National Academy of Sciences

Decarbonizing the United States: Challenges of Scale, Scope, and Rate

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July 22, 2019

DDPP DEEP DECARBONIZATION PATHWAYS PROJECT

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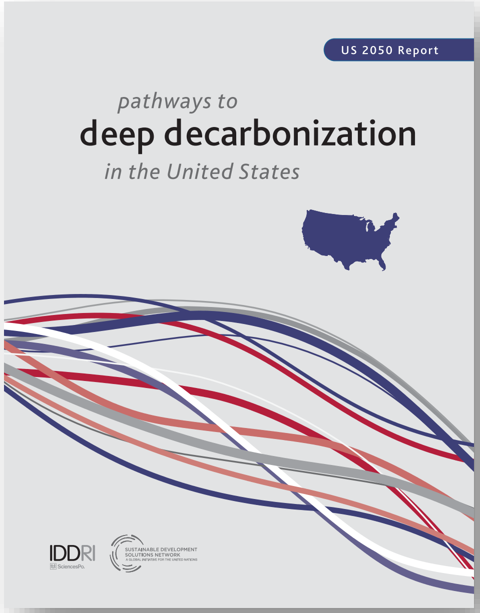
US 2050 Report

pathways to
deep decarbonization
in the United States

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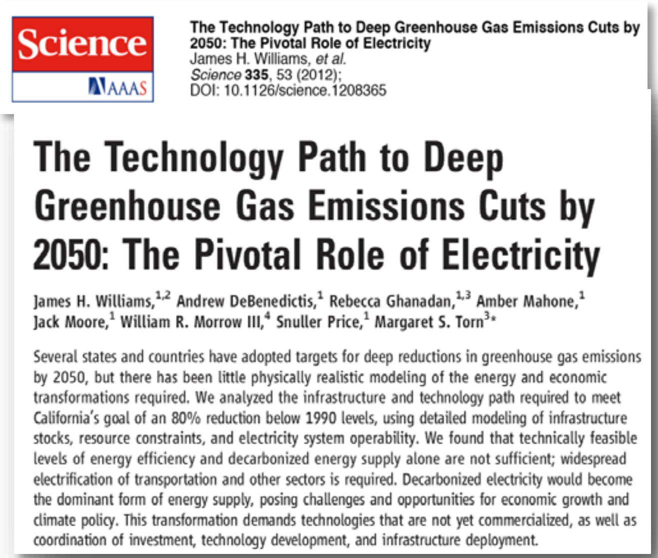
Science AAAS

The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity
James H. Williams, *et al.*
Science **335**, 53 (2012);
DOI: 10.1126/science.1208365

The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity

James H. Williams,[1,2] Andrew DeBenedictis,[1] Rebecca Ghanadan,[1,3] Amber Mahone,[1] Jack Moore,[1] William R. Morrow III,[4] Snuller Price,[1] Margaret S. Torn[3]*

Several states and countries have adopted targets for deep reductions in greenhouse gas emissions by 2050, but there has been little physically realistic modeling of the energy and economic transformations required. We analyzed the infrastructure and technology path required to meet California's goal of an 80% reduction below 1990 levels, using detailed modeling of infrastructure stocks, resource constraints, and electricity system operability. We found that technically feasible levels of energy efficiency and decarbonized energy supply alone are not sufficient; widespread electrification of transportation and other sectors is required. Decarbonized electricity would become the dominant form of energy supply, posing challenges and opportunities for economic growth and climate policy. This transformation demands technologies that are not yet commercialized, as well as coordination of investment, technology development, and infrastructure deployment.


350 PPM PATHWAYS
FOR THE UNITED STATES
May 8, 2019

EVOLVED
ENERGY
RESEARCH

DEEP DECARBONIZATION PATHWAYS PROJECT
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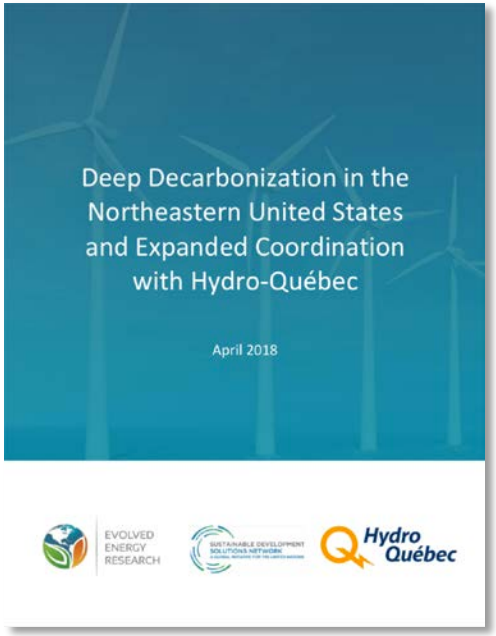
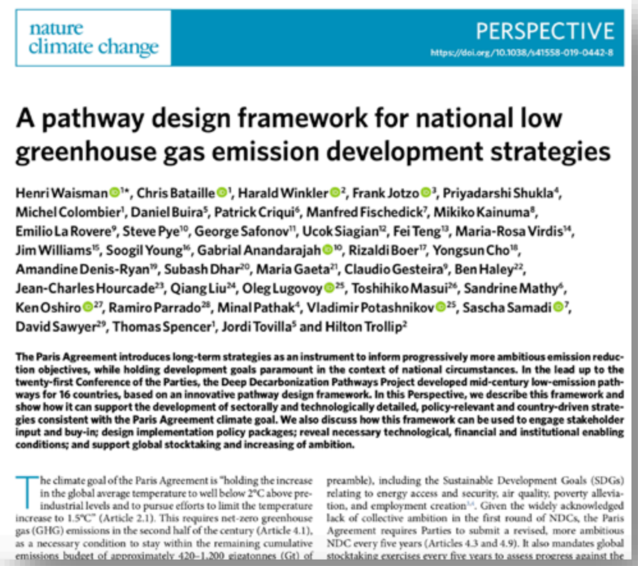

Deep Decarbonization in the Northeastern United States and Expanded Coordination with Hydro-Québec

April 2018

EVOLVED ENERGY RESEARCH
SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
Hydro Québec


nature climate change
PERSPECTIVE
https://doi.org/10.1038/s41558-019-0442-8

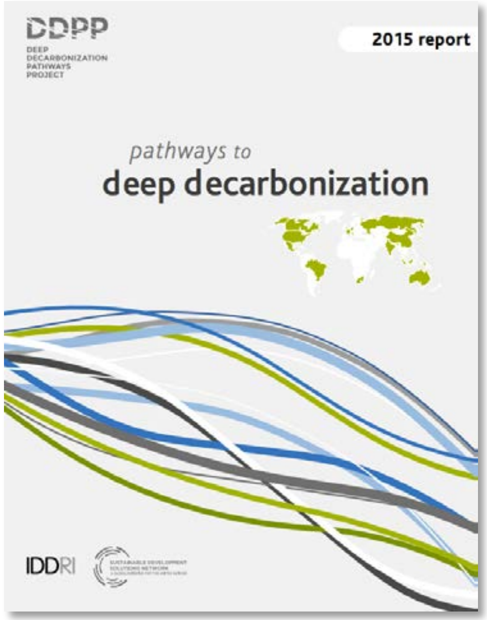
A pathway design framework for national low greenhouse gas emission development strategies

Henri Waisman[1]*, Chris Bataille[1], Harald Winkler[2], Frank Jotzo[3], Priyadarshi Shukla[4], Michel Colombier[1], Daniel Buira[5], Patrick Criqui[6], Manfred Fischedick[7], Mikiko Kainuma[8], Emilio La Rovere[9], Steve Pye[10], George Safonov[11], Ucok Siagian[12], Fei Teng[13], Maria-Rosa Virdis[14], Jim Williams[15], Soogil Young[16], Gabrial Anandarajah[10], Rizaldi Boer[17], Yongsun Cho[18], Amandine Denis-Ryan[19], Subash Dhar[20], Maria Gaeta[21], Claudio Gesteira[9], Ben Haley[22], Jean-Charles Hourcade[23], Qiang Liu[24], Oleg Lugovoy[25], Toshihiko Masui[26], Sandrine Mathy[6], Ken Oshiro[27], Ramiro Parrado[28], Minal Pathak[4], Vladimir Potashnikov[25], Sascha Samadi[7], David Sawyer[29], Thomas Spencer[1], Jordi Tovilla[5] and Hilton Trollip[2]

The Paris Agreement introduces long-term strategies as an instrument to inform progressively more ambitious emission reduction objectives, while holding development goals paramount in the context of national circumstances. In the lead up to the twenty-first Conference of the Parties, the Deep Decarbonization Pathways Project developed mid-century low-emission pathways for 16 countries, based on an innovative pathway design framework. In this Perspective, we describe this framework and show how it can support the development of sectorally and technologically detailed, policy-relevant and country-driven strategies consistent with the Paris Agreement climate goal. We also discuss how this framework can be used to engage stakeholder input and buy-in; design implementation policy packages; reveal necessary technological, financial and institutional enabling conditions; and support global stocktaking and increasing of ambition.

The climate goal of the Paris Agreement is "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C" (Article 2.1). This requires net-zero greenhouse gas (GHG) emissions in the second half of the century (Article 4.1), as a necessary condition to stay within the remaining cumulative emissions budget of approximately 420–1,200 gigatonnes (Gt) of

preamble), including the Sustainable Development Goals (SDGs) relating to energy access and security, air quality, poverty alleviation, and employment creation[3,4]. Given the widely acknowledged lack of collective ambition in the first round of NDCs, the Paris Agreement requires Parties to submit a revised, more ambitious NDC every five years (Articles 4.3 and 4.9). It also mandates global stocktaking exercises every five years to assess progress against the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DEEP DECARBONIZATION PATHWAYS PROJECT

2015 report

pathways to
deep decarbonization

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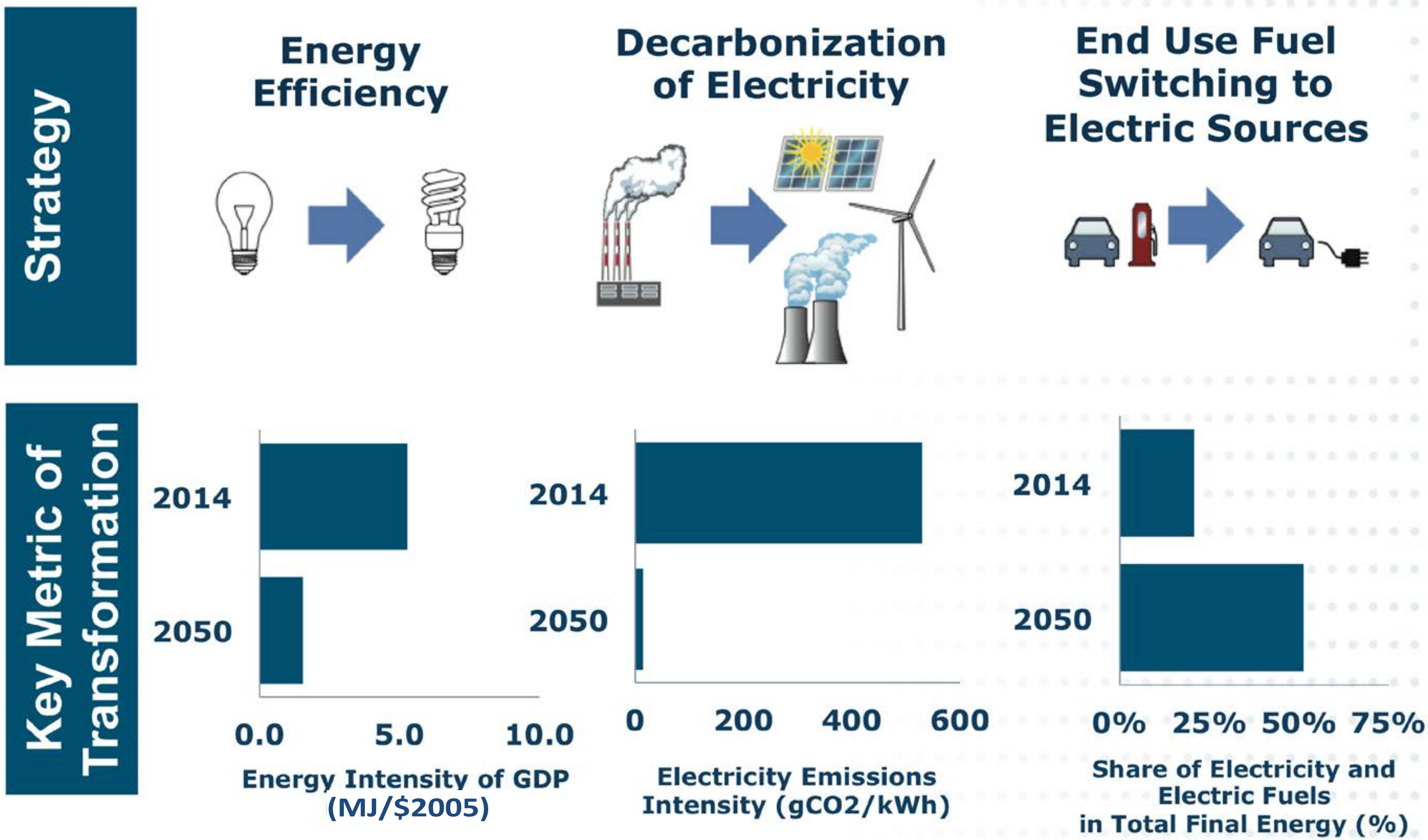
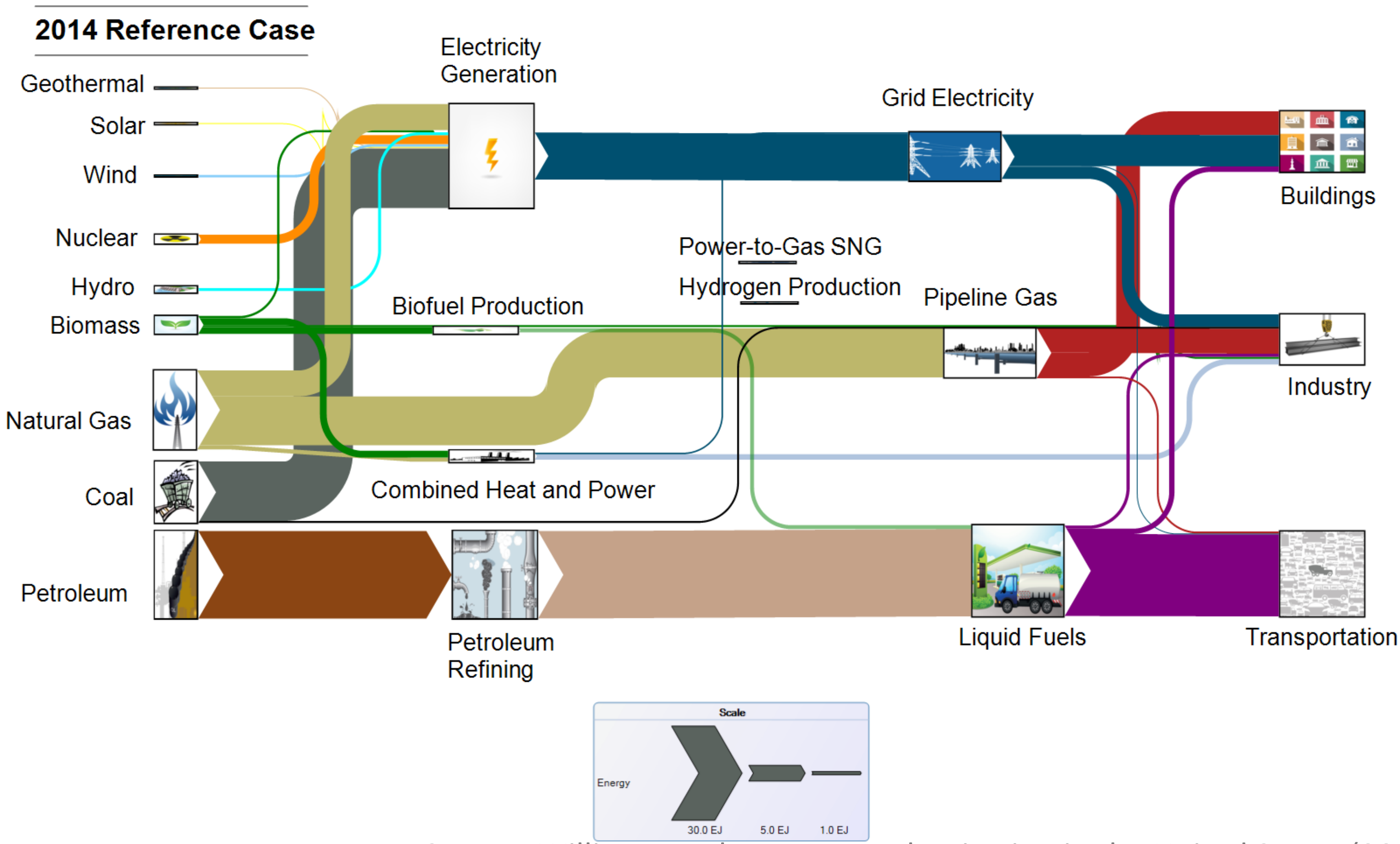
Three Pillars of Deep Decarbonization Required in All Cases



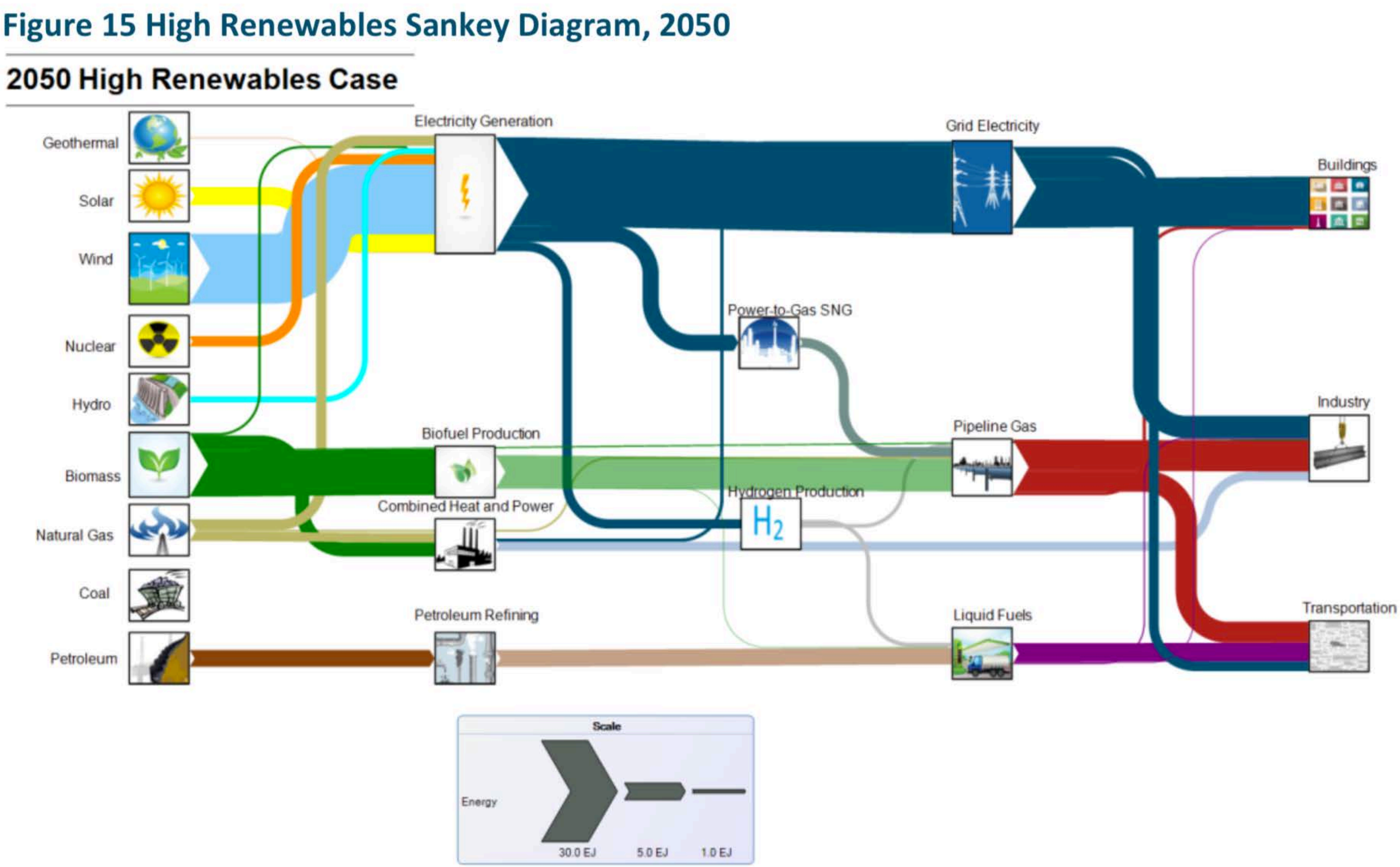
Pathways to Deep Decarbonization in the United States, Mixed case results

Current Energy System



Source: Williams et al. Deep Decarbonization in the United States (2015)

Low Carbon Energy System



Source: Williams et al. Deep Decarbonization in the United States (2015)

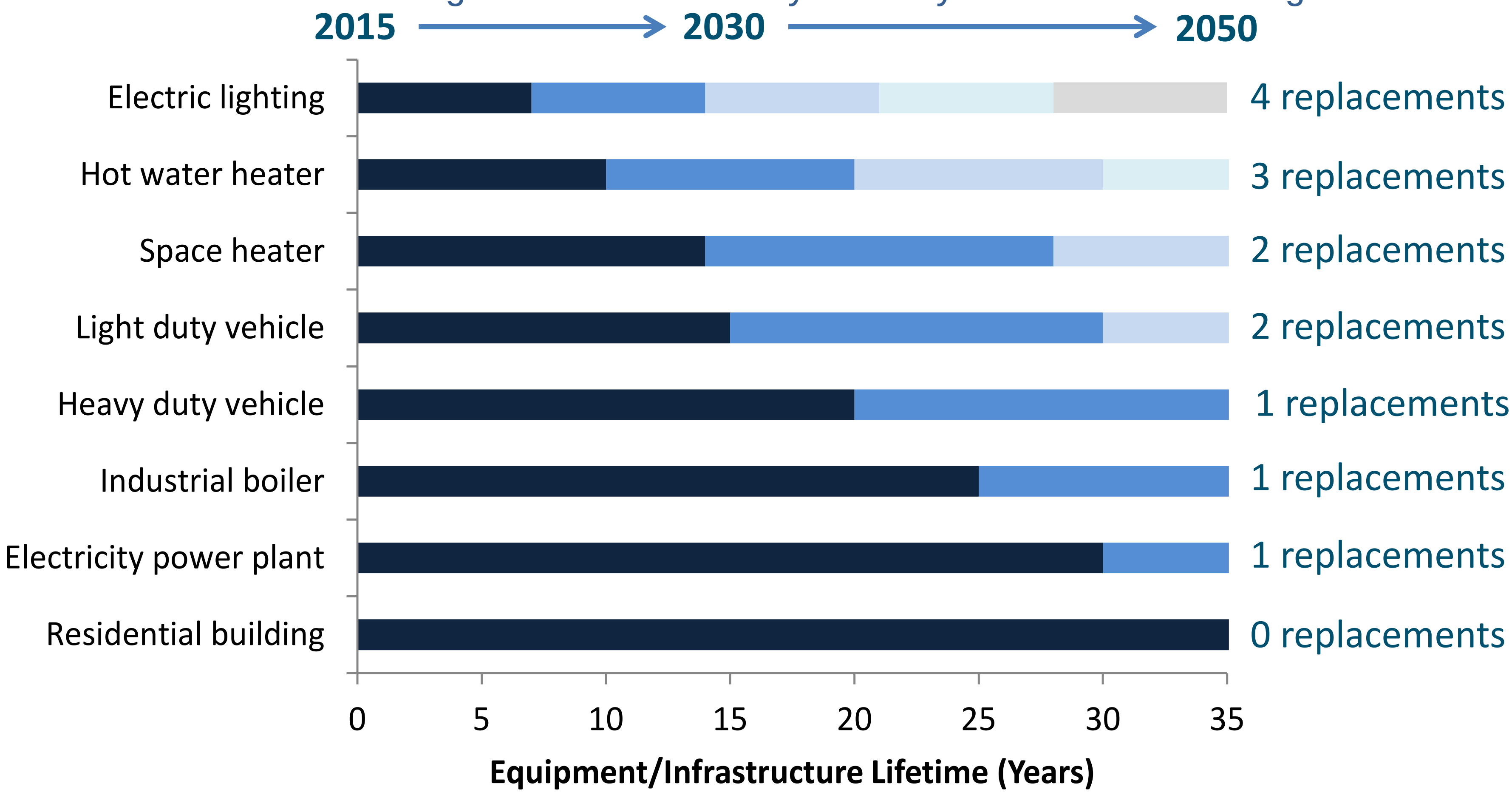
Sectoral Metrics: 2050 Benchmarks for US

Sector	Current Energy System	Deep Decarbonized Energy System	Key Metrics in 2050
Electricity	Coal and natural gas dominated	Renewable, nuclear, or CCS	Double output while reducing CO_2/kWh 30x
Transportation	Oil dominated	Electricity, hydrogen, CNG, LNG, biodiesel	Fuel economy >100 mpg equivalent
Buildings	Natural gas and oil dominate heating	Electrification, end use efficiency	Building energy use >90% electrified
Industry	Fossil fuel dominated	Electrification, CCS, efficiency, low C fuels	Double efficiency, >40% electrification

Source: Williams et al. Deep Decarbonization in the United States (2015)

Energy infrastructure typically has long lifetimes
Decarbonization strategy must account for this

- A car purchased today is likely to replaced at most 2 times before 2050.
  A residential building constructed today is likely to still be standing in 2050.



Systemic Nature of Low Carbon Transition
Light Duty Vehicle Example

Energy service demand (AEO)

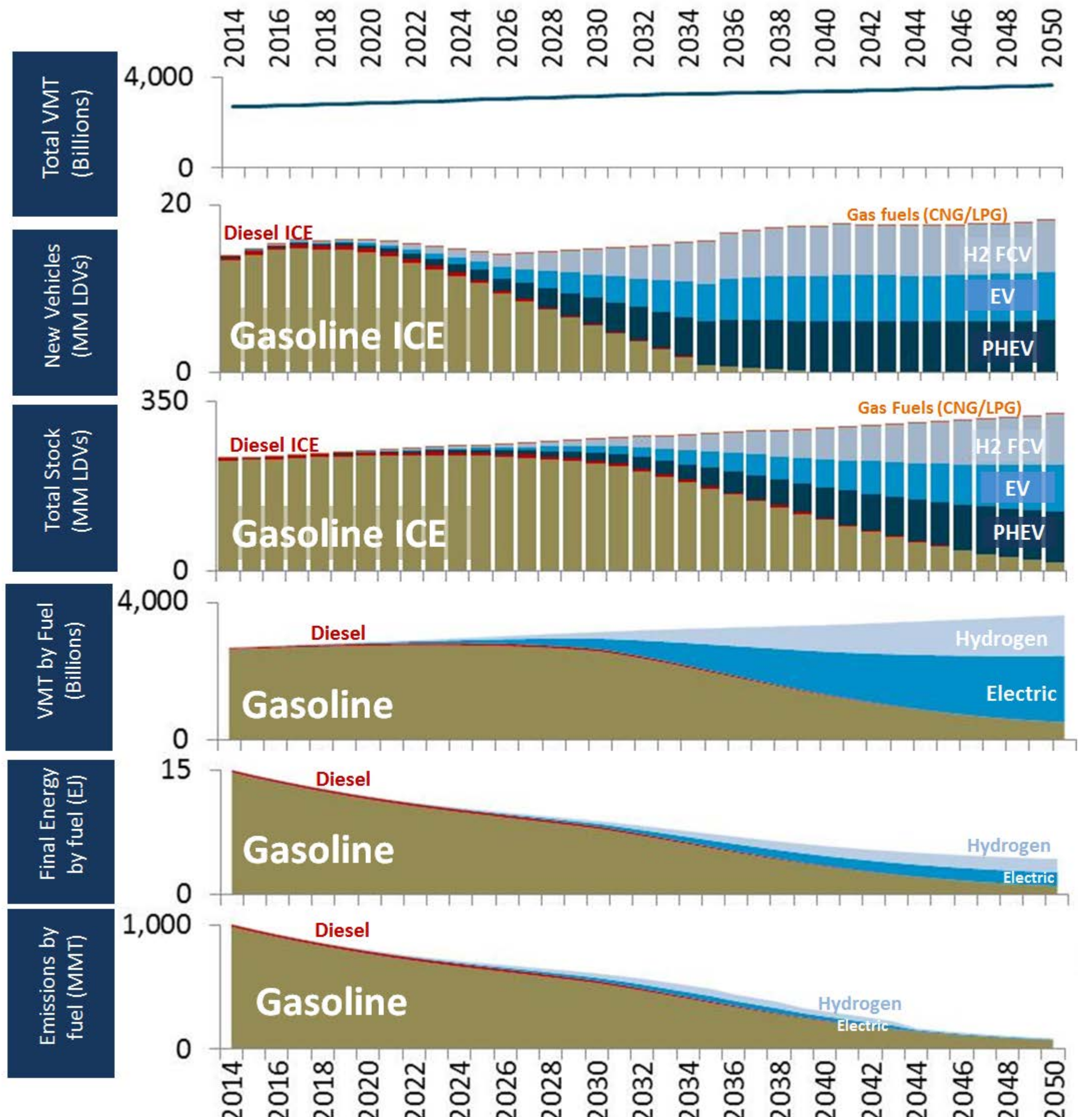
Annual LDV sales

LDV stocks by type

VMT by fuel type

LDV final energy by fuel type

GHG emissions by fuel type



Annual sales reach 100% low carbon vehicles in ~15 years

LDV stock ~300M low carbon vehicles in 2050

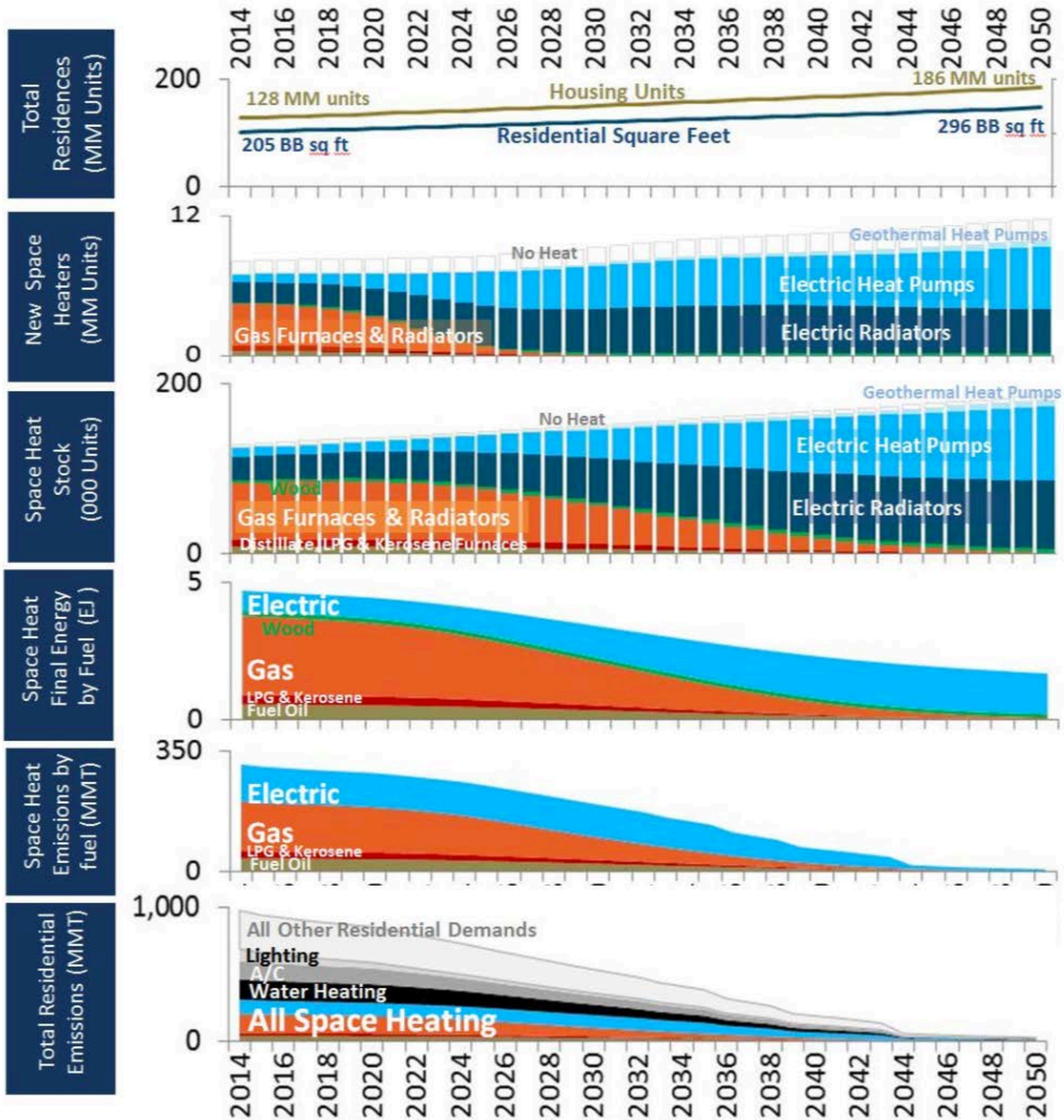
>90% of VMT from electricity or electric fuels

Electric drive train efficiency reduces final energy ~2/3

LDV emission reduced >95%

Source: Williams et al. Deep Decarbonization in the United States (2015)

Figure 58. Residential Space Heat Low Carbon Transition in Mixed Case



Annual sales reach ~100% electric heating in ~10 years

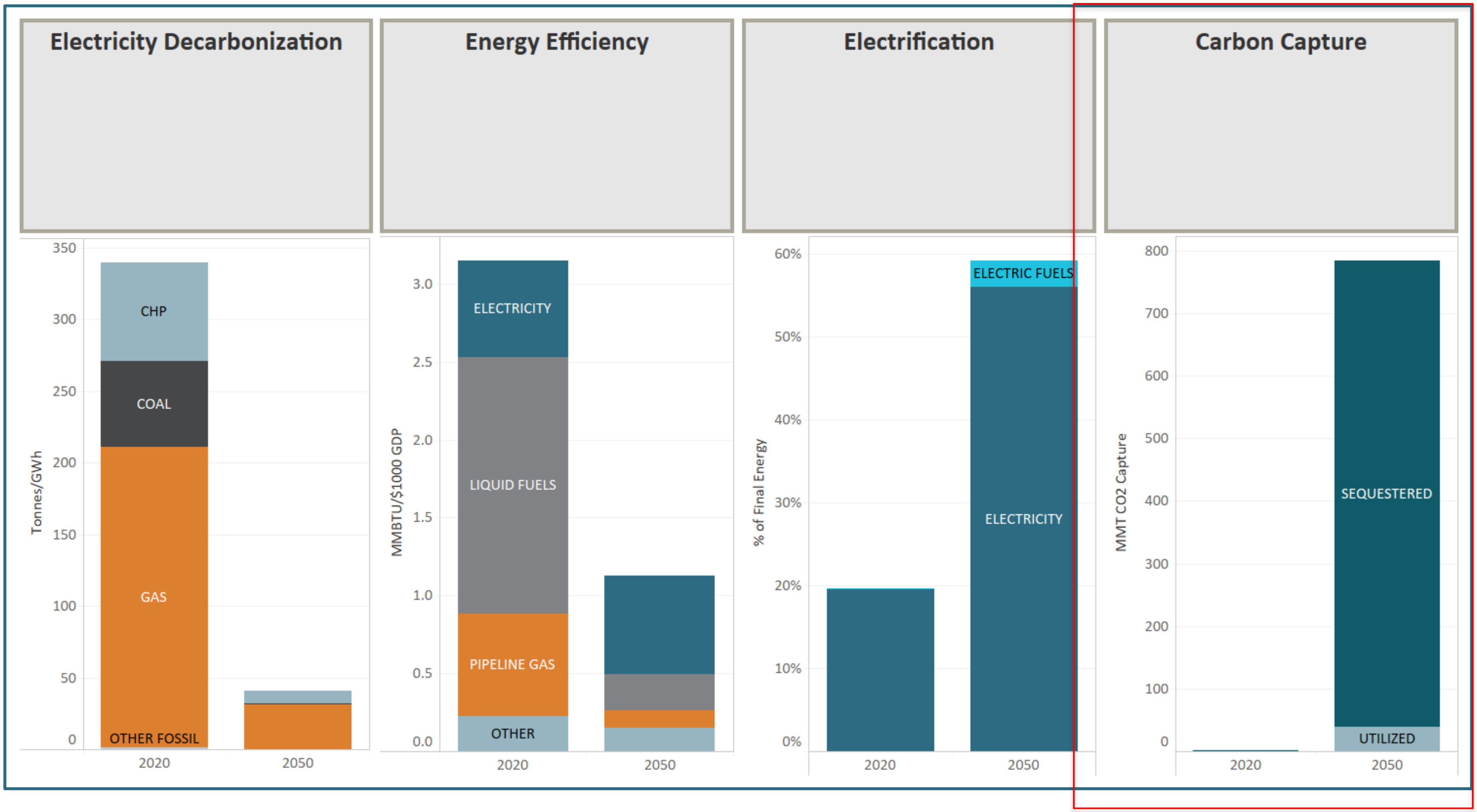
Space heating ~100% electrified by 2045

Electricity supplies all heating in 2050

CO_2 from heating almost eliminated by 2050

Source: Williams et al. Deep Decarbonization in the United States (2015)

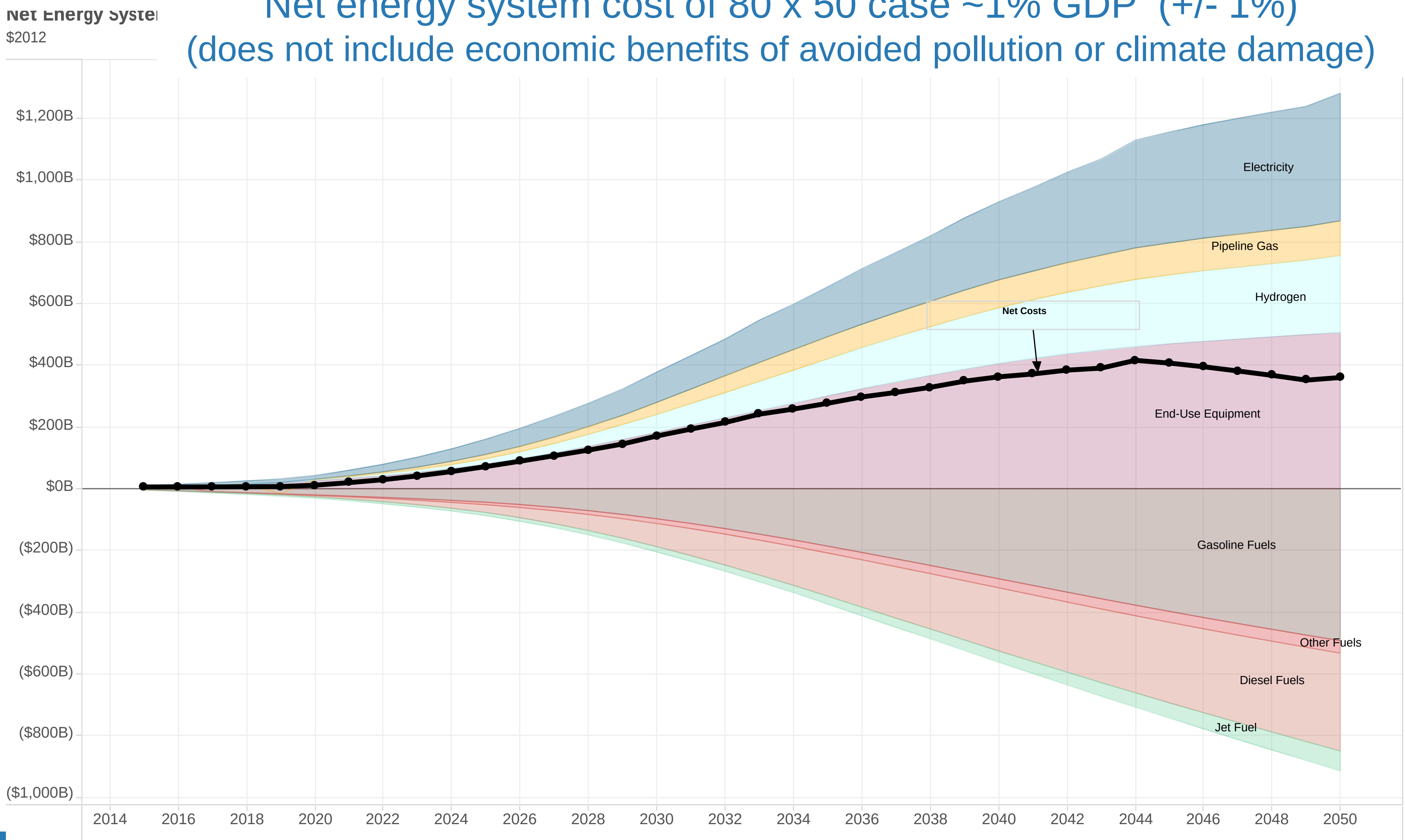
Deeper reduction targets require a 4th pillar: Carbon capture, utilization, sequestration



Source: Haley, et al. 350 ppm Pathways for the United States. (2019)

Energy Economy in Low Carbon Transition: Capital Costs Replace Fuel Costs

Net energy system cost of 80 x 50 case ~1% GDP (+/- 1%)
(does not include economic benefits of avoided pollution or climate damage)



Summary: The Low Carbon Transition

- Net zero carbon by mid-century is technically feasible
- Decarbonization is built on 3 pillars: energy efficiency, electrification, carbon-free electricity
- 4th pillar for deeper decarbonization: carbon capture, sequestration, by technology or land sink
- Fuel costs replaced by fixed costs in low carbon energy economy
- Large change in where money flows to, relatively small change in net flow (~1-2% of GDP)

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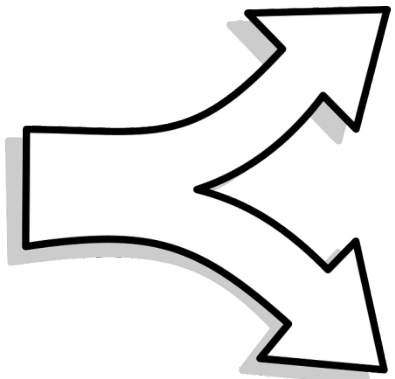
A few institutional challenges...

- Cross-sector coordination in planning and investment, e.g. electricity and transportation
- Certainty for investors
- Consumer adoption of low carbon technologies, e.g. heat pumps & ZEVs
- Adapting to energy system primarily powered by renewables & dominated by fixed costs
- New electricity markets, planning processes
- Retirement of natural gas distribution system
- Addressing land use, NETS requirements

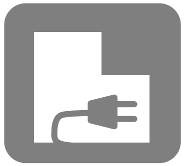
How to coordinate across sectors when the institutions don't currently exist?

1. Electric vs. Fuel Cell Vehicles

Zero Emissions Vehicles

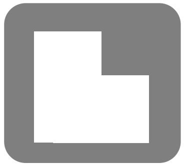


Electric vehicles



Electric charging infrastructure

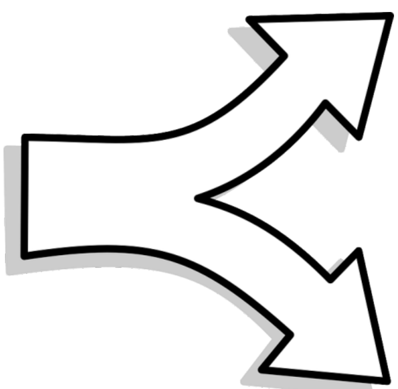
Fuel cell vehicles



H2 fuel production: grid electrolysis

2. Electrification vs. Low Carbon Gas in Buildings

Building strategy



Biogas and low-carbon synthetic methane

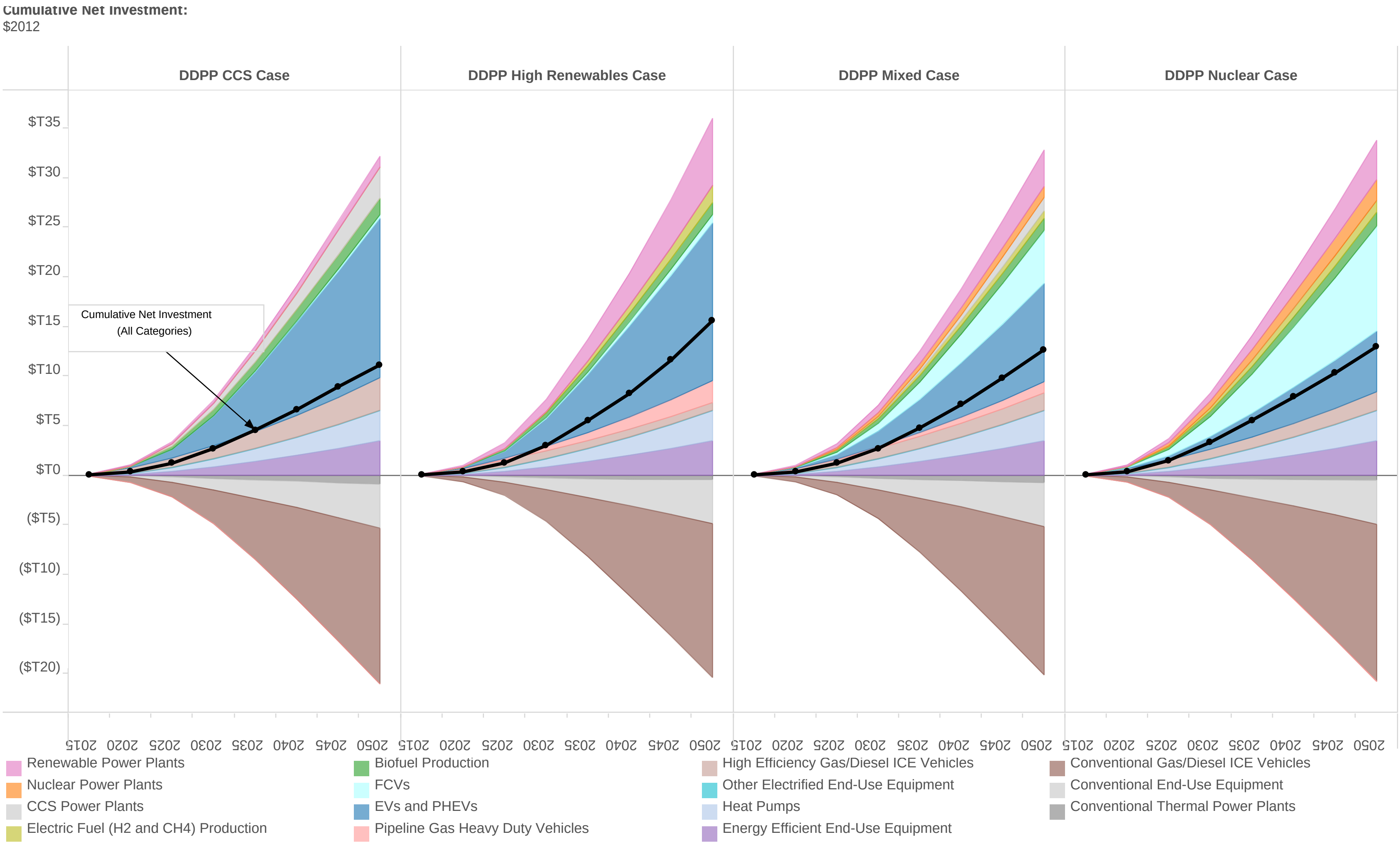
No building electrification, biogas in pipeline

Electric heat pumps, electrification

Building electrification, no gas pipeline

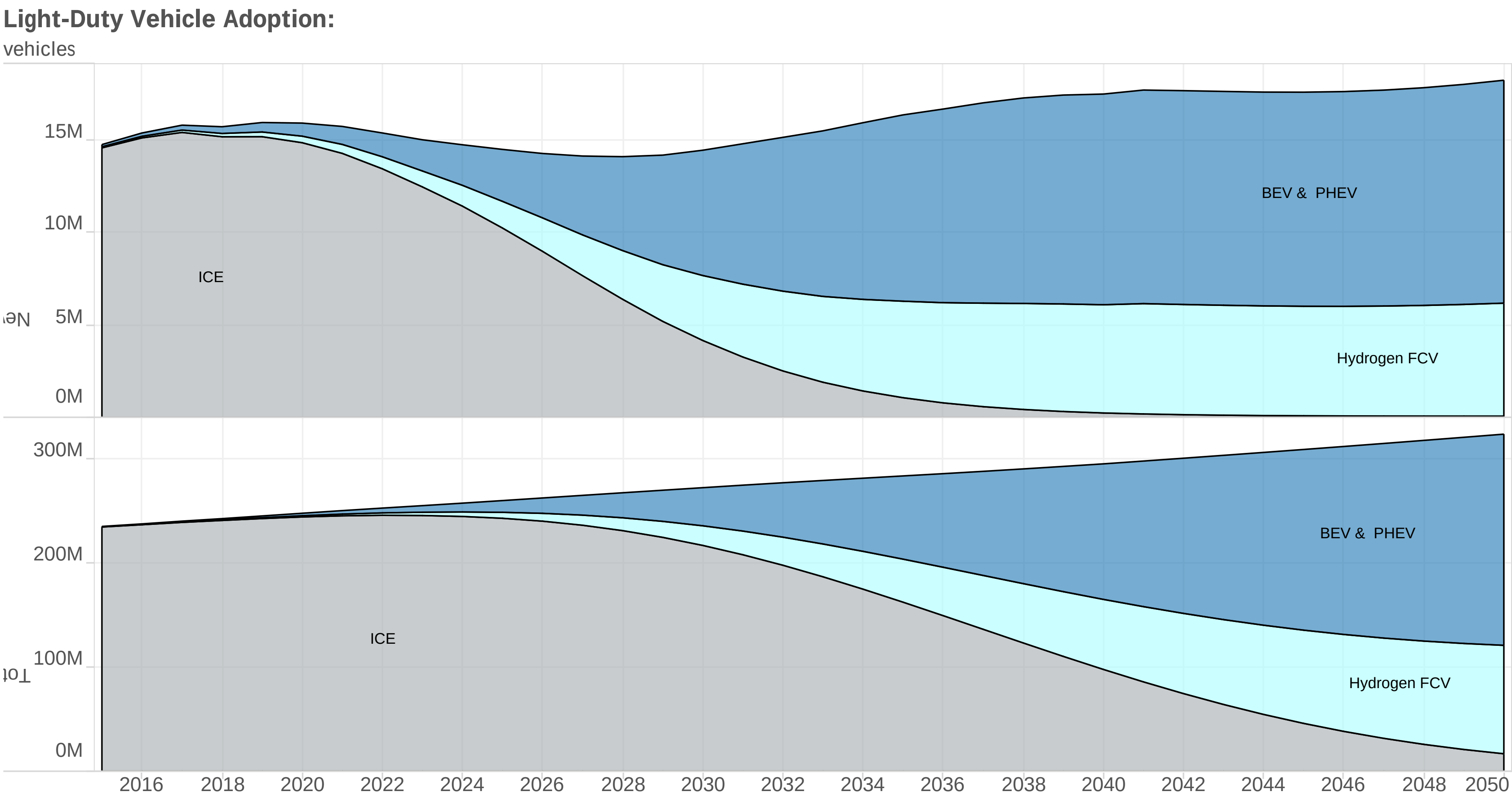
Source: Williams et al. Deep Decarbonization in the United States (2015)

How to drive investment flows into low carbon equipment and infrastructure?



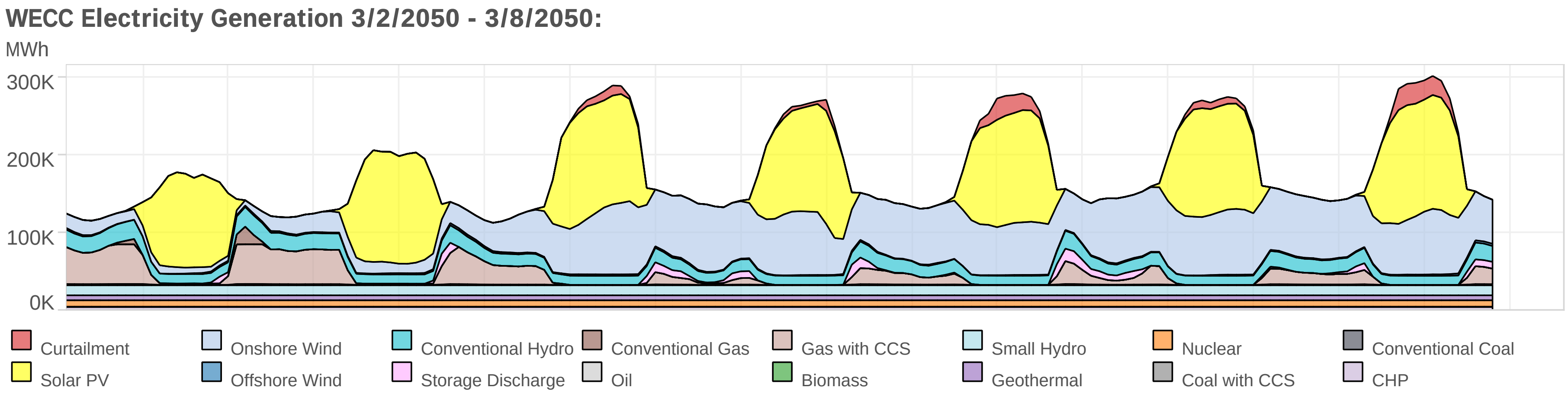
Source: Williams et al. Deep Decarbonization in the United States (2015)

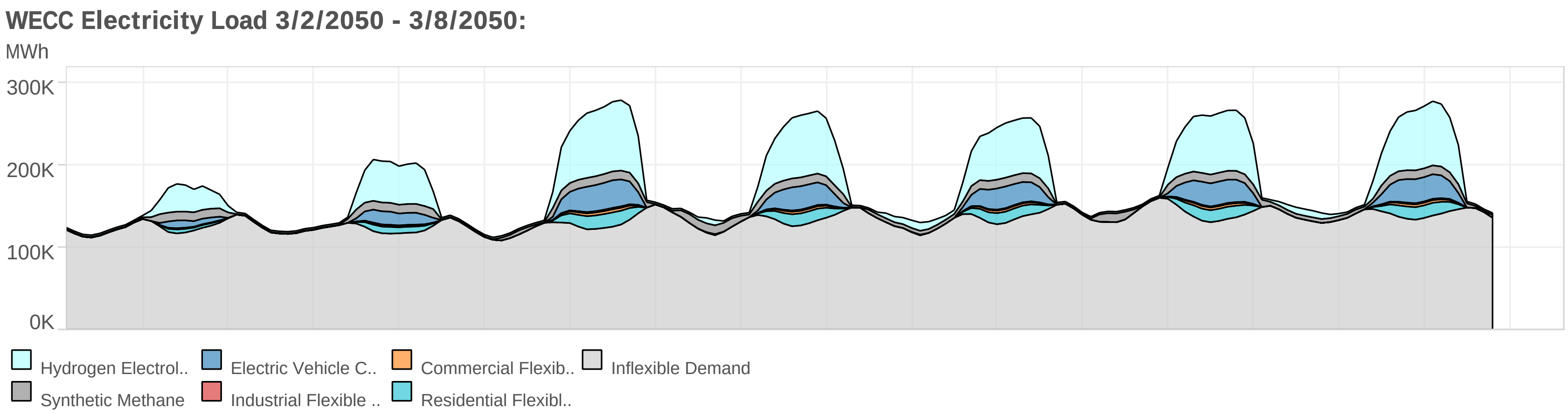
How to drive rapid consumer adoption?



Source: Williams et al. Deep Decarbonization in the United States (2015)

What changes are required for electricity balancing in high renewables system?





Source: Williams et al. Deep Decarbonization in the United States (2015)

Thank you!

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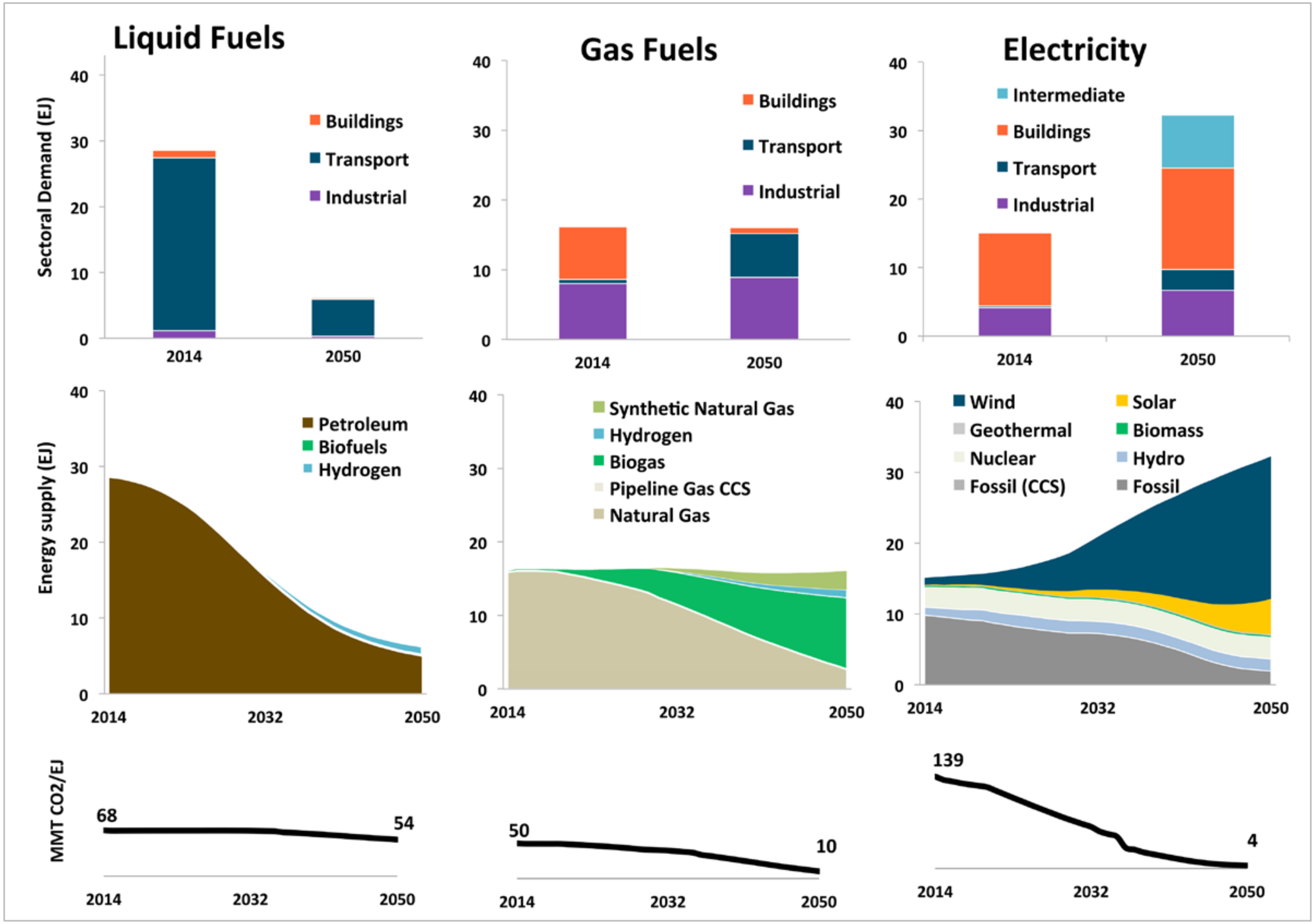
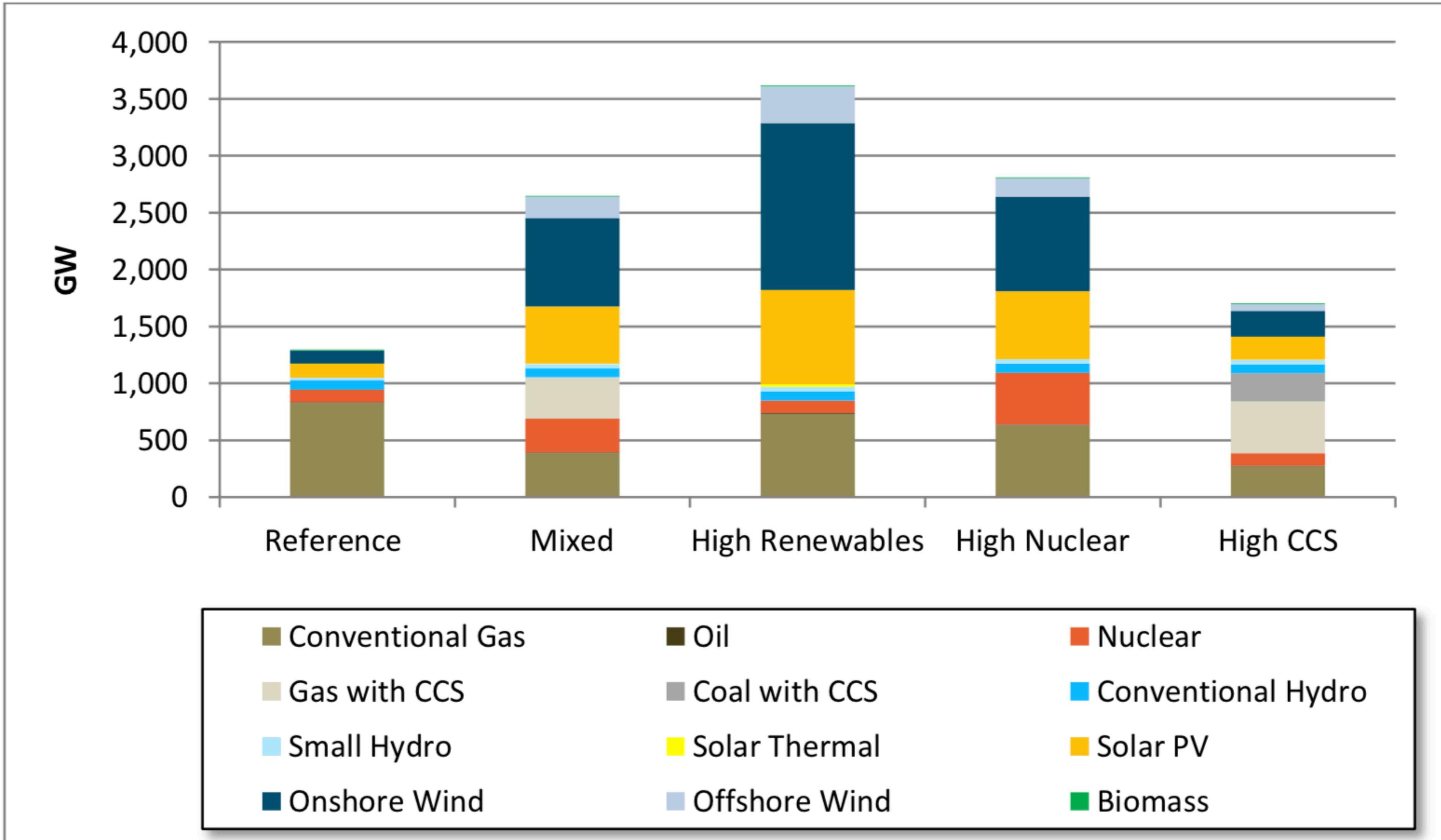
Energy Transition
(High Renewables Case)



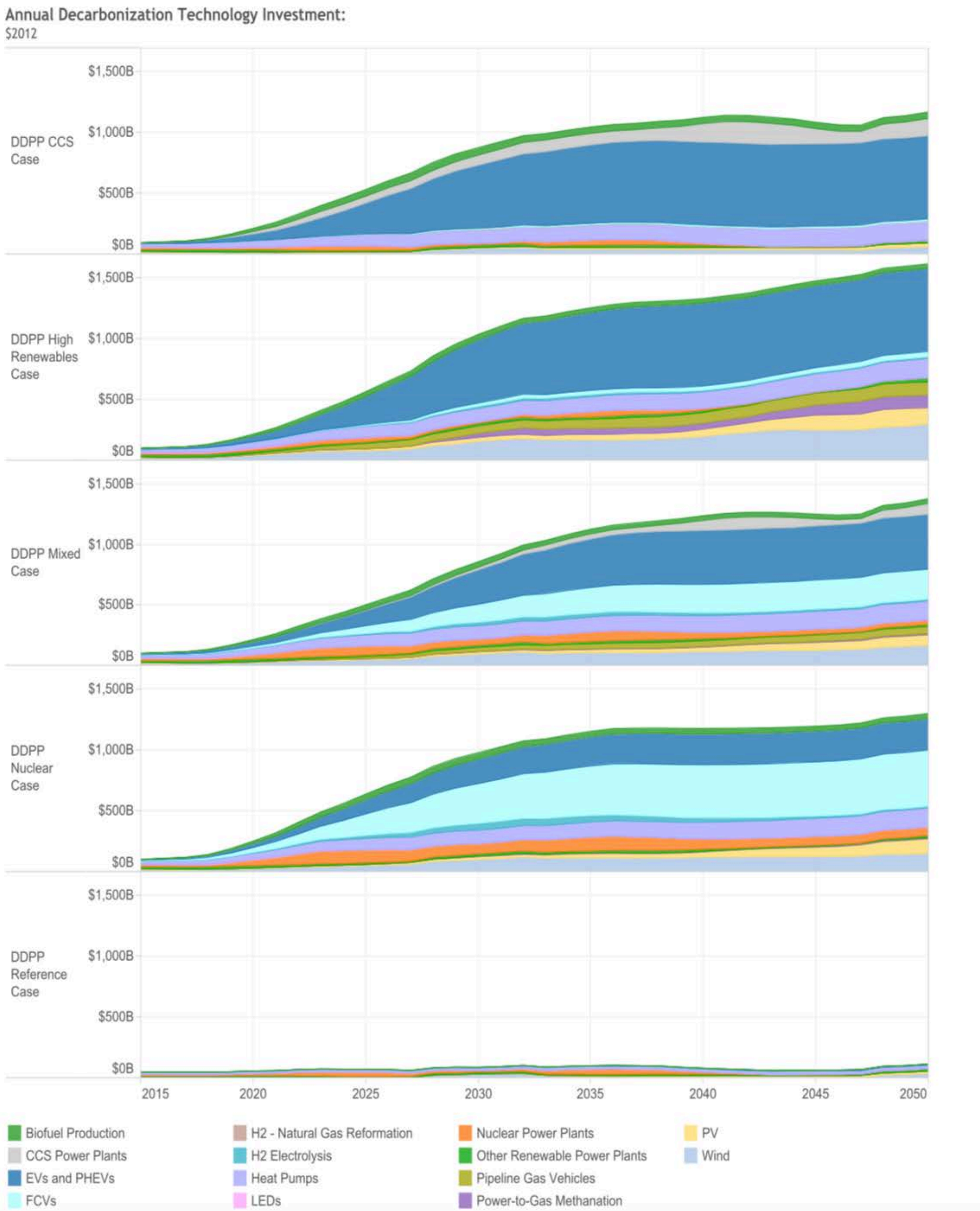
Source: Williams et al. Deep Decarbonization in the United States (2015)

Figure 30. 2050 Installed Electric Generating Capacity

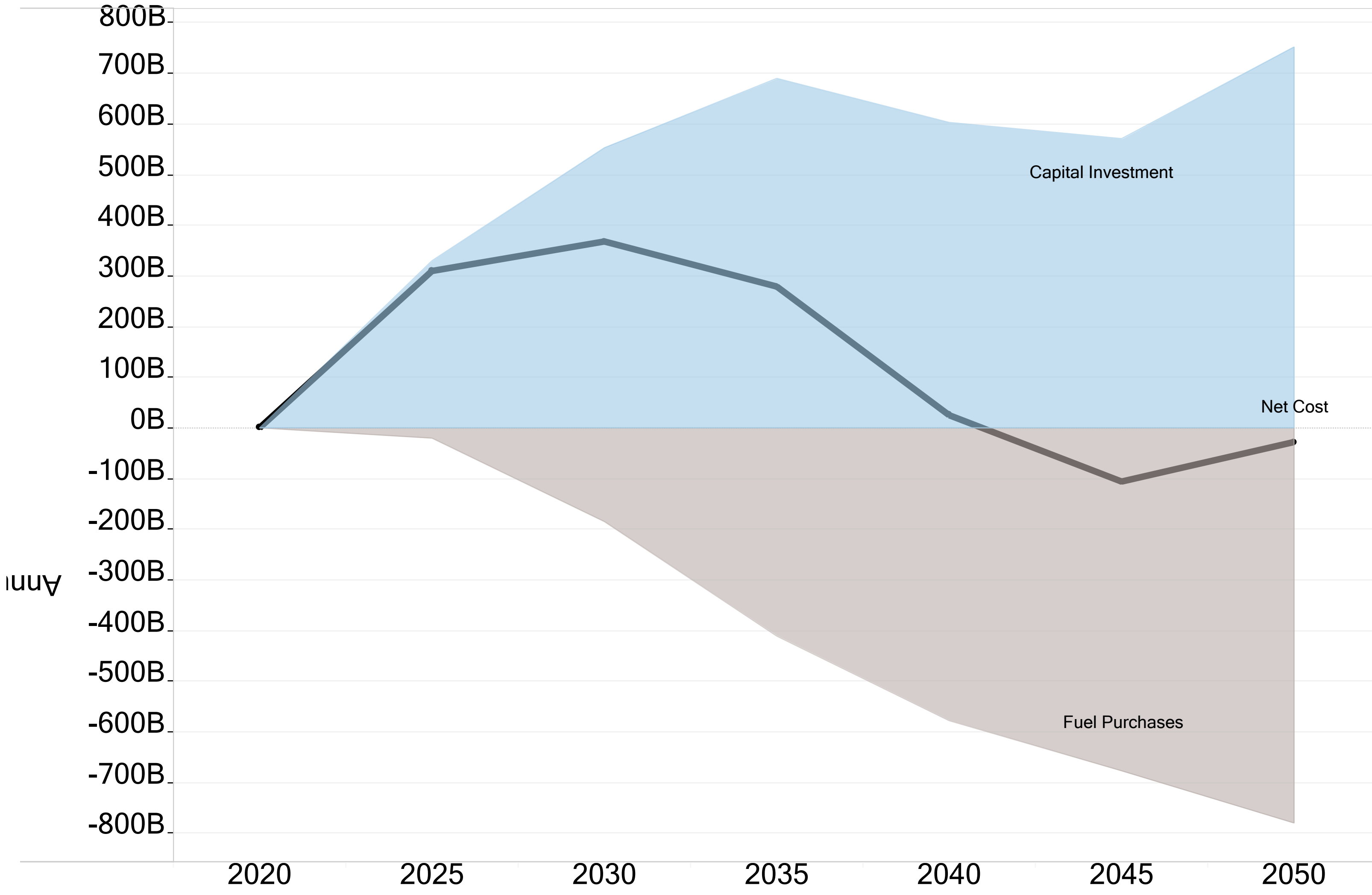


Source: Williams et al. Deep Decarbonization in the United States (2015)

Figure 5 Low-Carbon Technology Investment by Technology Type, Year, and Case

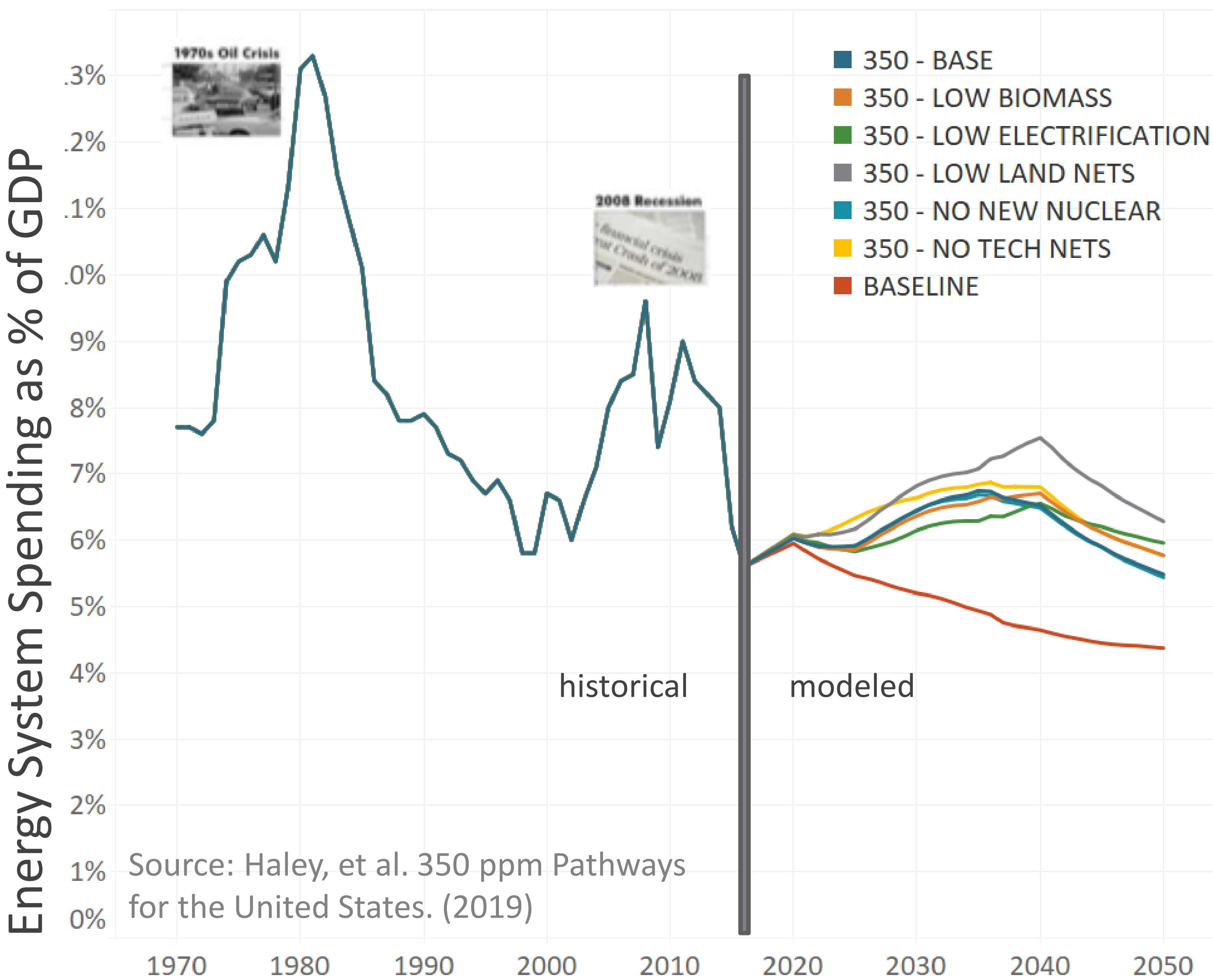


Energy Economy in Low Carbon Transition
Capital Costs Replace Fuel Costs



Source: Haley, et al. 350 ppm Pathways for the United States. (2019)

Net Energy System Cost of Carbon Neutral Pathways Compared to Historical Energy Spending in U.S.



Seasonal overgeneration solution: electric fuel production & other flexible loads

Seasonal undergeneration solution: natural gas generation at very low capacity factors for reliability

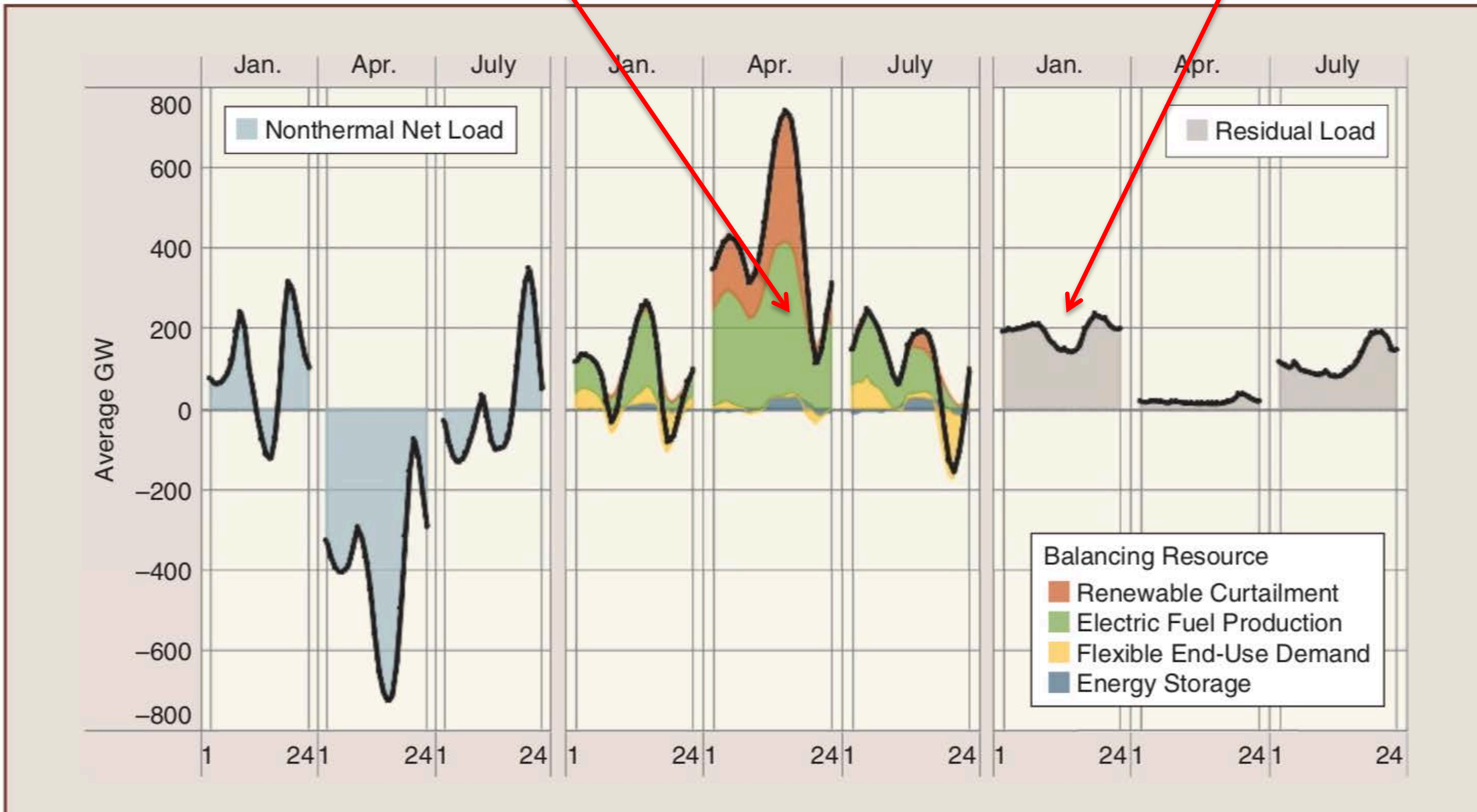
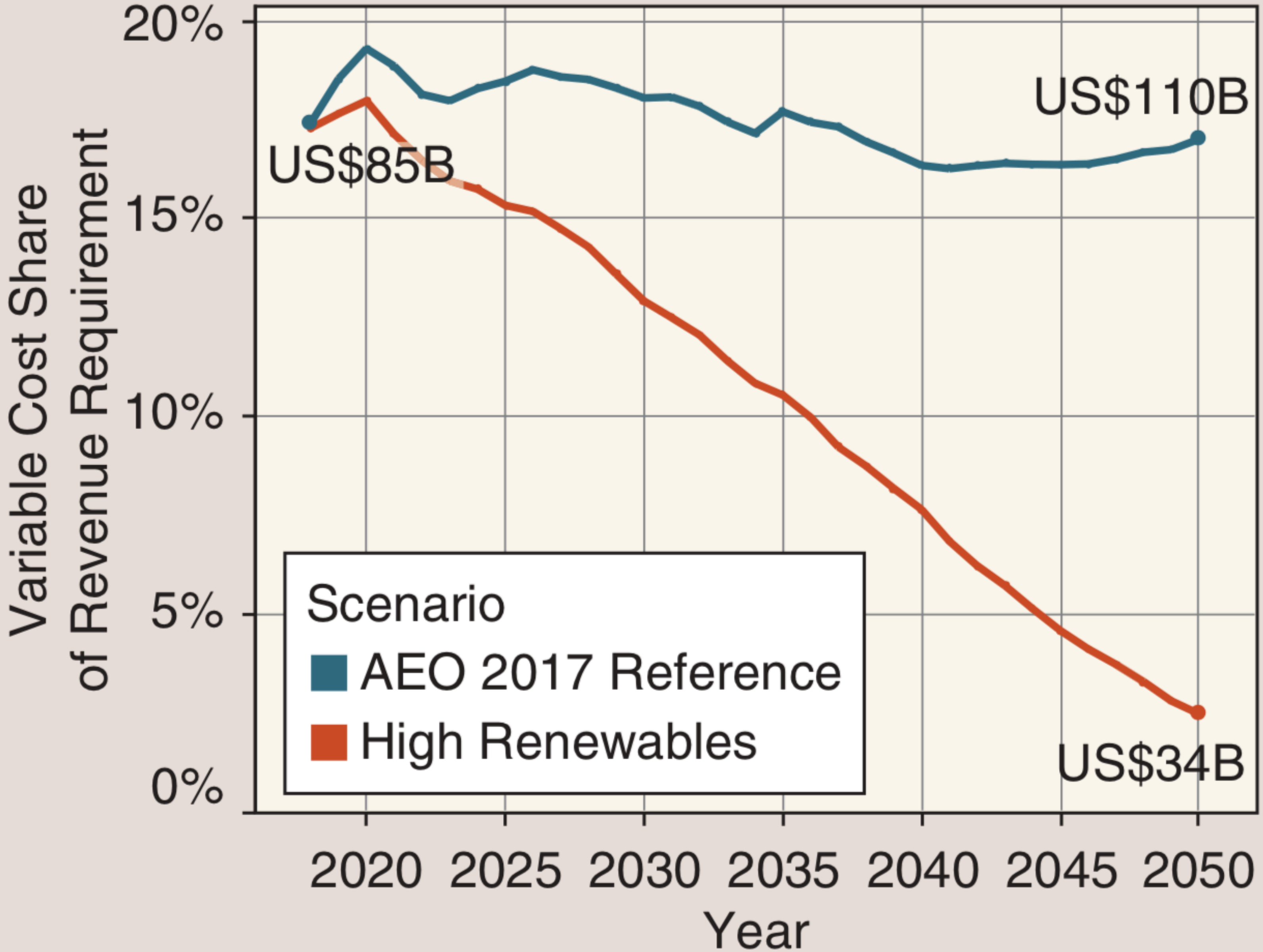
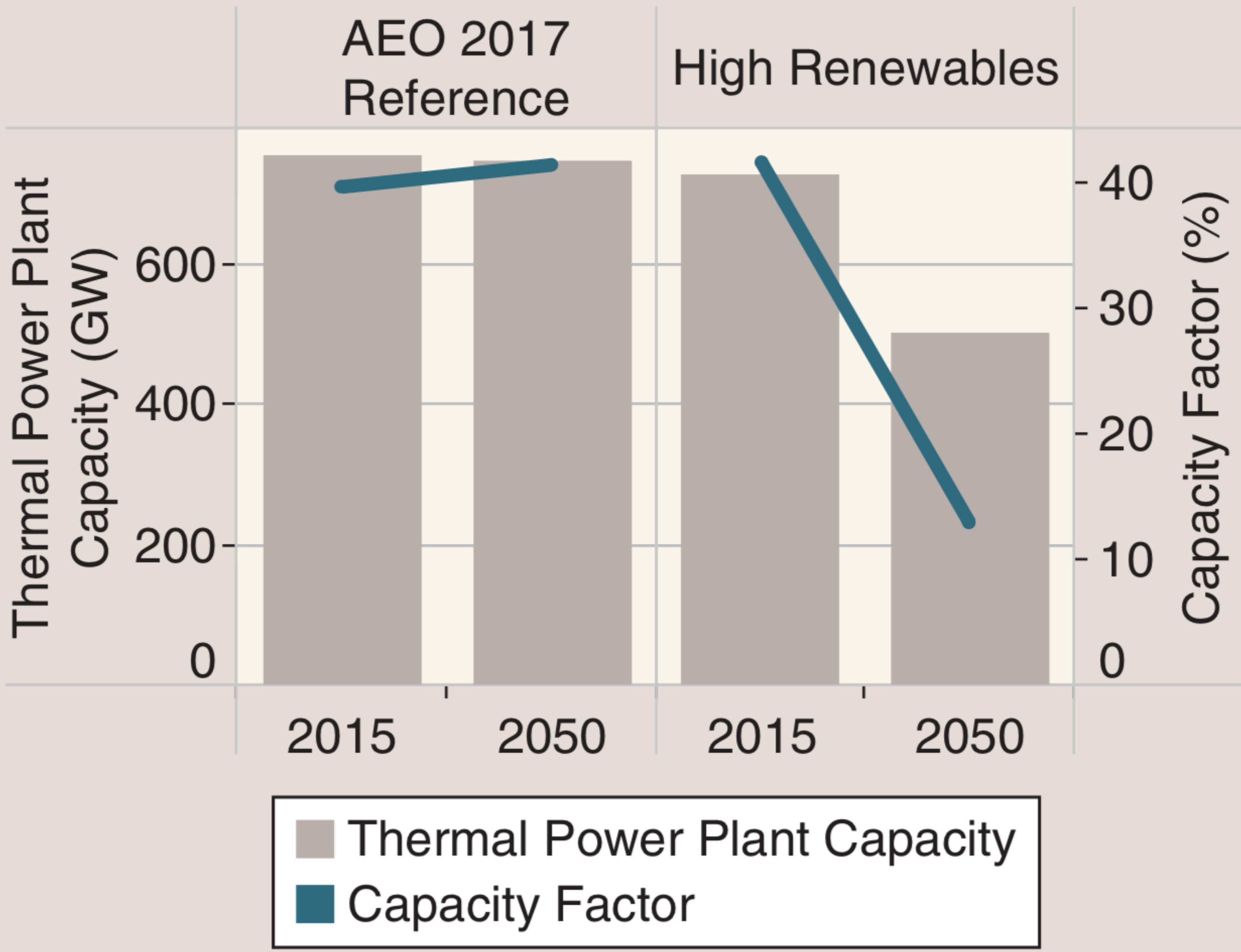


figure 7. An example of the magnitude of flexible demand that operates in a high-renewables system taken from the U.S. DDPP high-renewables scenario.

Jones et al, IEEE Power and Energy, 2018



Jones et al, IEEE Power and Energy, 2018



Jones et al, IEEE Power and Energy, 2018

Some questions for future wholesale electricity markets

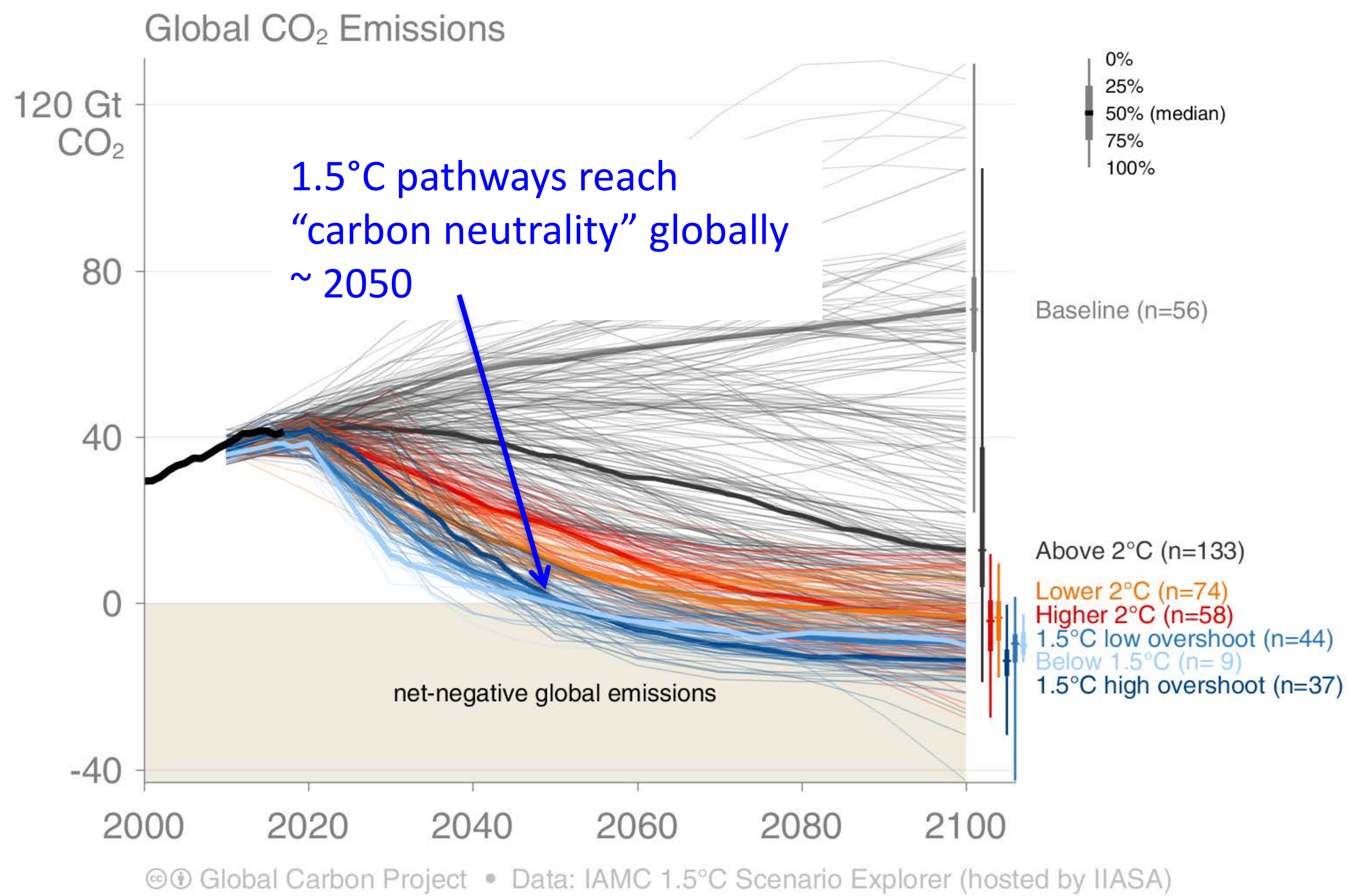
- How will conventional thermal power plants needed for reliability get paid?
- How will revenue requirements dominated by fixed costs be allocated among consumers?
- How will large flexible loads be induced to participate?
- How will future electricity system planning be conducted?

Summary: What carbon neutrality means for the electricity industry

- Fully decarbonized electricity
- 2-3x generation to serve new electric loads
- New approach to supply-demand balancing
- Much greater integration with demand side in operations, planning, procurement
- Very different wholesale electricity markets
- Increasing interactions with land use

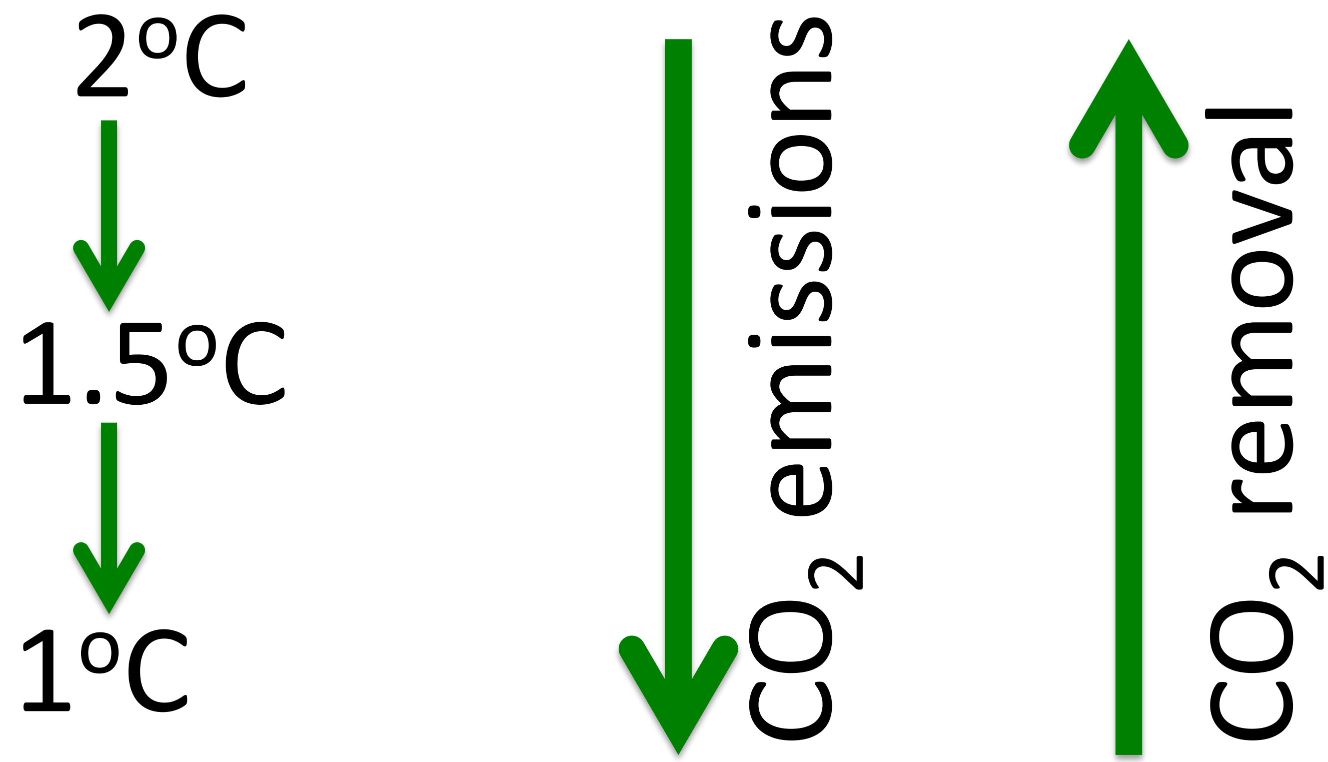
The IPCC Special Report on "Global Warming of 1.5°C"

The IPCC Special Report on "Global Warming of 1.5°C" presented new scenarios:
1.5°C scenarios require halving emissions by ~2030, net-zero by ~2050, and negative thereafter



Net emissions include those from land-use change and bioenergy with CCS.
Source: Huppmann et al 2018; IAMC 1.5C Scenario Database; IPCC SR15; Global Carbon Budget 2018

Mitigation Targets and Net CO_2 Emissions



Land use implications of carbon neutrality for energy system

- The deeper the emissions target, the more land use is involved
- Sink: energy system emissions target depends in part on how big the land sink is
- Siting: large wind and solar build out requires significant land area
- Biomass: competes with other land uses, e.g. food, biodiversity
- All occurring under pressure of increasing population, climate change, other threats

LAND, ENERGY, AND CLIMATE CHANGE

September 11, 2018

9:00 a.m. – 9:00 p.m.
McLAREN COMPLEX

Low-Emissions Solutions CONFERENCE

GLOBAL CLIMATE ACTION SUMMIT
AFFILIATE EVENT