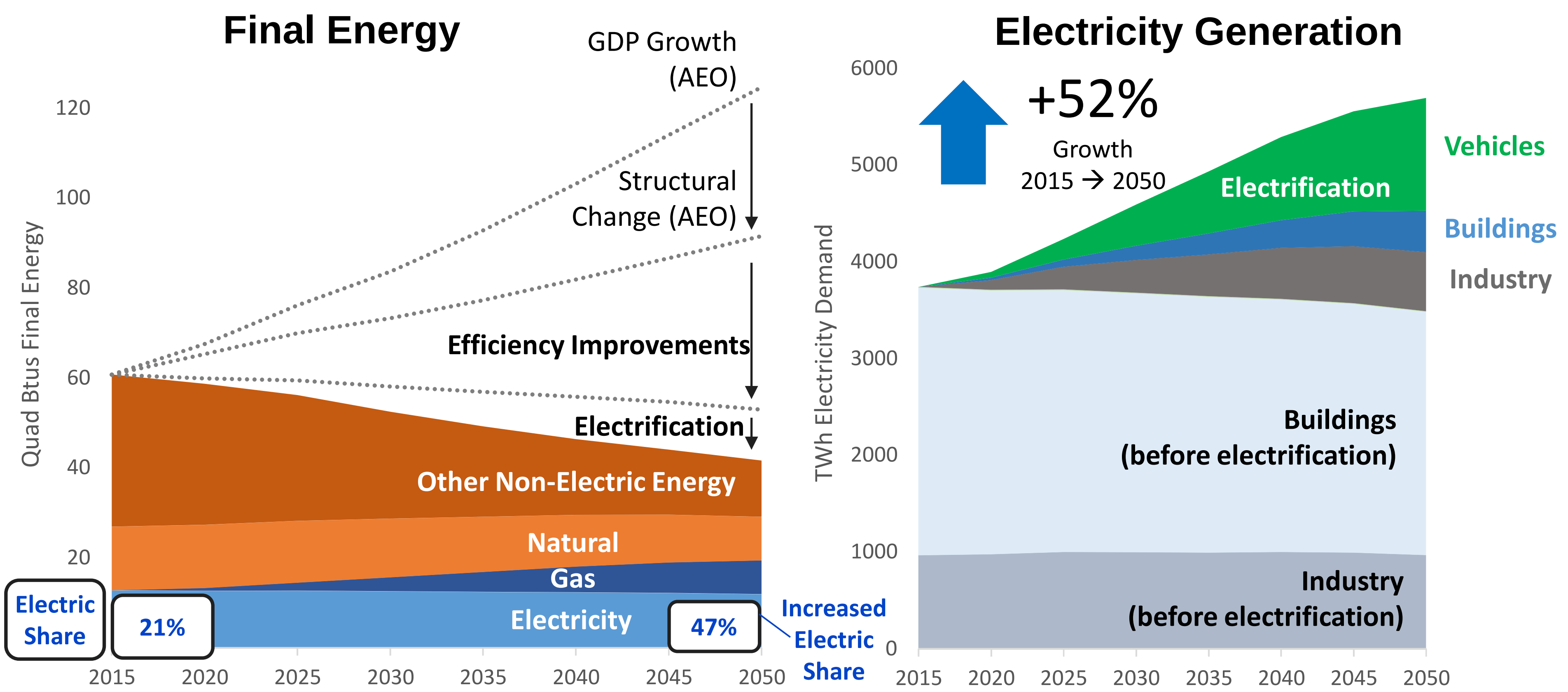
	CONSERVATIVE	REFERENCE	PROGRESSIVE	TRANSFORMATION
Light-duty vehicle costs	**Slower decline in battery costs**	EPRI/ANL estimates	EPRI/ANL estimates	EPRI/ANL estimates
Other technology costs	EPRI estimates	EPRI estimates	EPRI estimates	EPRI estimates
Efficiency Improvements	EPRI estimates	EPRI estimates	EPRI estimates	EPRI estimates
Economic growth / service demands	AEO 2017	AEO 2017	AEO 2017	AEO 2017
Primary fuel prices (NG, oil)	AEO 2017 Low Price Case	AEO 2017 Low Price Case	AEO 2017 Low Price Case	AEO 2017 Low Price Case
Electric sector policies	State RPS only	State RPS only	**State RPS + $15/tCO2 in 2020, rising at 7%**	**State RPS + $50/tCO2 in 2020, rising at 7%**
End-use sector policies	None	None	**$15/tCO_2$ in 2020, rising at 7%**	**$50/tCO_2$ in 2020, rising at 7%**

Efficient Electrification: Reference Scenario





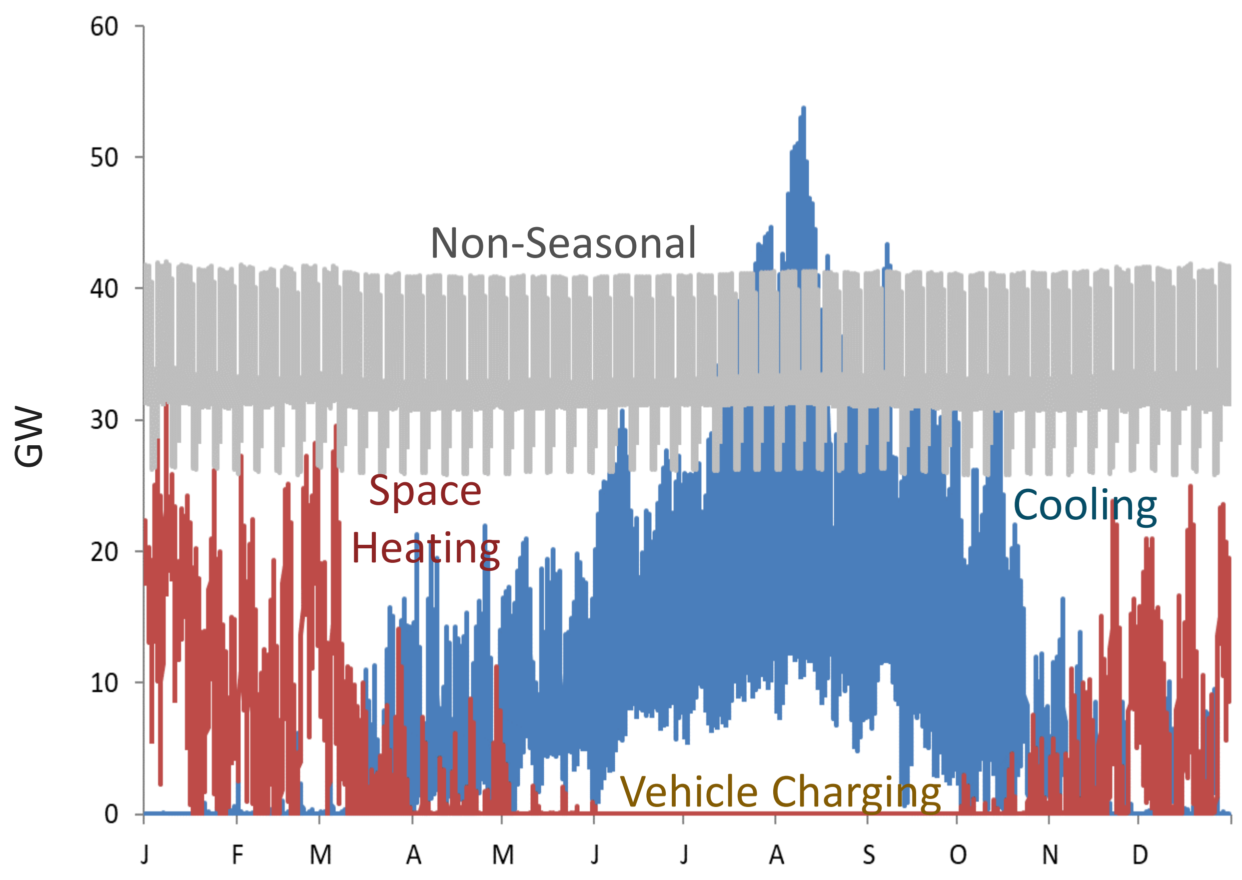
Efficient Electrification: Transformation (tight carbon target)



U.S. National Electrification Assessment (USNEA) – Results

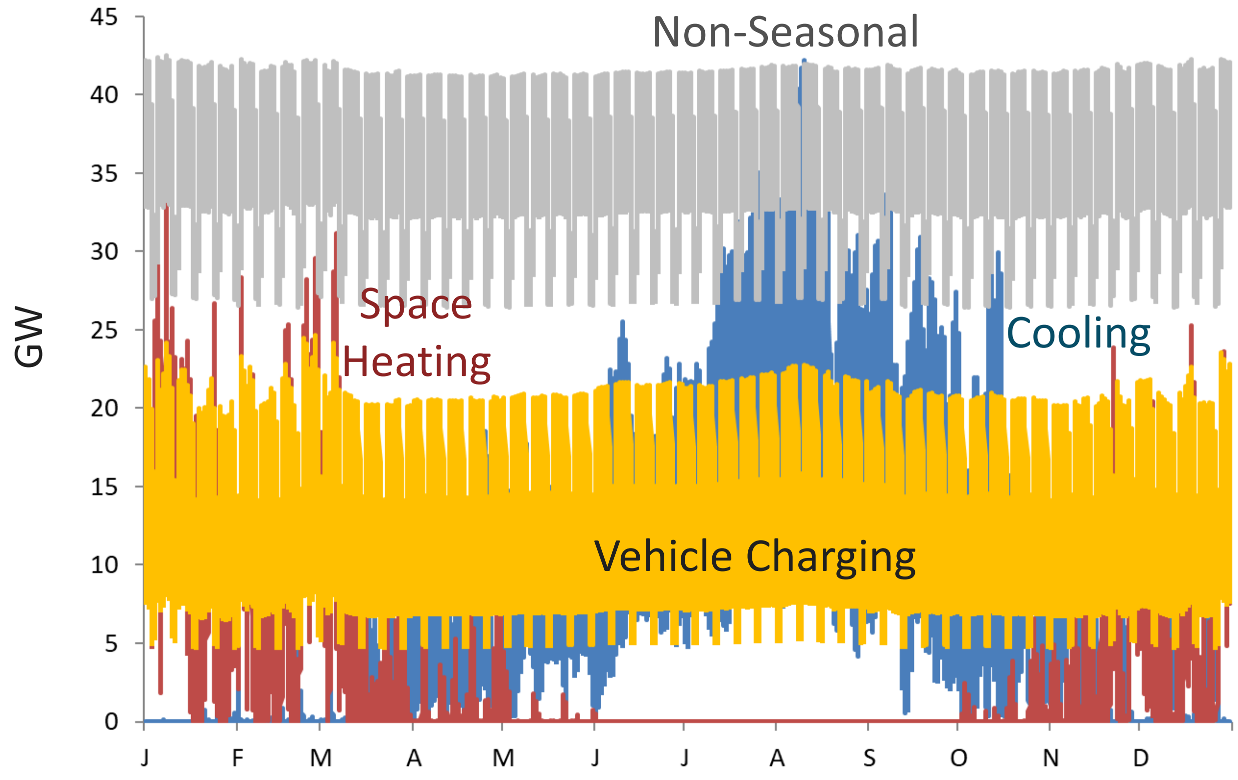
SCENARIO (Electricity Portion of Final Energy in 2015 & 2050)	Total Final Energy	Electric Load	Natural Gas	Economy Wide
CONSERVATIVE (21% & 32%)	20%	24%	33%	19%
REFERENCE (21% & 36%)	22%	32%	40%	20%
PROGRESSIVE (21% & 39%)	27%	35%	31%	57%
TRANSFORMATION (21% & 47%)	32%	52%	18%	67%

Texas 2015 Load Profiles by End-Use



How Will Sectoral Loads Change Over Time?

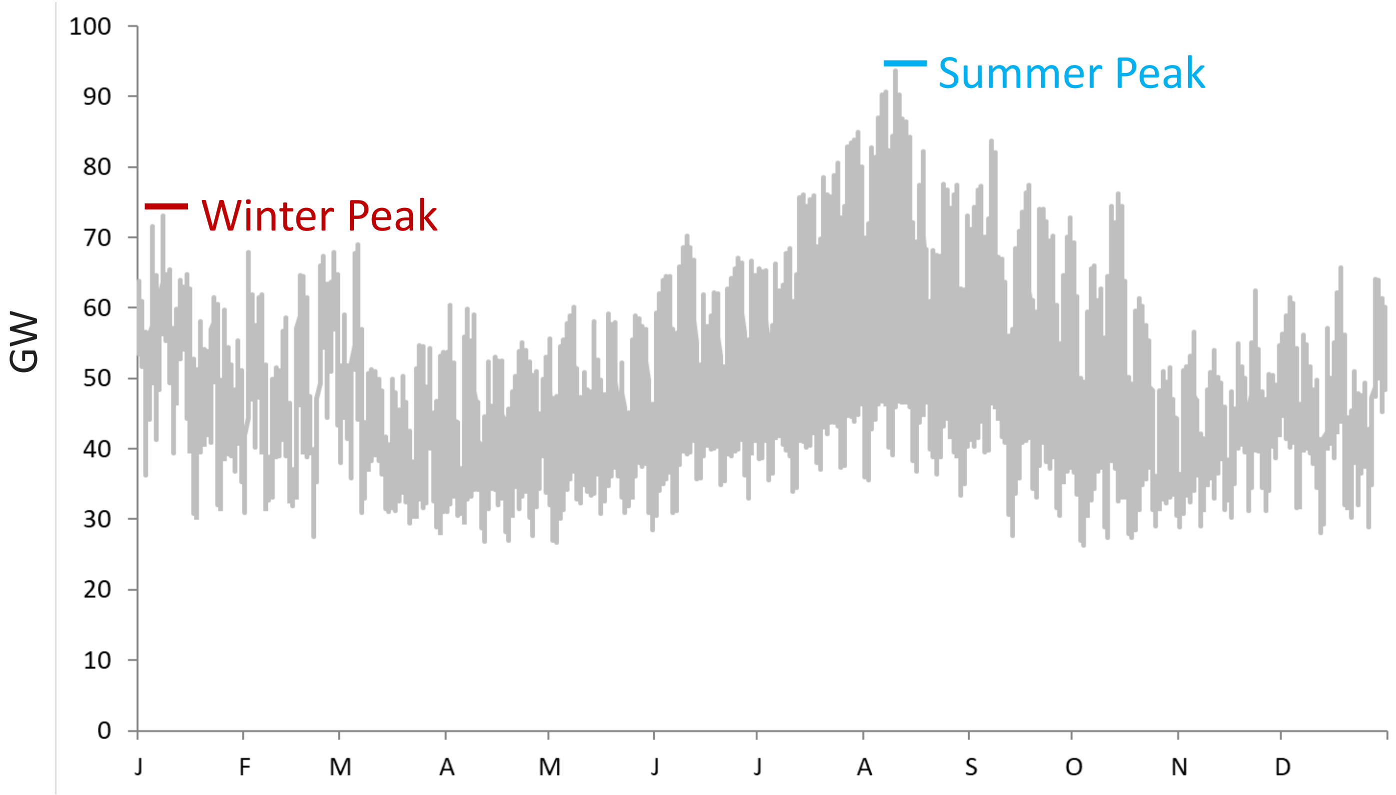
Texas 2050 Reference Reflects Efficiency and Electrification Gains



Vehicle Charging Emerges

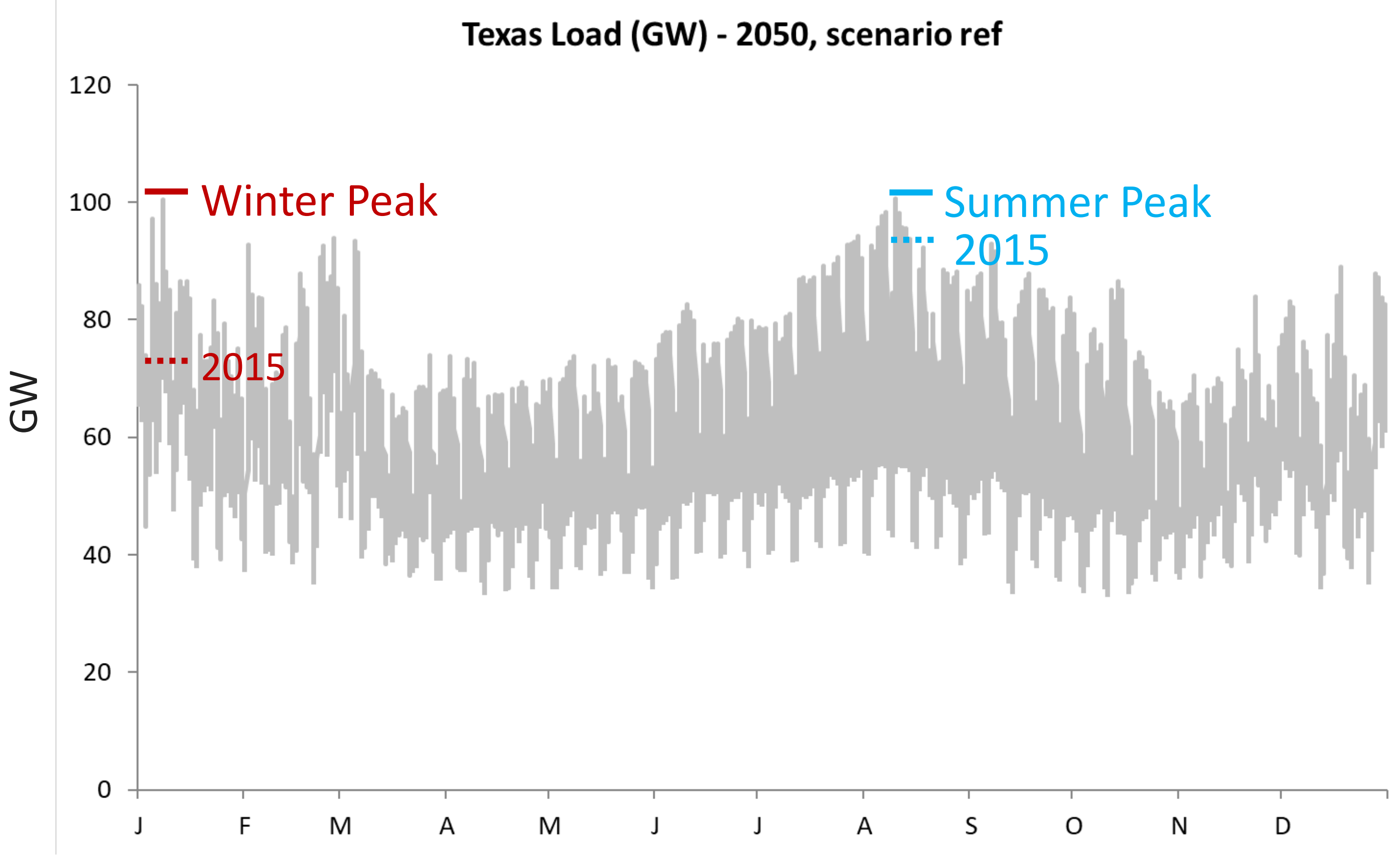
Efficiency Gains Offset Increased Cooling and Non-Seasonal Demands

Texas 2015 Aggregate Load Profile



How Will Aggregate Load Change Over Time?

Texas 2050 Aggregate Load Profile



Winter Peak Grows to Match Summer Peak

Electrification is not a Given: Opportunities and Challenges Abound

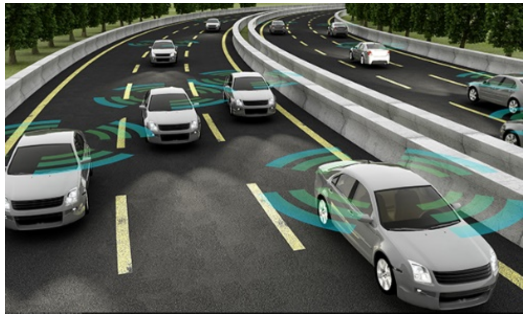
Technology Improvement: Cost + Performance

Policy and Market Design: An Economy-wide View

Infrastructure Investment

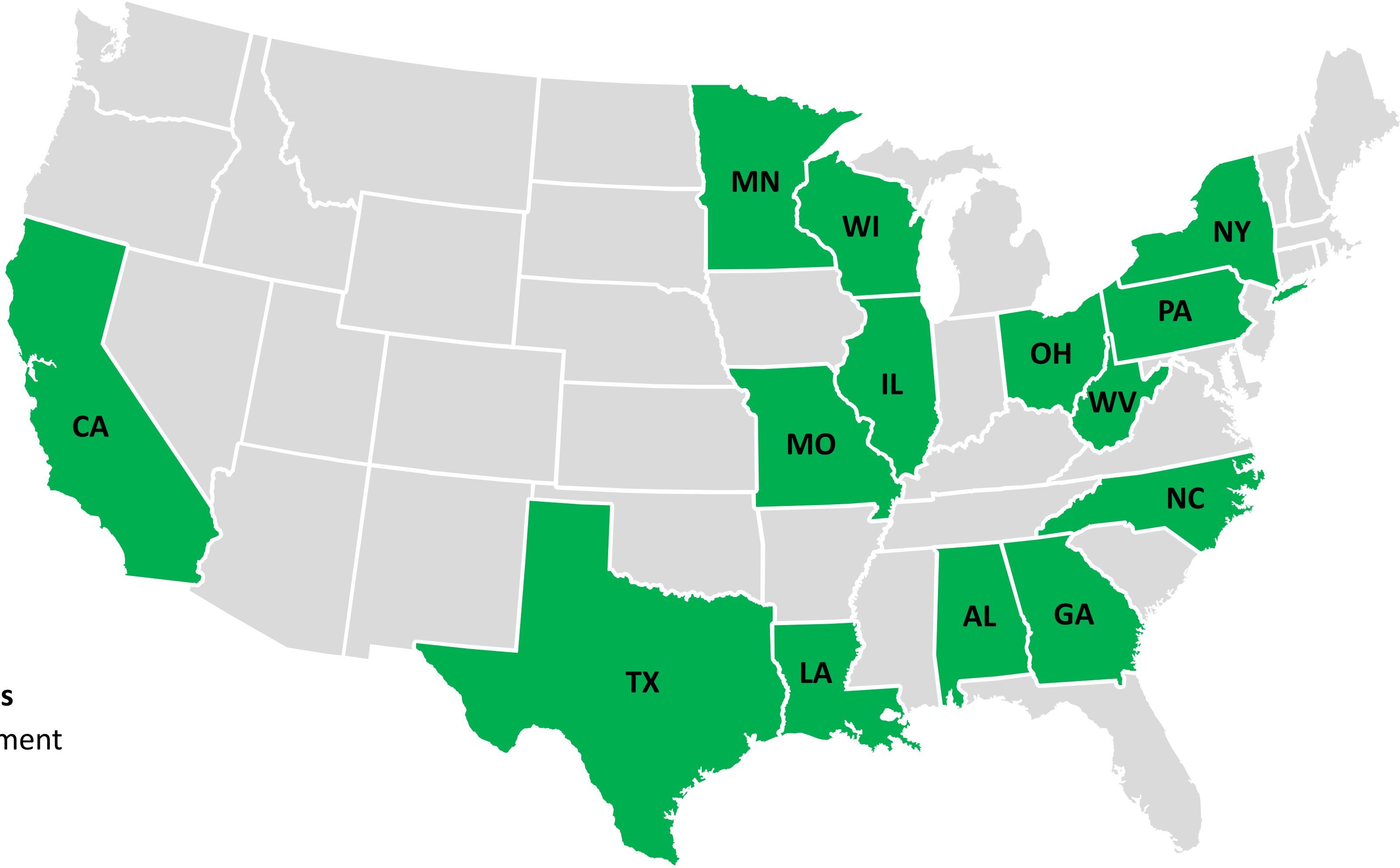
Analyzing Customer Choice

Overcoming Non-Economic Barriers



Fundamental New Options: Autonomous/Shared Mobility

U.S. State & Utility Electrification Assessment … Delivering Regional Insights



State	Project Start
AL	Mar 2018
CA	Apr 2018
GA	Mar 2018
IL	Nov 2018
LA	Apr 2019
MN	Dec 2018
MO	July 2019
NY	Feb 2018
NC	Nov 2018
OH	JAug 2019
PA	Apr 2018
TX	Apr 2019
WV	Nov 2018
WI	Mar 2018

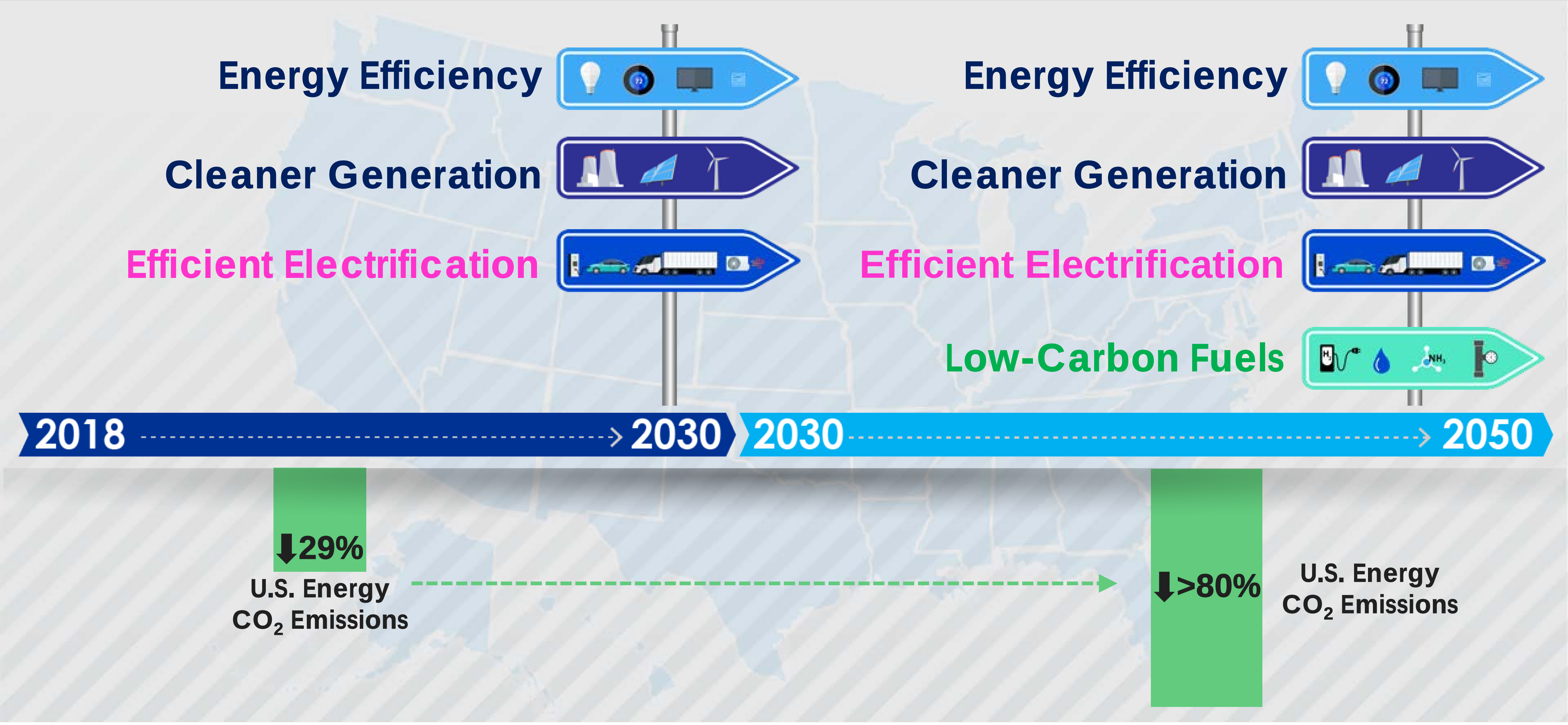
Key – State Project Status

- Funding Commitment

Current U.S. Participation: 14 States with 17 Members

Update: June 13, 2019

Beyond 2030, Deeper Reductions Require More Options



Additional Key Technologies in A Very Low-Carbon 2050

Zero-Carbon Electric Generation

- Carbon Capture & Storage
- Advanced Nuclear

Low Carbon Fuels:

cleaner electricity → cleaner energy carriers (H_2, NH_3) → heavy duty transportation, heating, & industry

Hydrogen blending leverages existing natural gas pipeline infrastructure to reduce emissions from natural gas use

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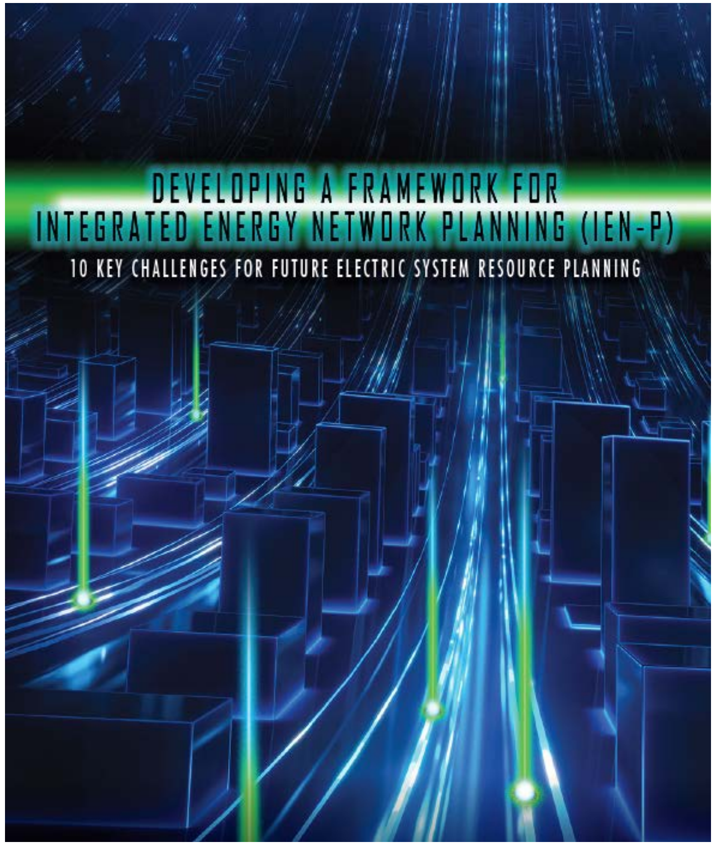
The Integrated Energy Network

Source:
EPRI 3002009917
February 2017

...Best Serves the Customer

Integration of Interdependent Energy Resources is Enabled by Advances in Digitization, Information and Communication Technologies

Electric Sector Planning Drives (or Supports) Investment… What are the Key Planning Challenges?



See: http://integratedenergynetwork.com/

Technical Basis:

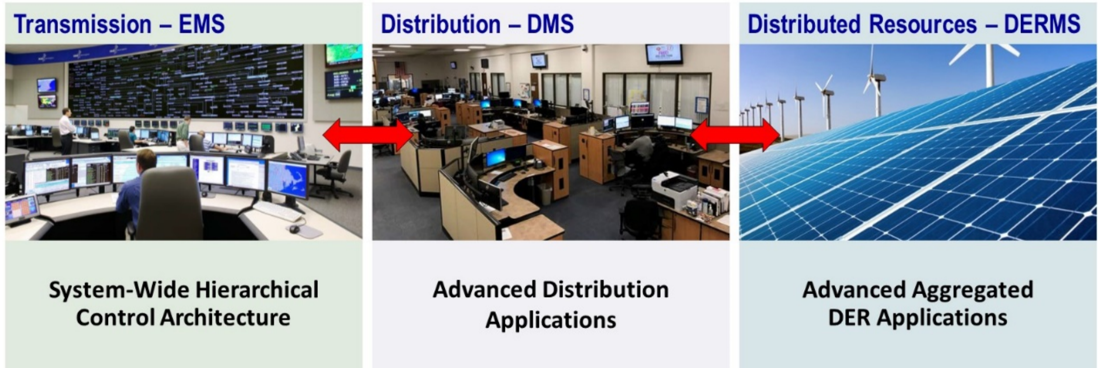
- 2 years in development
- Technical advisory committee of 23 utility, ISO, and other industry organizations from 5 countries
- Extensive discussions with regulators, academics, other stakeholders and EPRI program advisors

Integrated Energy Network: Resource Planning Challenges

Category	Key IEN Planning Challenge
Modeling the Changing Power System	1. Incorporating operational detail 2. Increasing modeling granularity 3. Integrating generation, transmission & distribution planning 4. Expanding analysis boundaries and interfaces 5. Addressing uncertainty and managing risk
Integrating Forecasts	6. Improving forecasting 7. Improving modeling of customer behavior and interaction
Expanding Planning Objectives	8. Incorporating new planning objectives and constraints 9. Integrating wholesale power markets 10. Supporting expanded stakeholder engagement

Example: Challenges We Have to Address at the Grid Edge

1. **Architecture** for integration of resources at the customer and community levels (as well as the distribution system)
2. Shared **communication infrastructure** with **cyber security**
3. **Market and regulatory constructs** for flexibility and capacity
4. **Models and tools for planning** – Customers, Distributed Controls, Non Wires Alternatives
5. Integration of Distributed Energy Resource Management Systems **(DERMS**) with Distribution Operations
6. **Platforms** that integrate customer resources with distribution planning and real time operations
7. **Transmission/Distribution Coordination** – both planning and operations



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Concluding Thoughts

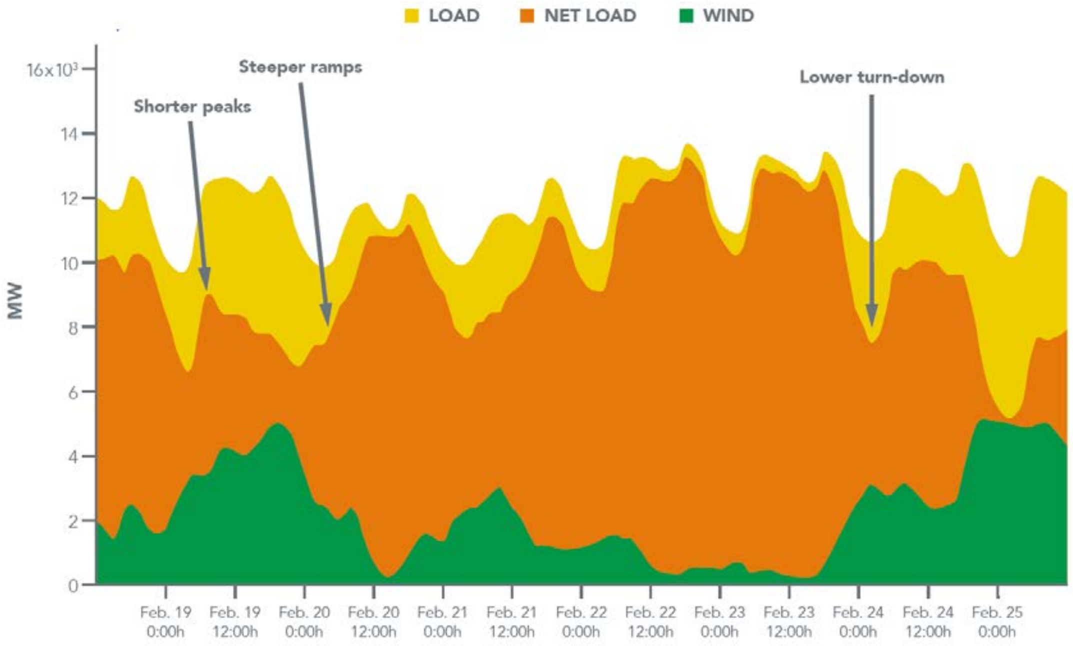
- Projecting the electric sector future is more challenging than ever – many actors/many speeds
  - Electric is increasingly part of an integrated energy network and is increasingly seem as a means to many ends (e.g., decarbonization, local air improvement)
  - Technology advances are global; fundamental changes are progressing in supply, delivery and use
  - Policies are national and regional while regulation, energy resources and customers are local
- Actions that can help all
  - Near-term actions to speed deployment of lower carbon technologies
  - Secure standards for interoperability/communication
  - New tools for planning and communication
  - Market designs that engage all assets and players
  - Customer perspective – engaging 110+ million households with disparate preferences and incomes capital stock turnover challenges
  - Near-term RD&D to develop and test the technologies needed to make deeper reductions economic

Together…Shaping the Future of Electricity

Backup Slides on Planning Challenges

1. Incorporating Operational Detail

- Evaluate and address potential reliability impacts (e.g., frequency response, voltage stability and short circuit considerations) associated with the changing resource mix.

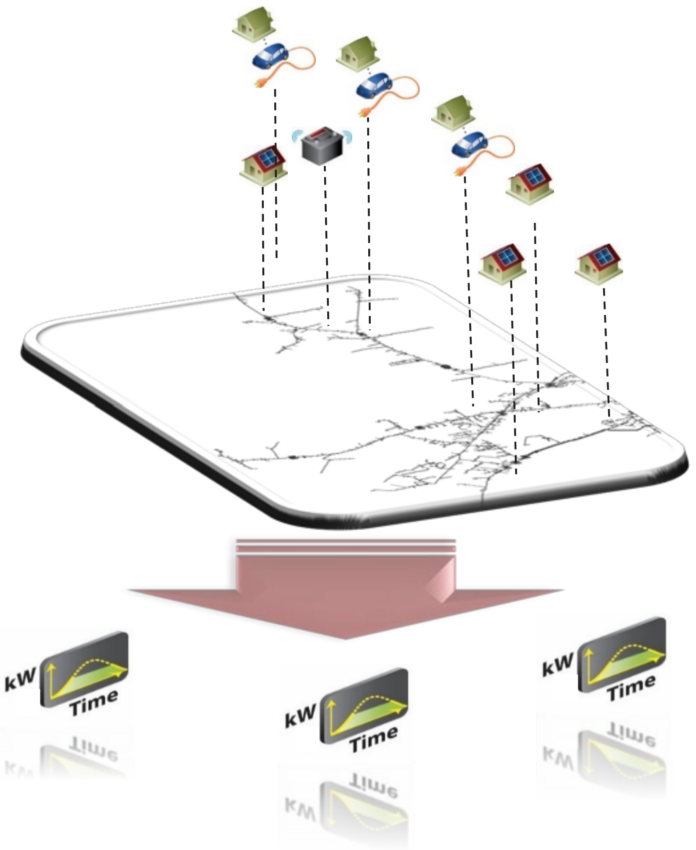


Wind and Solar Generation Can Increase Power System Flexibility Needs.
Source: Flexibility in 21st Century Power Systems, 21st Century Power Partnership.

- It is becoming more important to incorporate operational reliability capabilities (e.g., ramping rates, minimum generation levels), and adverse interactions (e.g., variability, uncertainty, active and reactive control capabilities) into resource planning.

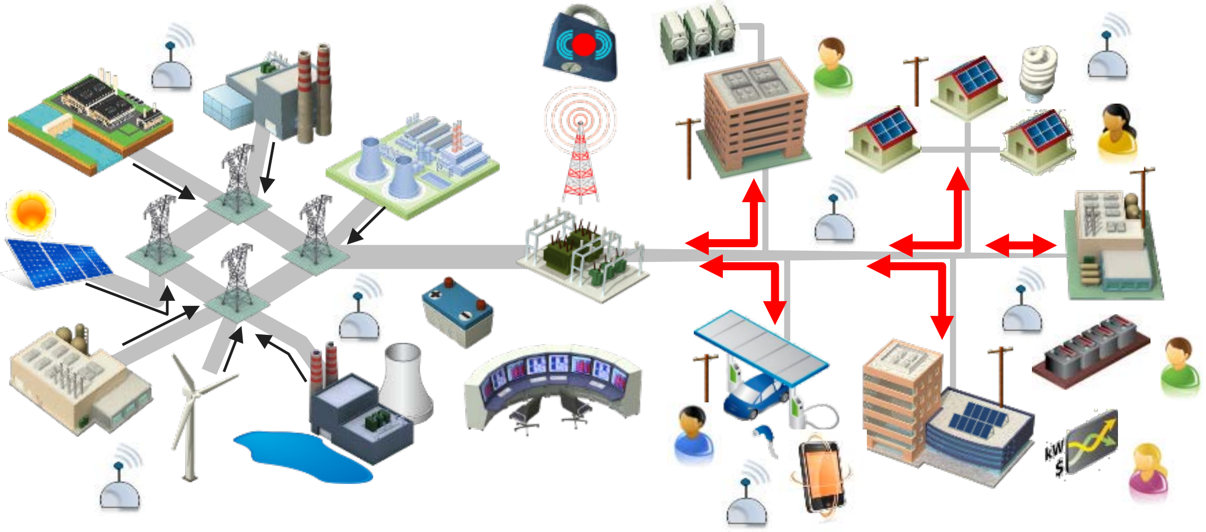
- Existing resource adequacy metrics (e.g., LOLE) may not be the "best" or only metric to use to measure electric reliability.

2. Increasing Modeling Granularity



- *Temporal* Resolution
  - Hourly / sub-hourly time steps and multiple timeframes
  - Evaluation of energy storage systems and variable renewable resources require inter-temporal constraints and opportunities to be more fully recognized.
  - Understand potential net load impacts from utility renewable generation, customer choice, storage, DER deployment, and increased electrification.
- *Geographic* Resolution
  - "Birds of a feather flock together" – EVs and rooftop PV typically are adopted in neighborhoods, so disproportionally impact circuits. Traditional deterministic and stochastic modeling do not capture the geographic nature of customer preferences.
  - DER targeting and location have a direct impact on transmission and generation investment decisions and depend on customer preferences.

3. Integrating G, T, and D Planning



- TSO/DSO interaction increasingly is important, particularly as the distribution system provides more services
- Allows for evaluation of "non-wires alternatives" (NWA) to new G, T and/or D investments
- DER valuation and targeting, including locational attributes
- Improve communications and "hand shakes" between planning functions
- Connections to other critical infrastructure (e.g., natural gas, H_2O, electric vehicle charging)

4. Expanding Analysis Boundaries

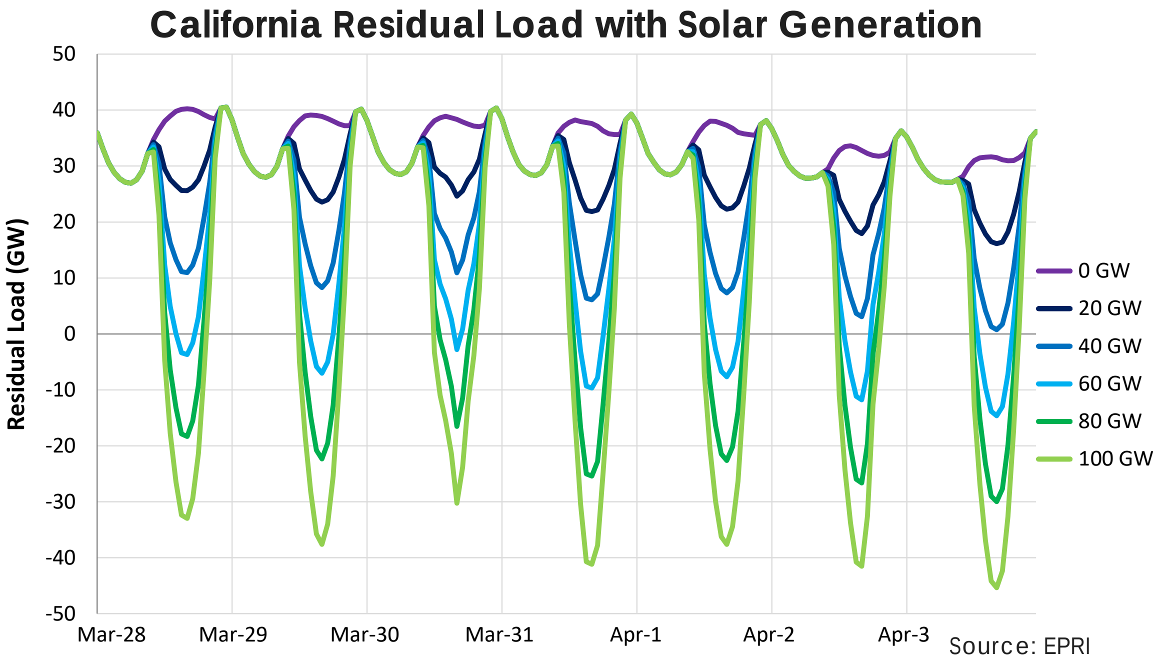
- Interactions with other sectors of the economy to achieve least-cost GHG emissions reductions (e.g., CA SB-350)
- "Gas-electric" coordination to better optimize planning and operations of natural gas fuels with electric operations
- Energy-water nexus – Planning to address both consumption and use of water in power generation and potential impacts of power generation on water resources is becoming more prominent.
- Multi-jurisdictional planning – Some companies are now facing conducting resource planning across multiple jurisdictions in an integrated manner. Examples include PacifiCorp in the western US and Duke in the eastern U.S.

5. Addressing Uncertainty and Managing Risk

- **Risk**
  - Deterministic v. stochastic modeling – Deterministic modeling and scenario analysis may not be adequate. Planners may need to do more stochastic modeling to capture the inherent uncertainty in the electric system.
  - Non-market risks – Growing need to develop methods and approaches to evaluate "non-market" risks, such as a perceived lack of "fuel diversity," and the ability to respond to changes in the external operating, policy and regulatory environments.
- **Uncertainty** – Becoming increasingly important to incorporate forecast uncertainty and variability in future loads, VER production, and DER adoption and use.
  - Production profiles for VERs are uncertain over time horizons from minutes to years, with each different time horizon causing their own challenges
  - Capacity values for variable generation are uncertain
  - VERs can increase variability and volatility of energy prices
  - Increasing DR capabilities may make it more difficult to forecast load

6. Improving/Integrating Forecasting

- Key areas of forecasting are critical for robust long-term resource planning.
  - Electric load
  - DER adoption
  - Natural gas prices
  - Weather



Source: EPRI

- Need to better characterize natural <u>uncertainty</u> inherent in these key factors, and gain insights using computationally tractable methods.

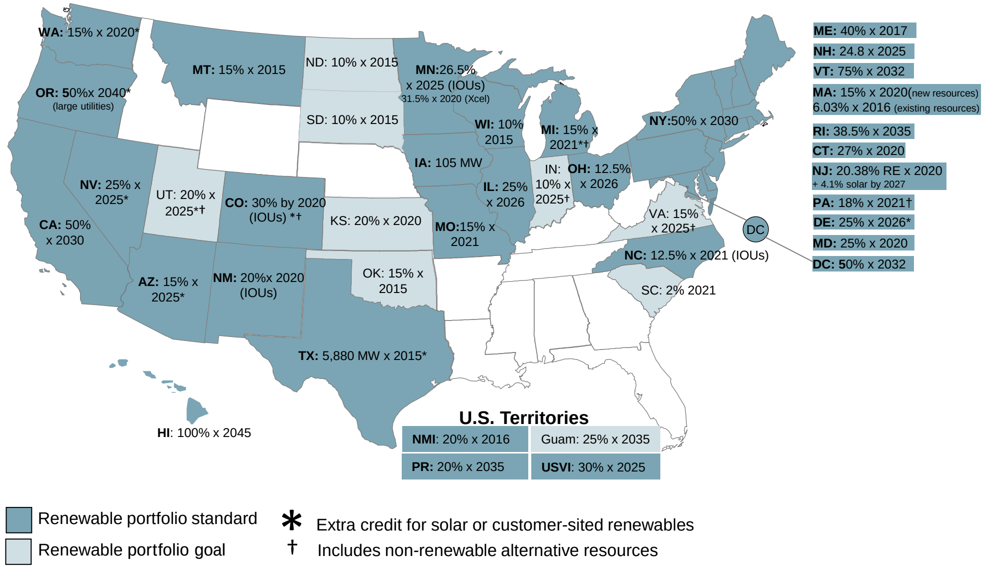
- The ability to analyze "big data" related to DER, customer behavior, operations and other aspects of the future electric system may require new analysis capabilities and computational power.

7. Customer Behavior and Interaction

- Customer behavior is expected to have a direct and tangible impact on resource planning in the future.
- Some ways customer behavior and resource planning may interact include:
  - Behind the meter generation (e.g., solar PV)
  - DER approaches, such as EE and DR
  - Electric transportation, electrification, and smart devices
  - Electric rates and rate structures may impact consumer behavior, electric demand, and planning

8. New Planning Objectives and Constraints

- GHG emissions and RPS – CA requires IRPs to achieve least-cost GHG emissions reductions and aggressive RPS targets.

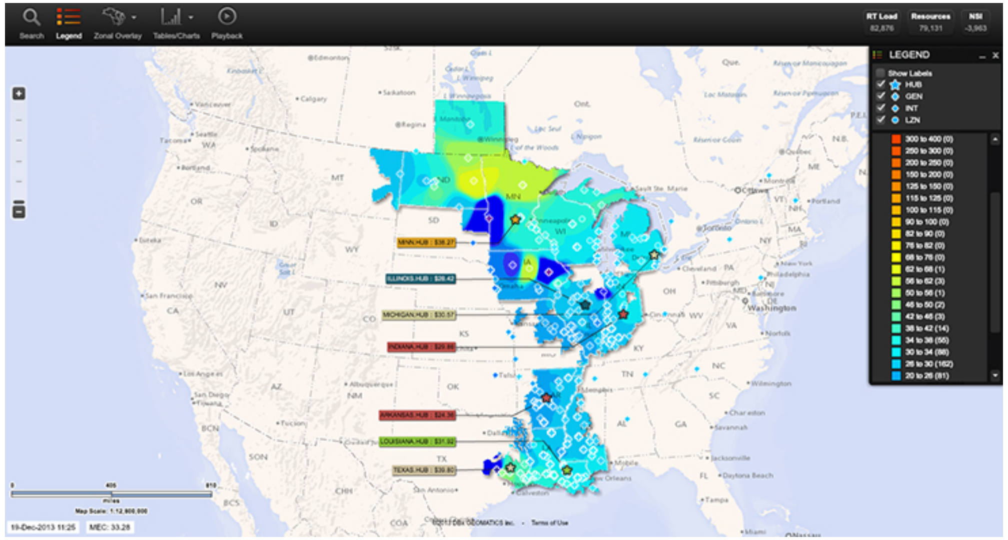


29 States + Washington DC + 3 territories have a Renewable Portfolio Standard
Source: www.dsireusa.org / February 2017

- Water resources – Some electric companies are being asked to consider impacts on local water resources.

- Resiliency – Electric companies are being asked to more fully address system resiliency in resource planning. This includes two facets:
  - *Physical* – Protect the system from extreme weather events and restore it
  - *Cyber* – Protect the electric system from cybersecurity threats and restore it

9. Wholesale Power Market Interactions



- Interactions between companies and ISO/RTOs markets are starting to create new challenges for resource planners.
- Planners are challenged by considering buying and selling energy, capacity, and ancillary services (A/S) rather than building new resources or procuring “own” resources.
- Growing need to project uncertain potential future wholesale power prices, and incorporate them into modeling tools.
- Growing need to better understand how A/S and capacity markets may evolve, and impacts on future value of power resources.
- Planning methods will have to consider how ISOs/RTO markets will value different resource capabilities in the future.

10. Expanding External Stakeholder Engagement

- The primary audience for company IRPs traditionally has been state PUCs and other regulators. Additional important audiences have included business associations, environmental and consumer advocates, and local non-governmental organizations (NGOs).

- In recent years, public expectations regarding involvement in company resource planning have changed dramatically
  - New stakeholders are engaged and participating in the planning process
  - Stakeholders want to address a broader array of issues than have been addressed in company resource planning in the past (e.g., rate design, rate setting, others…)
  - Stakeholders are becoming engaged in the entire resource planning process

- More companies now are engaged in designing and managing extensive stakeholder engagement processes related to resource planning activities.