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The Outlines of Deep Decarbonization

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July 22, 2019

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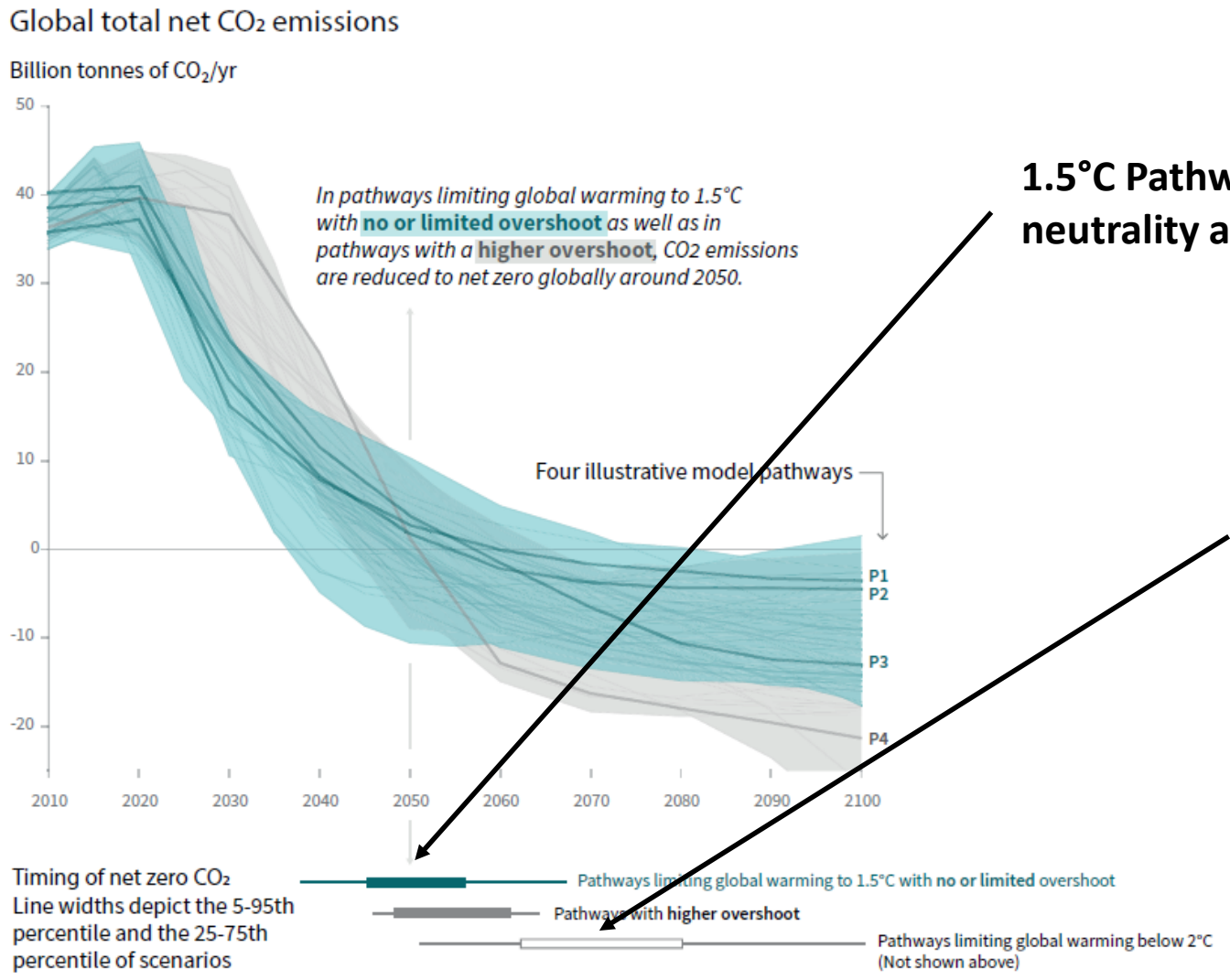
Limiting temperature change to 2C or 1.5C requires rapid emissions reductions



1.5°C Pathways: Carbon neutrality around 2050

2.0°C Pathways: Carbon neutrality around 2070

Source: IPCC, 2018, Global Warming of 1.5C"

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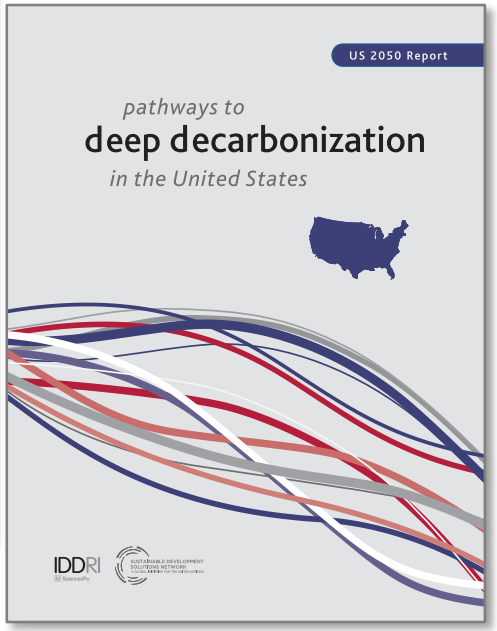
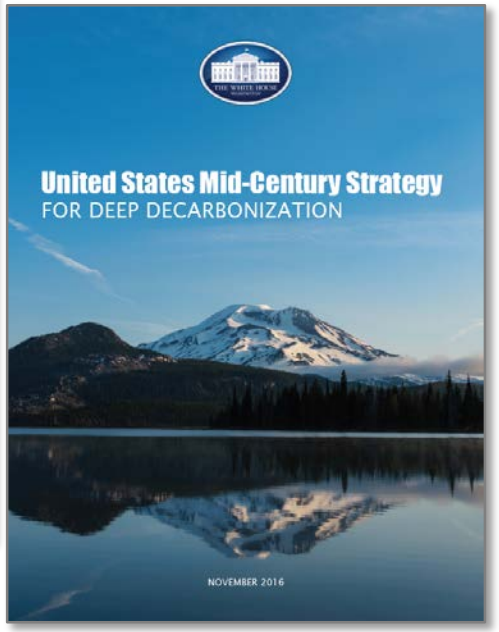
Many studies have explored deep decarbonization in the U.S.

Energy Modeling Forum 22 (2009)

Energy Modeling Forum 24 (2014)



Deep Decarbonization Pathways Project (2014)



U.S. Mid-Century Strategy (2016)

Climate Innovation 2050 (2019)

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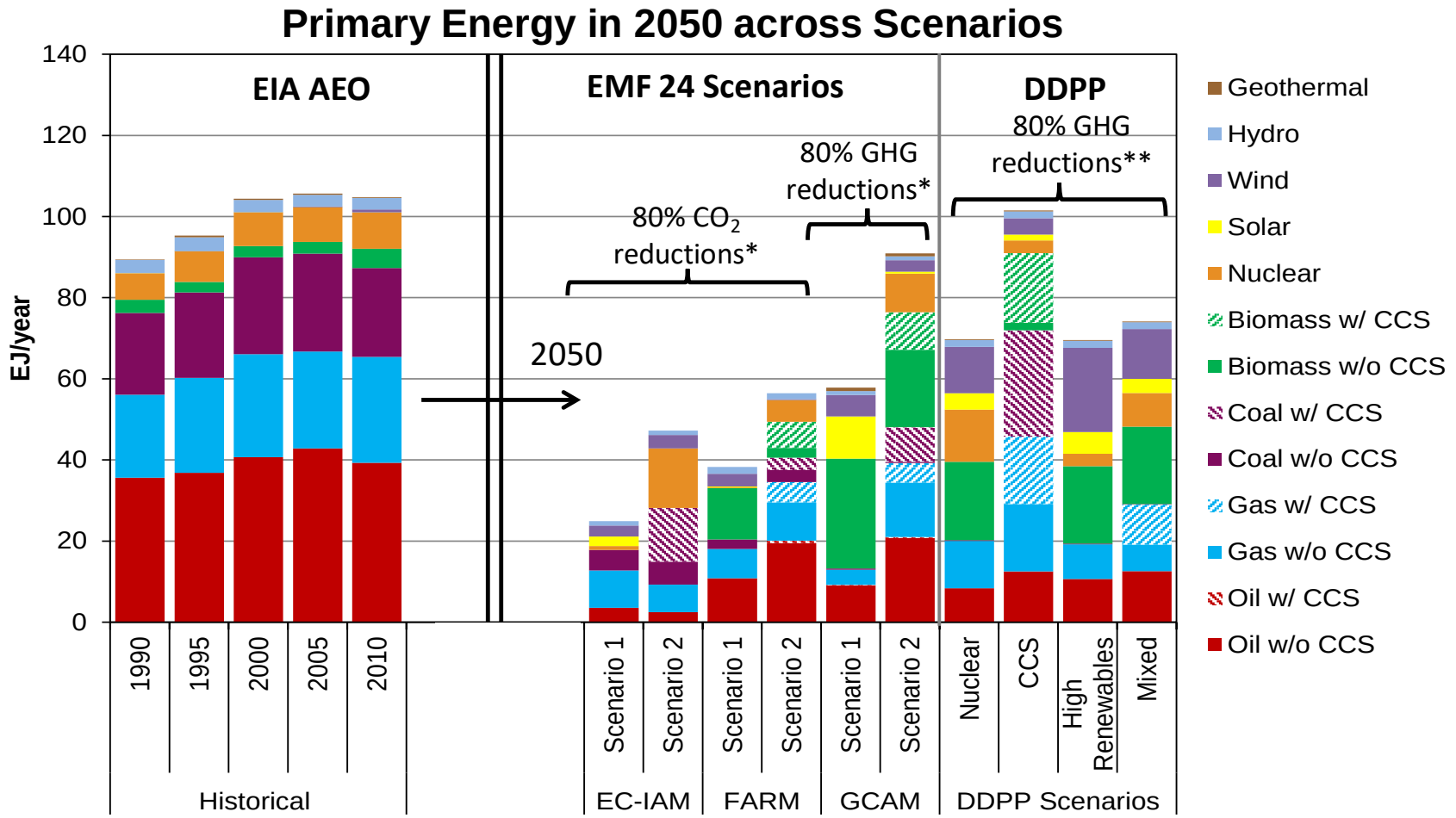
Many energy system pathways are possible



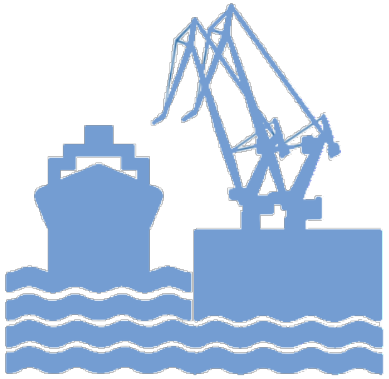
*80% reductions with respect to 2005. Excludes LUC
**80% reductions with respect to 1990. Includes LUC

Results reflect a variety of sources that use different modeling approaches.

There are multiple societal pathways to deep decarbonization

C2ES CLIMATE INNOVATION 2050

A Competitive Climate

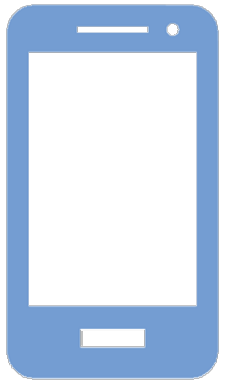


Strong international pressure in the form of carbon tariffs and growing recognition of the competitive benefits of low-carbon innovation lead to a strong, early U.S. federal response, including an economy-wide price on carbon.

Climate Federalism

Responding to economic opportunities and intensifying climate-related disasters, a growing number of U.S. states implement ambitious climate policies, leading to calls from business for a more harmonized national response.

Low-Carbon Lifestyles



Increased urbanization, generational shifts, and technological breakthroughs lead to strong market demand for low-carbon consumption products and services, along with the emergence of innovative low-carbon business models.

Every scenario requires broad societal support and involves actors across the economy (e.g., governments, businesses, consumers)

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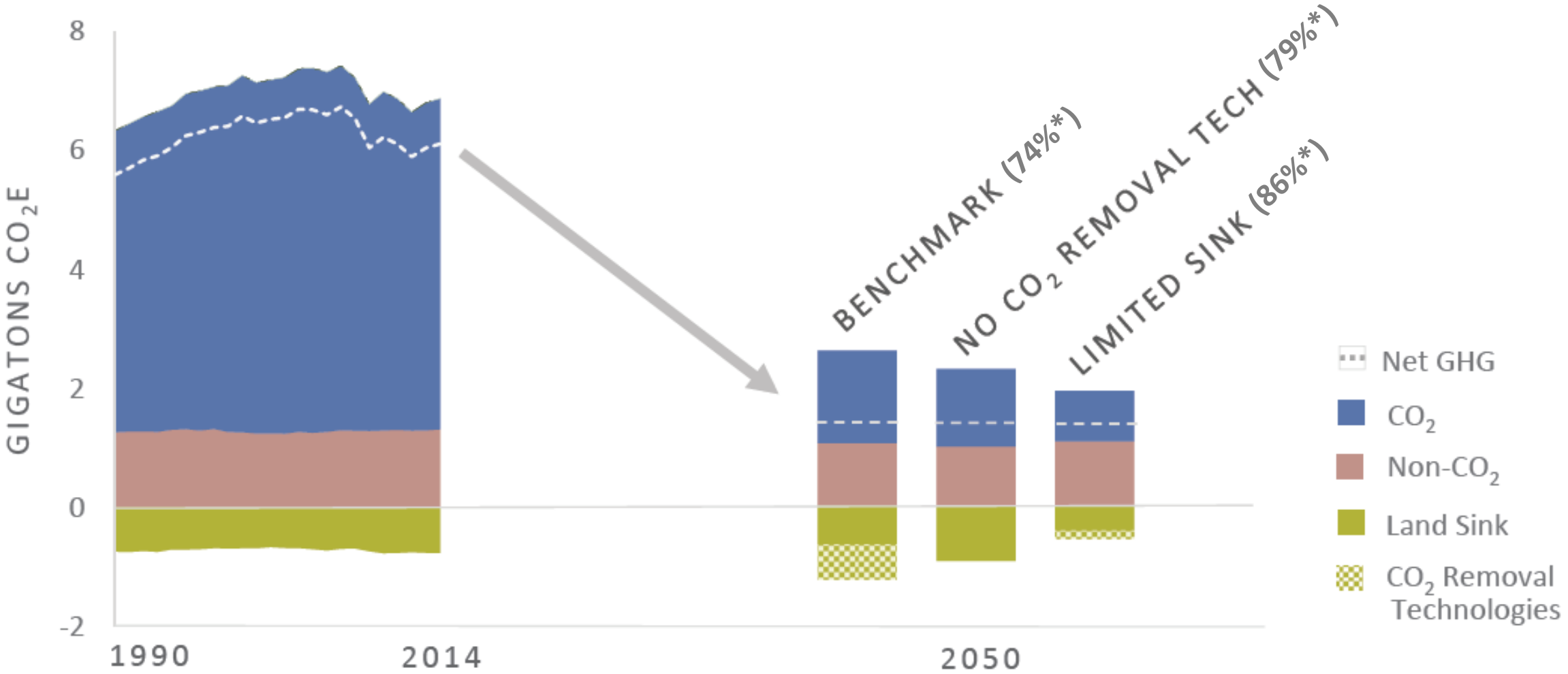
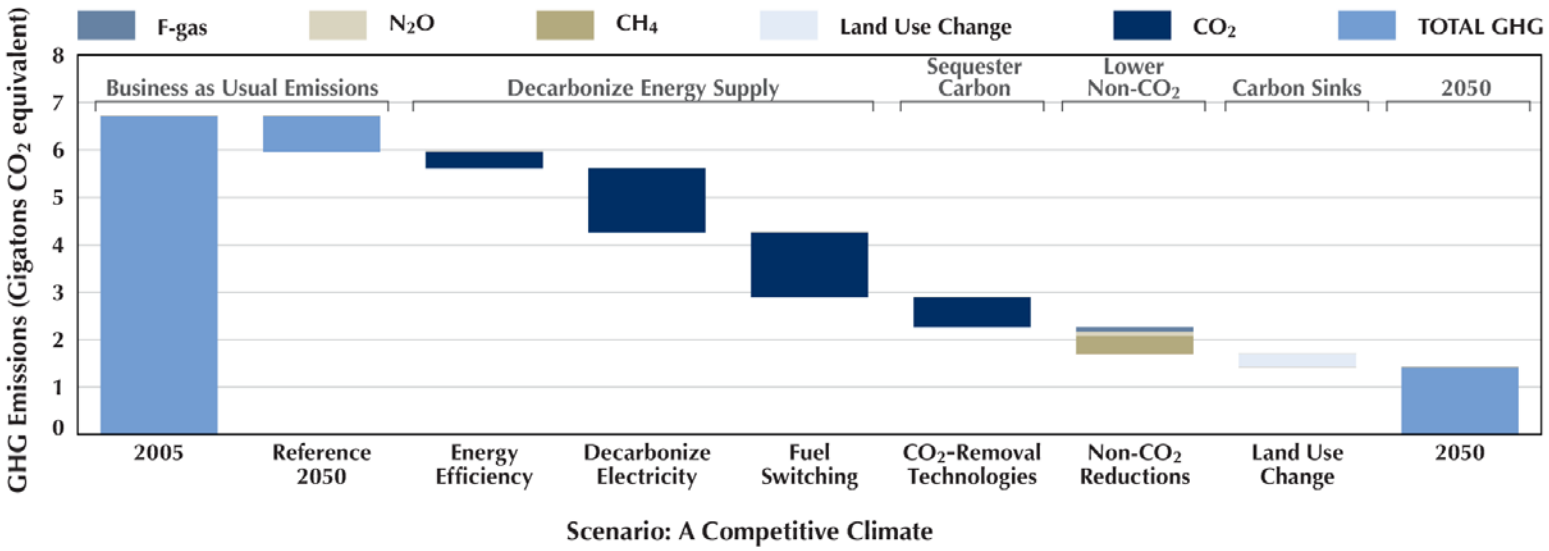
Energy emissions in context

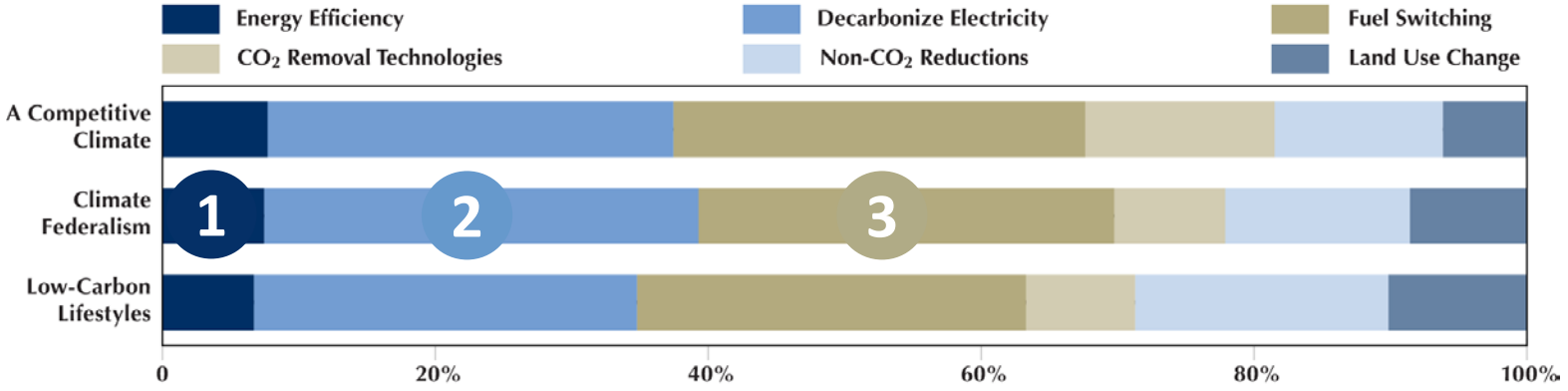


Source: United States Mid-Century Strategy (2016)

* **(Percent reduction in direct fossil combustion relative to 2005. Does not account for CDR from energy)**

Key Elements of Decarbonization





Three pillars of energy sector decarbonization

1. Energy Efficiency
2. Decarbonize electricity
3. Fuel switching

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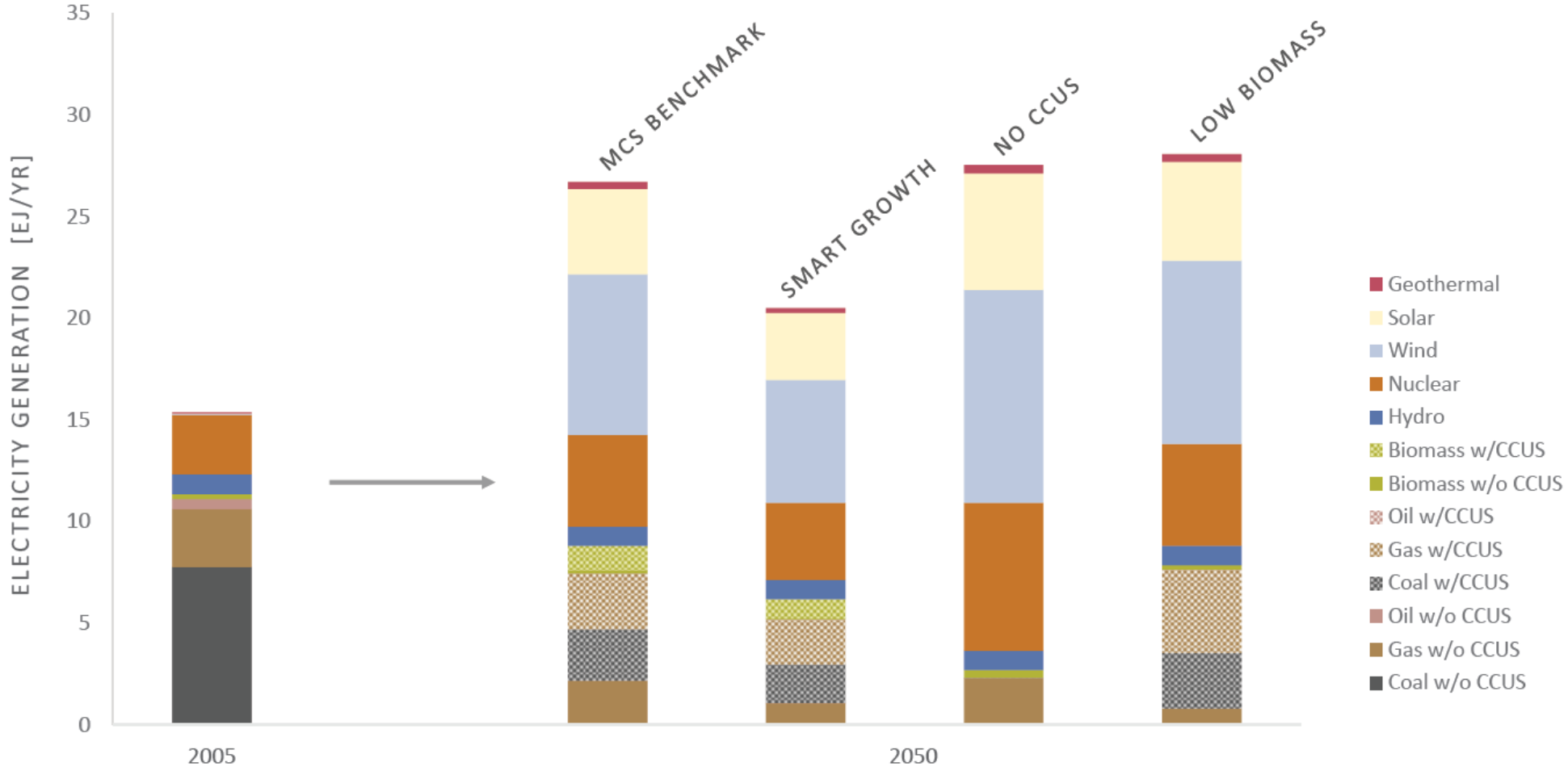
Electricity in the MCS Benchmark



Only 8% of electricity comes from freely-emitting fossil energy; no freely-emitting coal in the benchmark scenario

Source: United States Mid-Century Strategy (2016)

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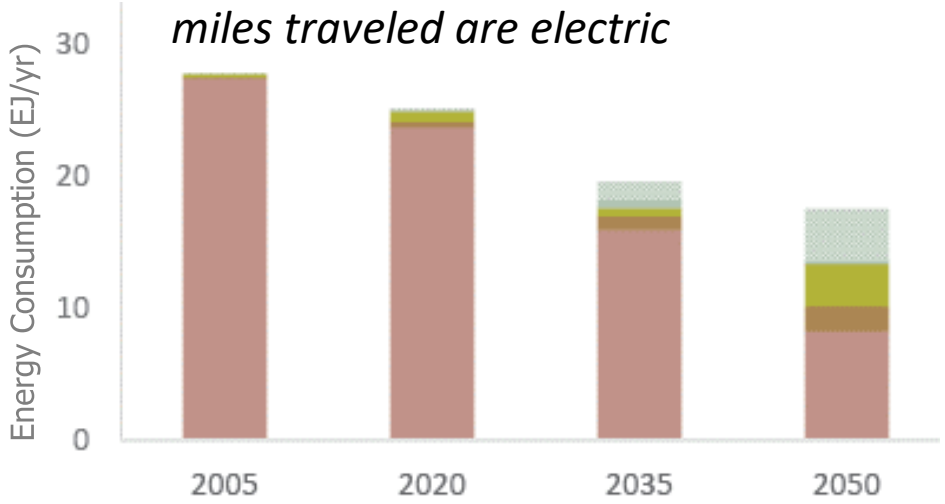
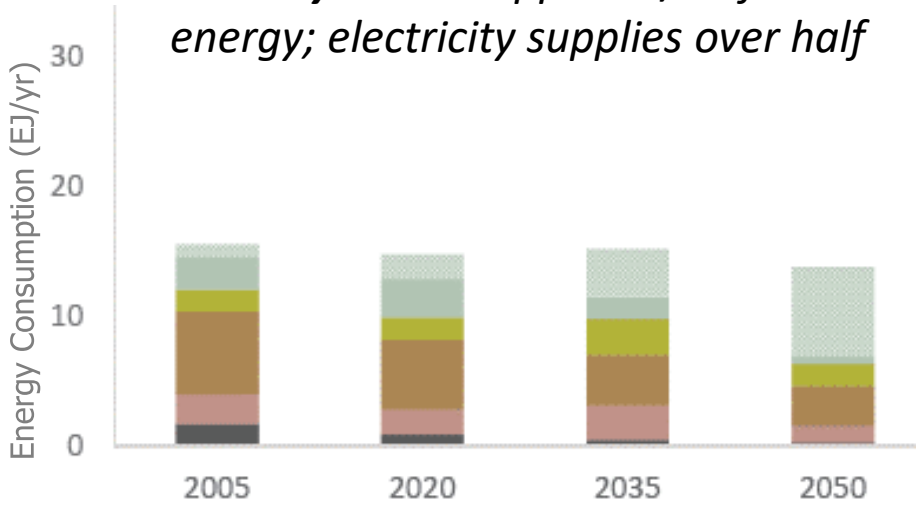
The transformation will extend across sectors

Primary energy use declines by over 20 percent between 2005 and 2050

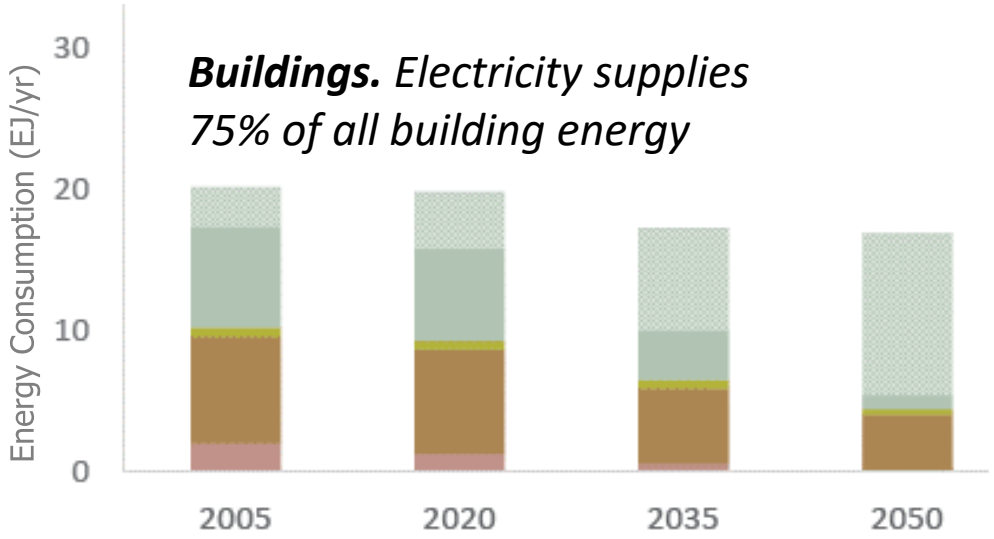
Transport. *60% of all light duty miles traveled are electric*



Industry. *Fossil supplies 1/3 of total energy; electricity supplies over half*



Buildings. *Electricity supplies 75% of all building energy*



Source: United States Mid-Century Strategy (2016)

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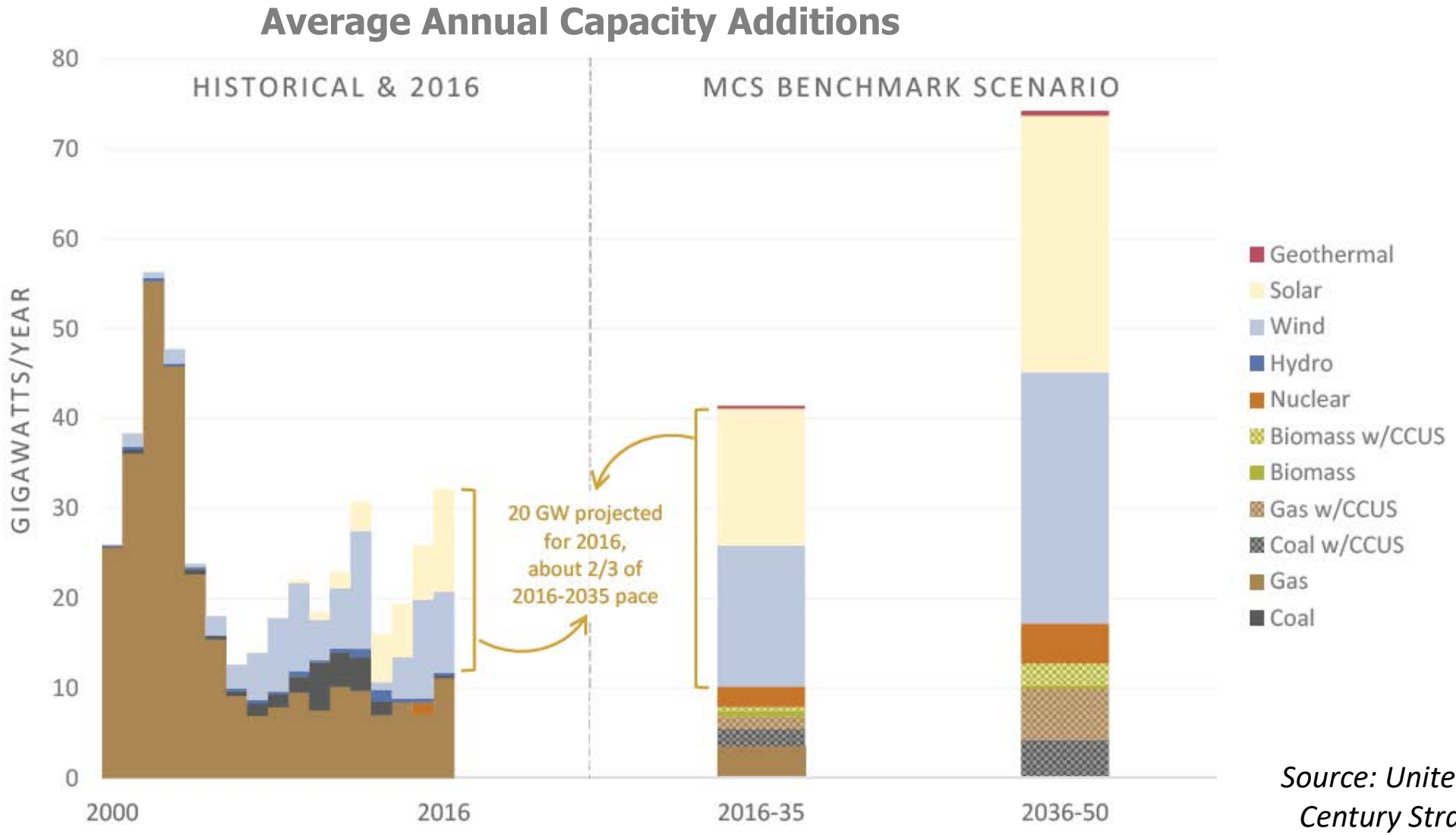
Investment patterns need to evolve



Source: United States Mid-Century Strategy (2016)

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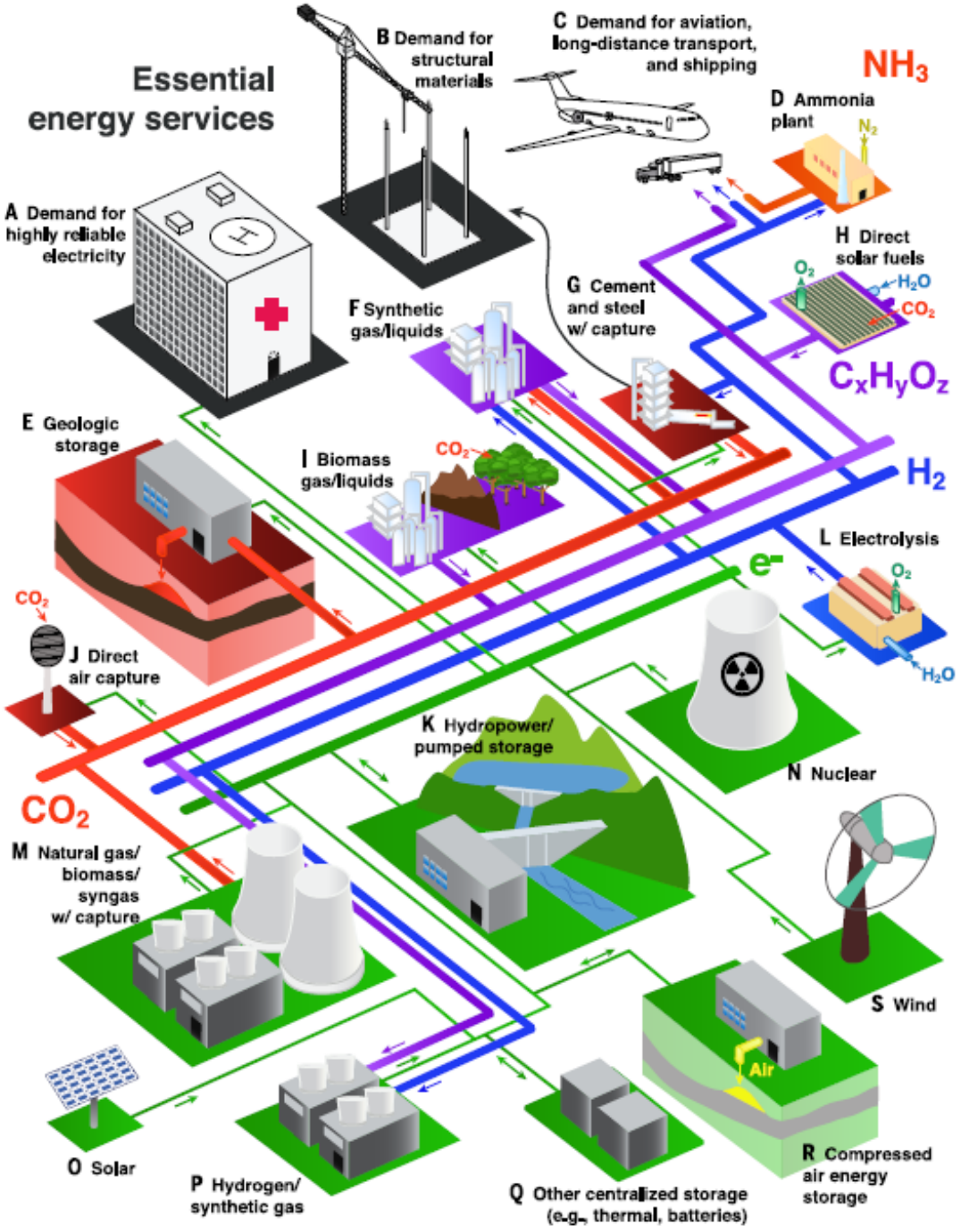
What do we know and not know?

Three pillars of energy sector decarbonization

1. Energy Efficiency
2. Decarbonize electricity
   Almost all electricity from clean sources by 2050
3. Fuel switching
   A major evolution toward electricity across end uses

Not so clear

1. The electricity mix
2. Bioenergy and alternative fuels like hydrogen
3. CCUS and the future of coal and gas
4. Carbon dioxide removal
5. Hard-to-decarbonize sectors (e.g., air transport, structural materials)
6. The industrial sector
7. Growth and evolution in energy services
8. Societal approach to mitigation (e.g., policies, consumer preferences)



The long-term goal is zero or negative emissions

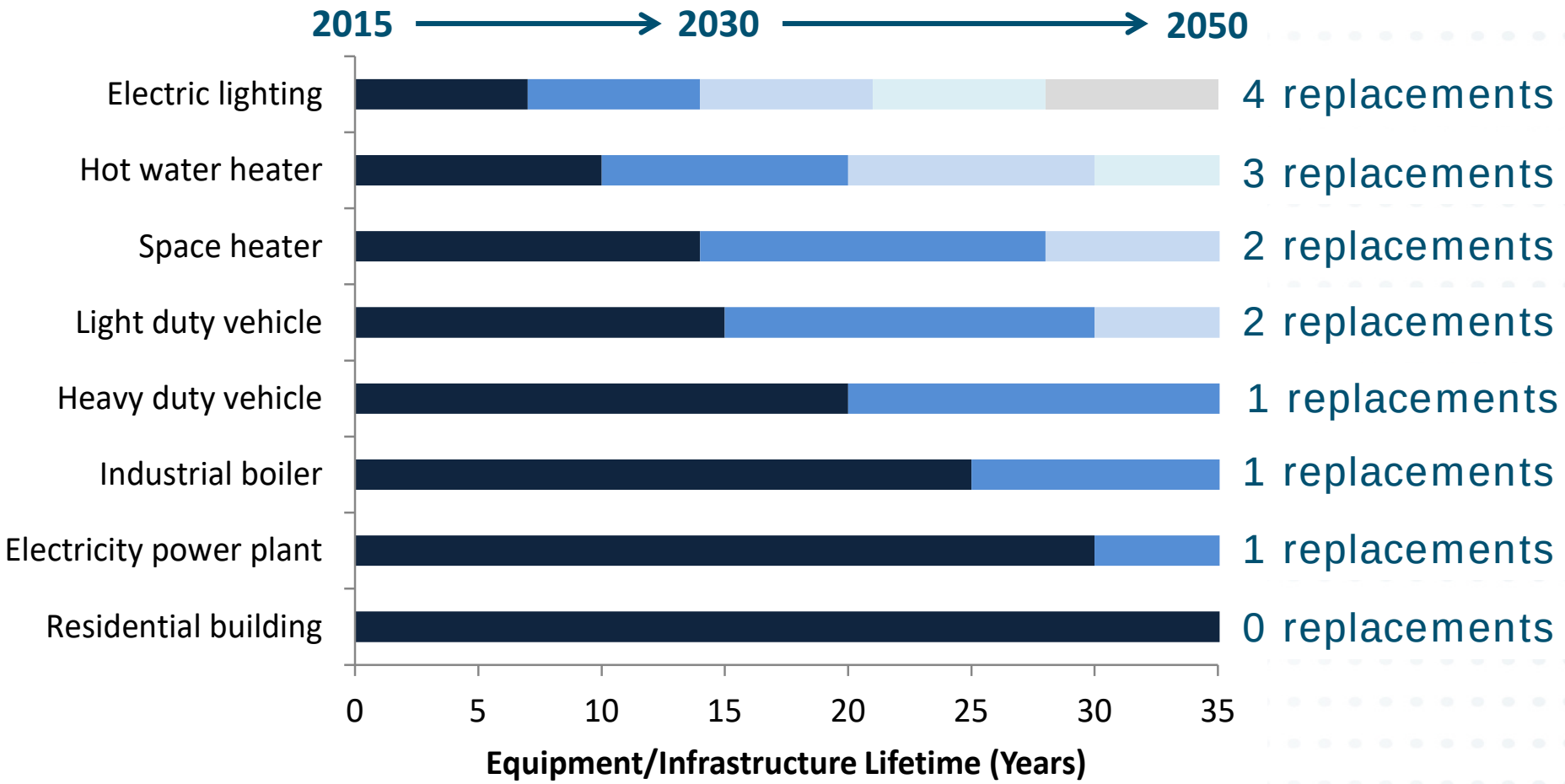
1. Aviation, long-distance transport, and shipping.
2. Structural materials (iron and steel, cement)
3. Load-following electricity

Source: Davis, S. J., Lewis, N. S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I. L., ... & Clack, C. T. (2018). Net-zero emissions energy systems. Science

- Carbon dioxide removal

Timing for Action is Limited

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



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Thank You