

Mid-Century Pathways

GOKUL IYER FOR THE GCAM TEAM

- ▶ Why is the mid-century important:
 - From NDCs to mid-century in the context of 2°C scenarios
 - Context from the Paris Agreement

- ▶ Key issues that the PNNL team is thinking about in the context of the U.S. deep decarbonization pathways

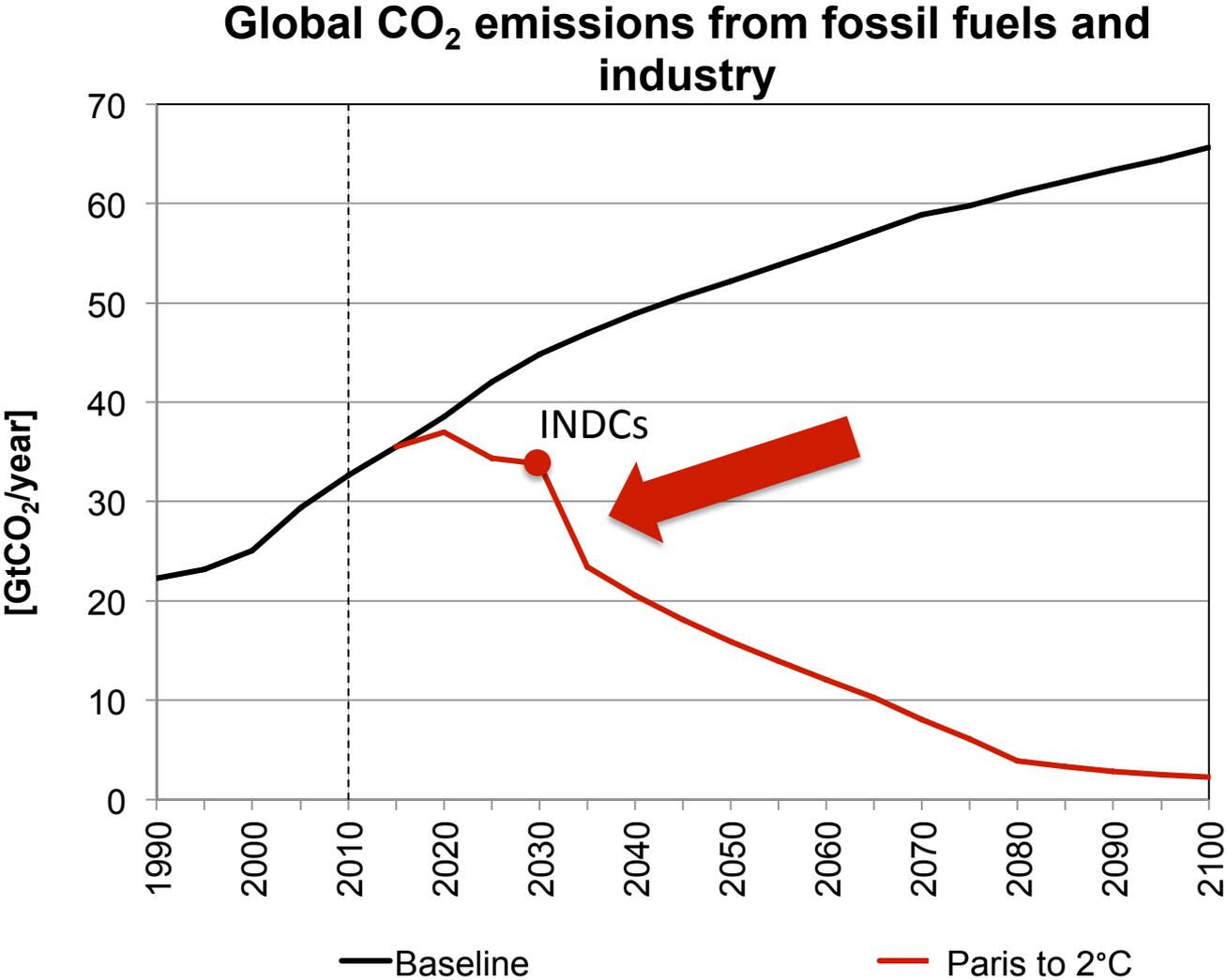


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Why is the mid-century important?

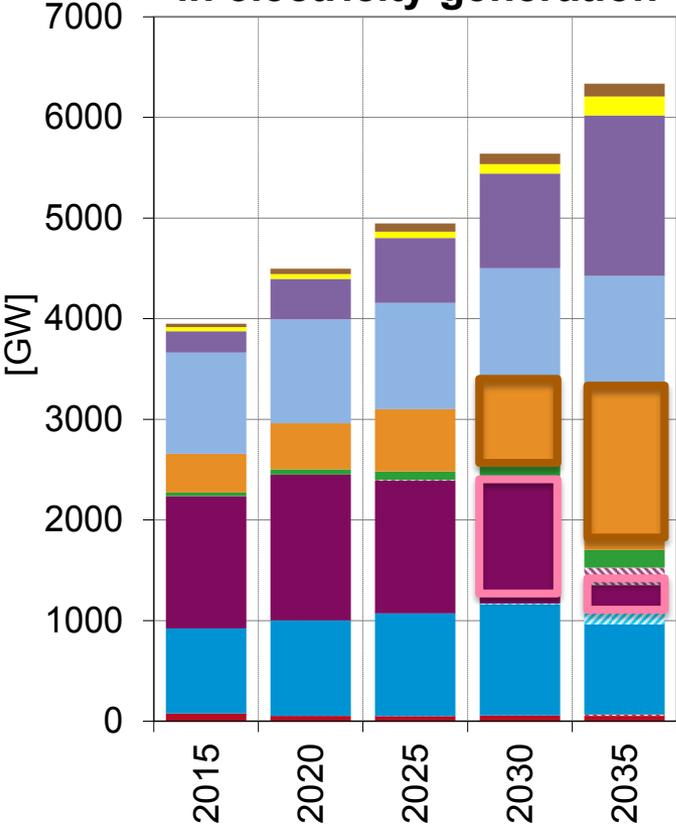
From INDCs to 2°C requires dramatic reductions beyond 2030 to maintain a cumulative budget



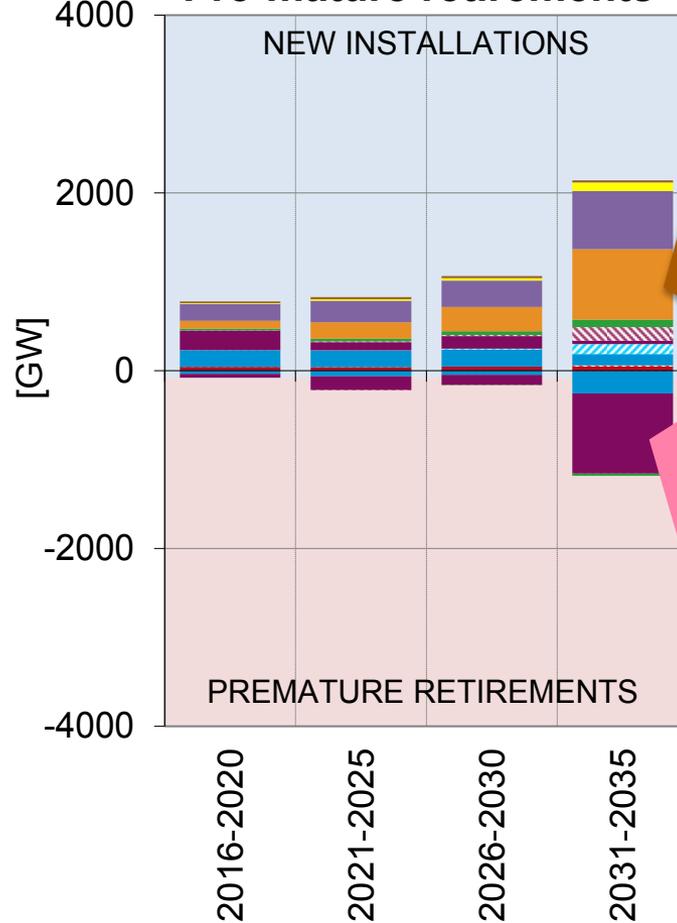
Source: Iyer, Gokul C., et al. "The contribution of Paris to limit global warming to 2° C" *Environmental Research Letters* 10.12 (2015): 125002.

Achieving 2 degrees with NDCs requires post-2030 investments in low-carbon capacity and pre-mature retirements in fossil fuel capacity

Total installed capacity in electricity generation



New Investments and Pre-mature retirements



New Low-carbon capacity

Pre-mature retirements of fossil capacity

- Geothermal
- Solar
- Wind
- Hydro
- Nuclear
- Biomass w/ CCS
- Biomass w/o CCS
- Coal w/ CCS
- Coal w/o CCS
- Gas w/ CCS
- Gas w/o CCS
- Oil w/ CCS
- Oil w/o CCS

The Paris Agreement invites countries to articulate mid-century goals

- ▶ The adoption text of the Paris Agreement:

Invites Parties to communicate, by 2020, to the secretariat mid-century, long-term low greenhouse gas emission development strategies...

- ▶ In Article 4, paragraph 1 of the Paris agreement Parties aim to, undertake rapid reductions ... so as to

achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century in order to achieve the long-term temperature goals set out in Article 2

Many countries are beginning to formulate their mid-century strategies

- ▶ The U.S. committed to submitting an MCS this year during the U.S.-Canada Joint Statement on Climate, Energy, and Arctic Leadership :

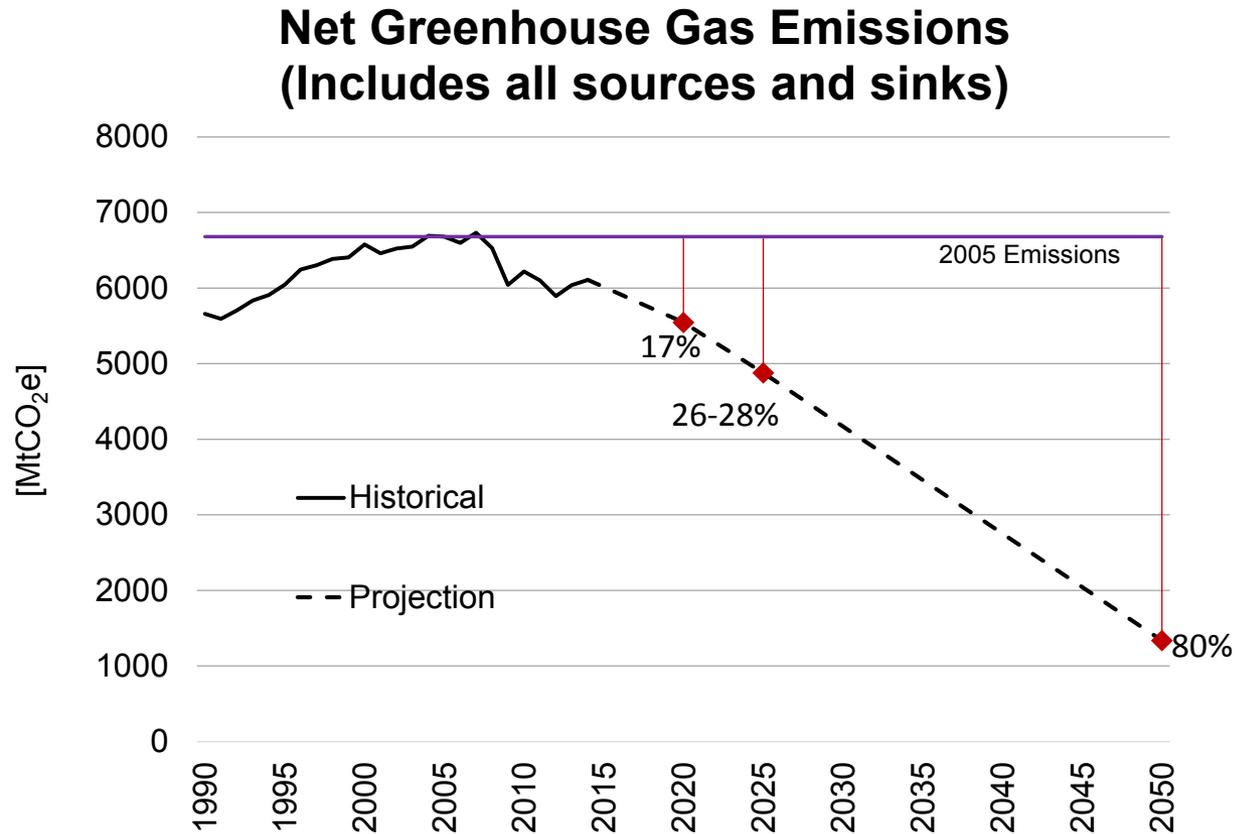
“As we implement our respective Intended Nationally Determined Contributions (INDCs), the leaders also commit to, in 2016, completing mid-century, long-term low greenhouse gas emission development strategies pursuant to the Paris Agreement and encouraging this approach with members of the G-20”

- ▶ A key question for the analytical community:

:

How do we extract lessons from the literature and conduct analyses that would help decision-makers in various countries make informed decisions about effective strategies for the mid-century depending on national priorities and circumstances?

U.S. as an example of national-level mid-century analysis



- ▶ The U.S. INDC states that the 2025 target *is consistent with a straight line emission reduction pathway from 2020 to deep, economy-wide emission reductions of 80% or more by 2050*

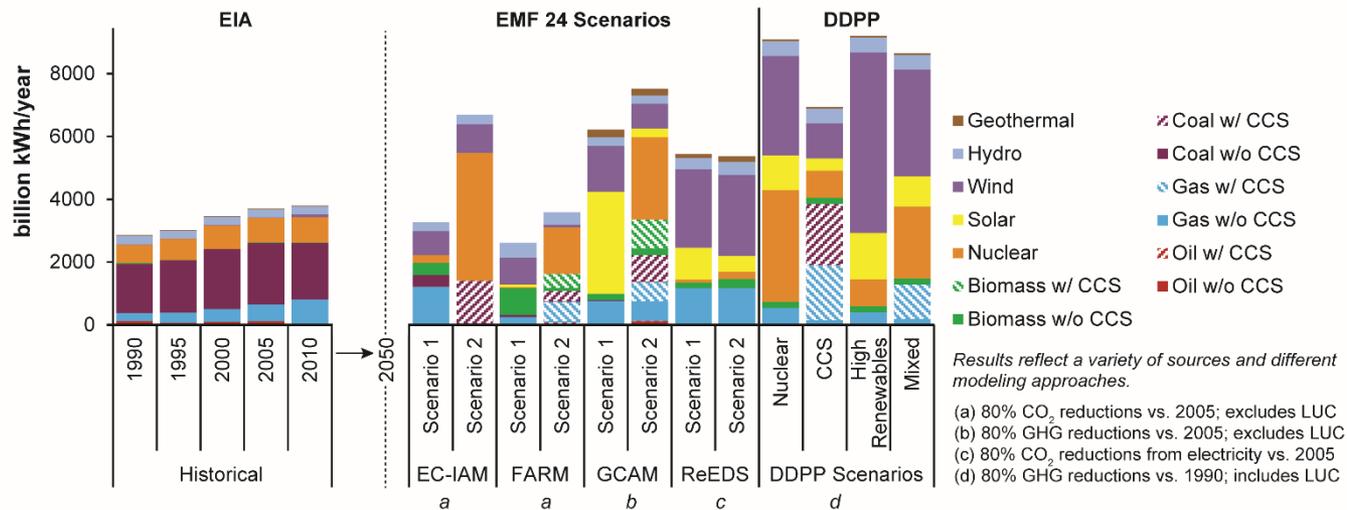


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Existing Analyses of U.S. Mid-Century Scenarios

The EMF-24 and other studies have explored deep-decarbonization scenarios for the U.S.



- ▶ Deep decarbonization will require a dramatic transformation of the energy system
- ▶ There are many different pathways to deep decarbonization
 - Deep decarbonization can be achieved in the absence of major technological breakthroughs
- ▶ The costs of deep decarbonization are highly uncertain, and they vary substantially based on policy structure, technological progress and the timing of emissions reductions

Sources: (i) Fawcett, et al. "The EMF24 Study on U.S. Technology and Climate Policy Strategies." *The Energy Journal* 35, Special Issue 1 (2014)
 (ii) Deep Decarbonization Pathways Project. *Pathways to deep decarbonization 2015 report*. (SDSN - IDDRI, 2015)

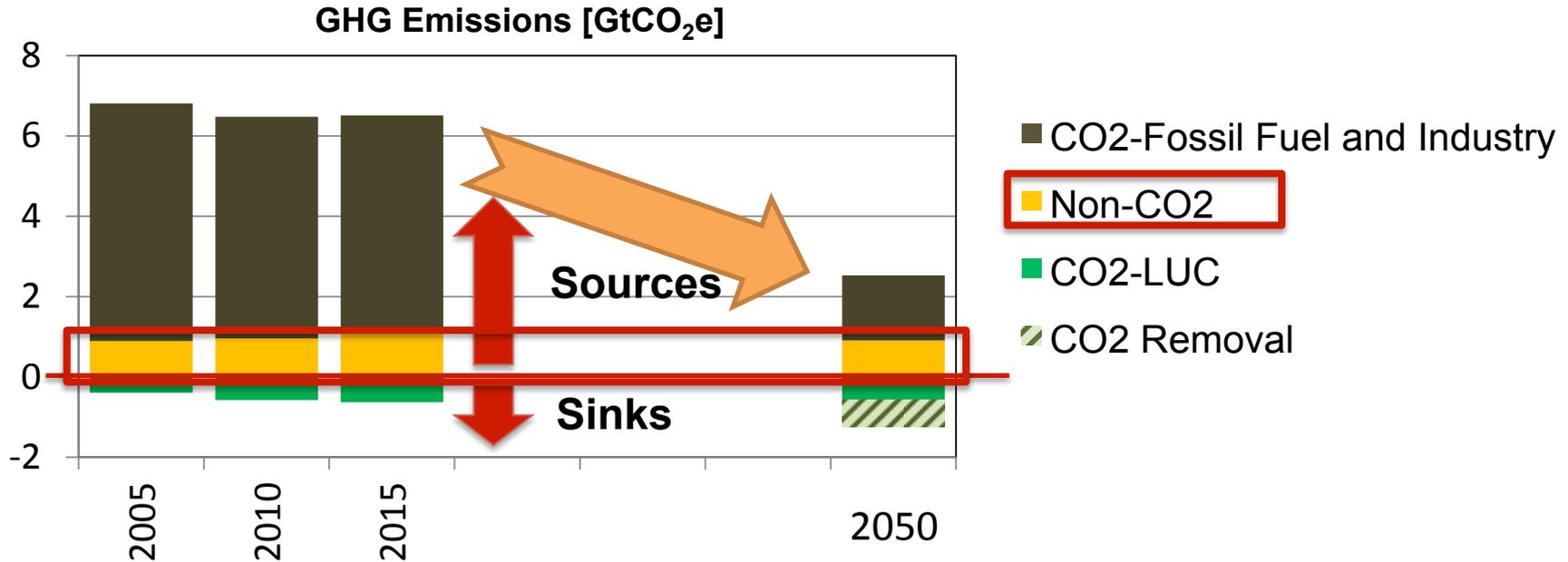


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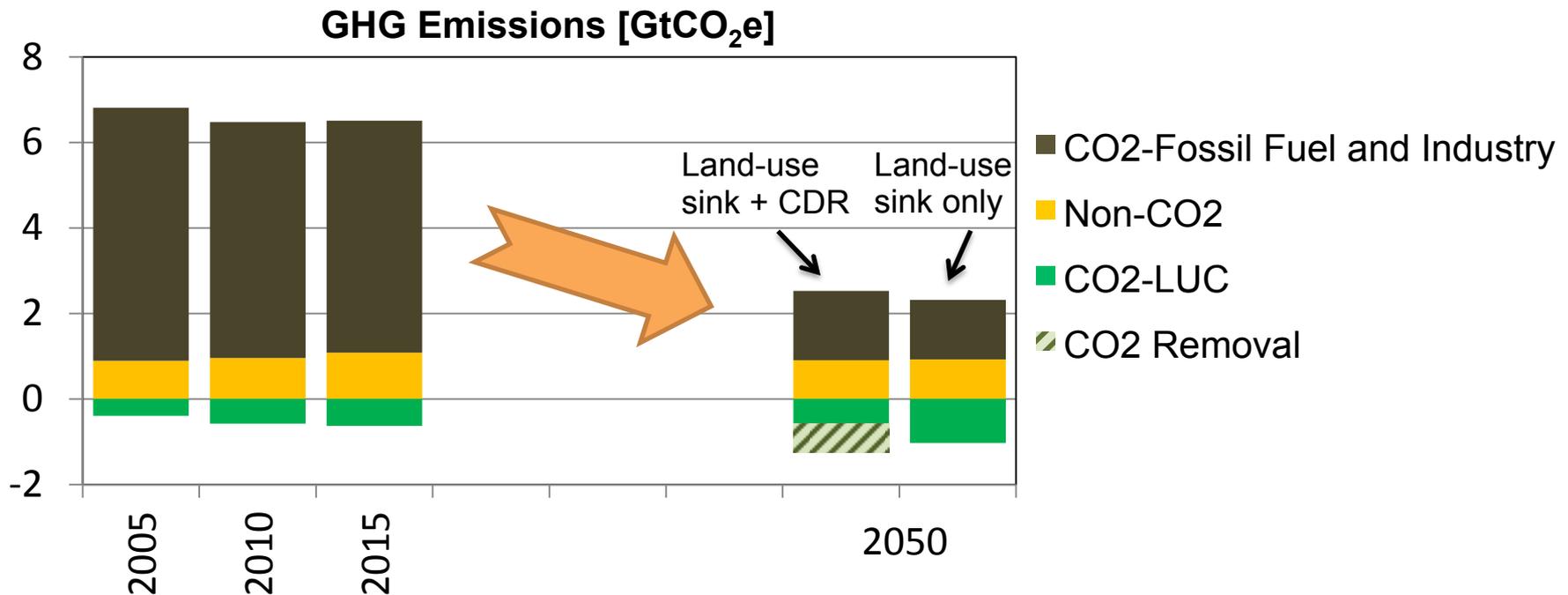
Conceptual framework of our analysis

The scale of change required in energy system will be determined by trade-offs between sources and sinks



- ▶ Meeting the 80% goal requires balancing between sources and sinks
- ▶ Some sources of non-CO₂ emissions are essentially irreducible
- ▶ Hence CO₂ reductions from the energy sector must either exceed 80% or be offset by sinks
- ▶ The scale of transition required in the energy sector will be determined by
 - Nature of the U.S. terrestrial sink and efforts to increase it
 - Deployment of CO₂ removal (CDR) technologies

Our analysis begins with two core scenarios



- ▶ In one scenario, sinks are achieved by a combination of terrestrial sinks and deployment of CDR technologies
- ▶ In the other, sinks comprise of terrestrial CO₂ sink alone
- ▶ Both assume optimistic technological advances, almost complete decarbonization of the electricity sector and increased electrification of end-uses

Some of the key branch-points that would define various pathways

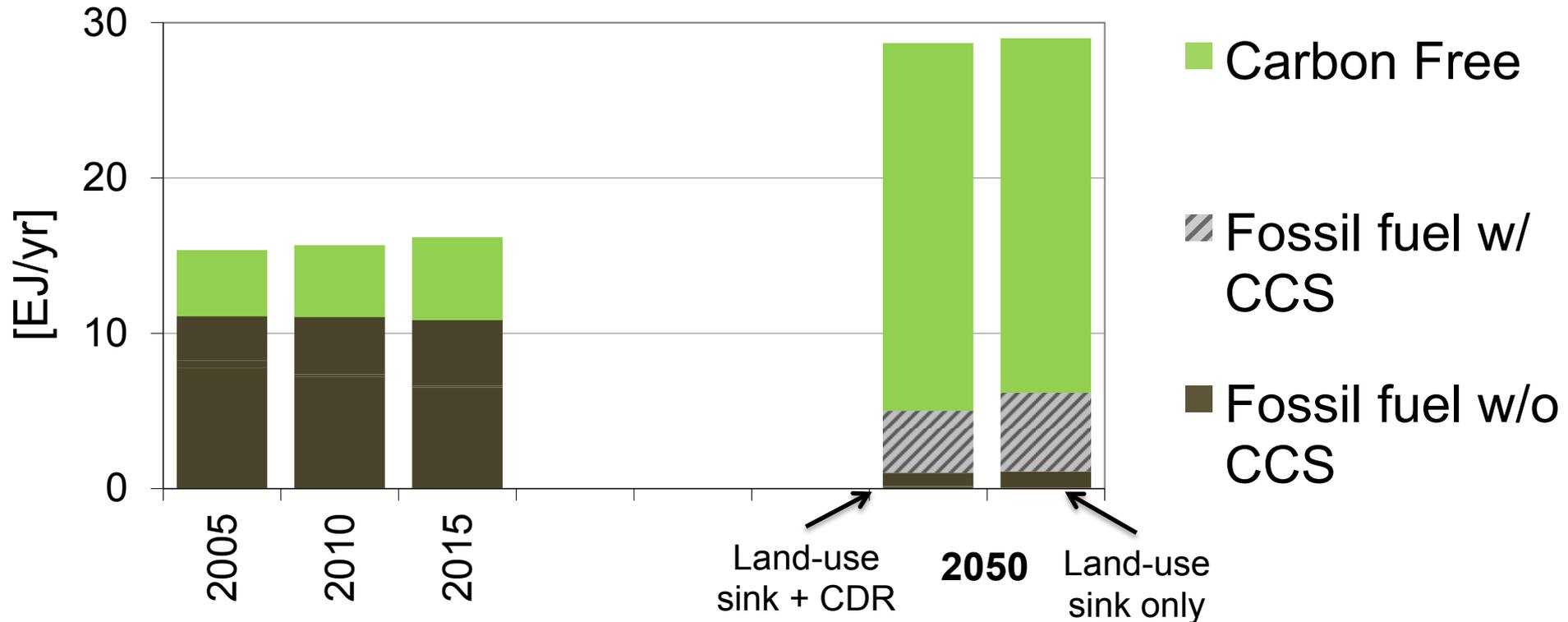
- ▶ Degree to which end-use sectors can be electrified
- ▶ Level of terrestrial sink
- ▶ The role of Nuclear and CCS
- ▶ The role of Bioenergy
- ▶ Implications of Technological Breakthroughs



Strategic insights using 50-state version of GCAM (GCAM-USA)

Electricity is almost totally decarbonized by 2050

Electricity generation

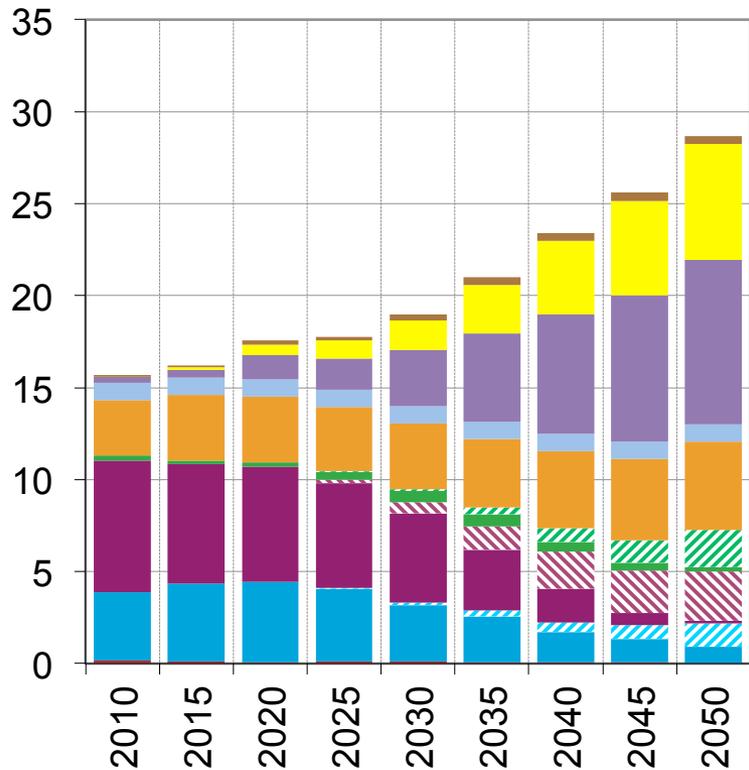


- ❖ There are a number of ways of decarbonize electricity
- ❖ Substantial increase in electricity production from low-carbon sources and retirements of fossil fuel based capacity

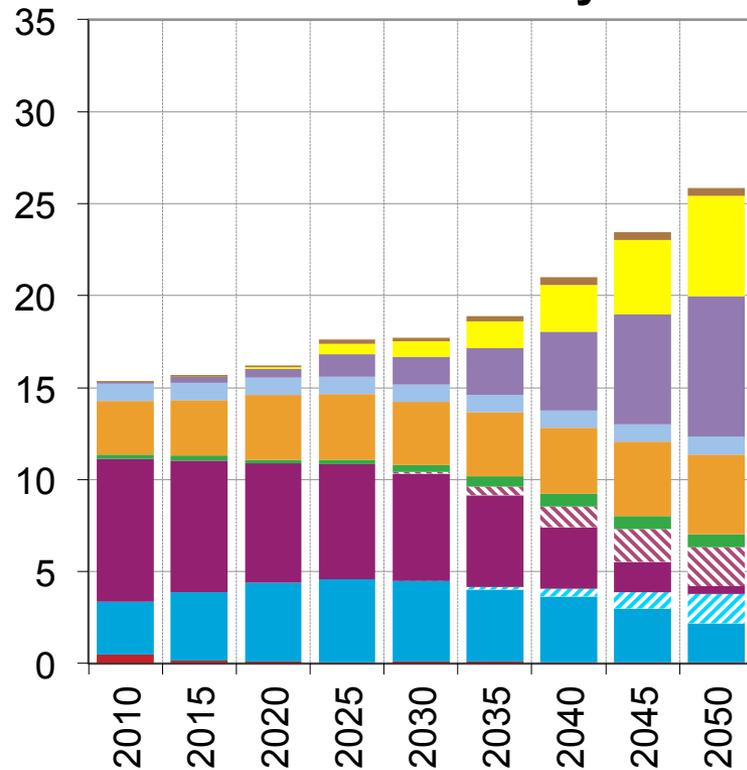
Coal without CCS is almost completely phased out over the next 35 years

Electricity generation [EJ/yr]

Land sink + CDR



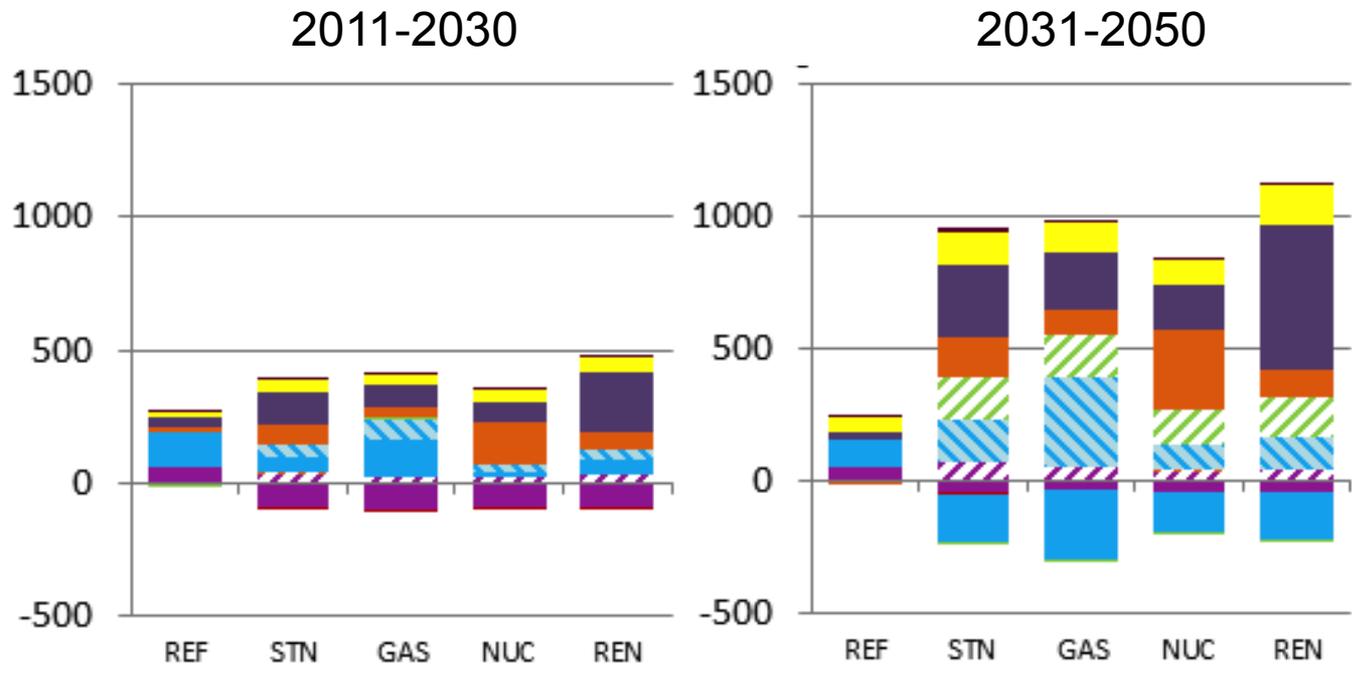
Land sink Only



- Geothermal
- Solar
- Wind
- Hydro
- Nuclear
- Biomass w/ CCS
- Biomass w/o CCS
- Coal w/ CCS
- Coal w/o CCS
- Gas w/ CCS
- Gas w/o CCS
- Oil w/ CCS
- Oil w/o CCS

Role of natural gas in deep decarbonization pathways

Electricity capacity additions and retirements [GW]



Scenario Key:

REF	Reference (No Policy)
STN	Standard
GAS	High Gas
NUC	High Nuclear
REN	High Renewable



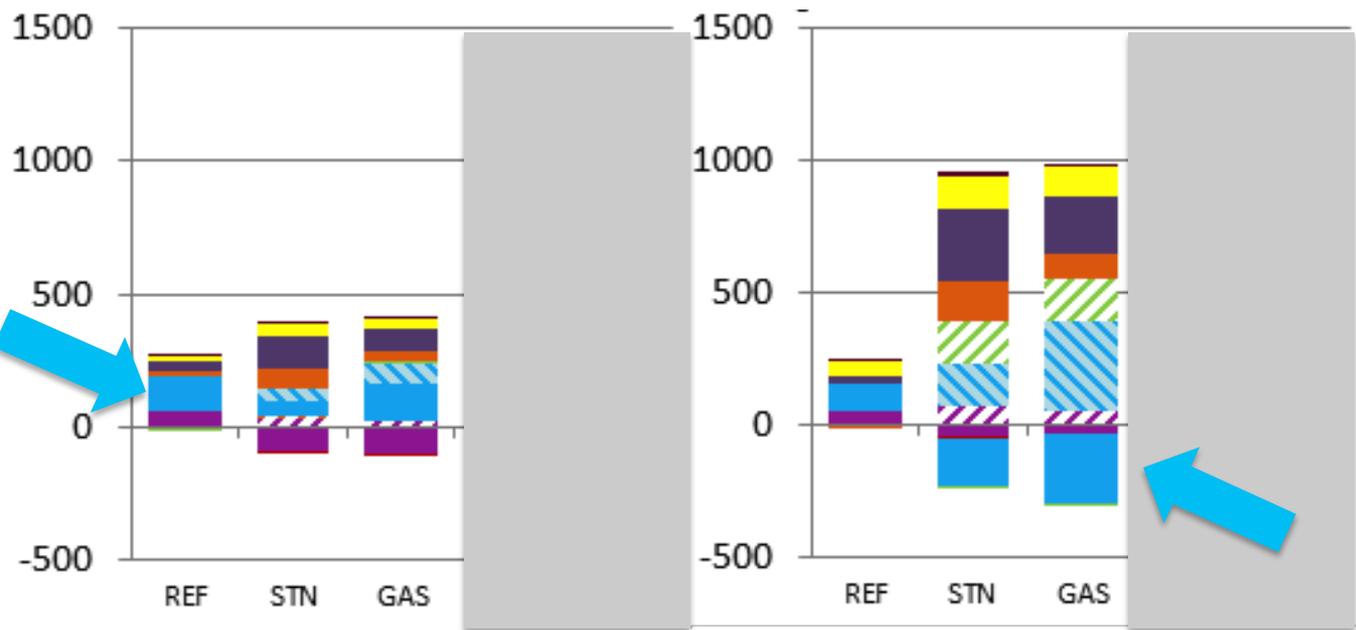
Source: Jones, McJeon, et al. Early Retirements or Carbon-Capture Retrofits Required for Natural Gas as Bridge to Deep Decarbonization. Under review.

Natural gas electricity without CCS can remain in the near-term, but will need to be phased out not long after

Electricity capacity additions and retirements [GW]

2011-2030

2031-2050



Scenario Key:

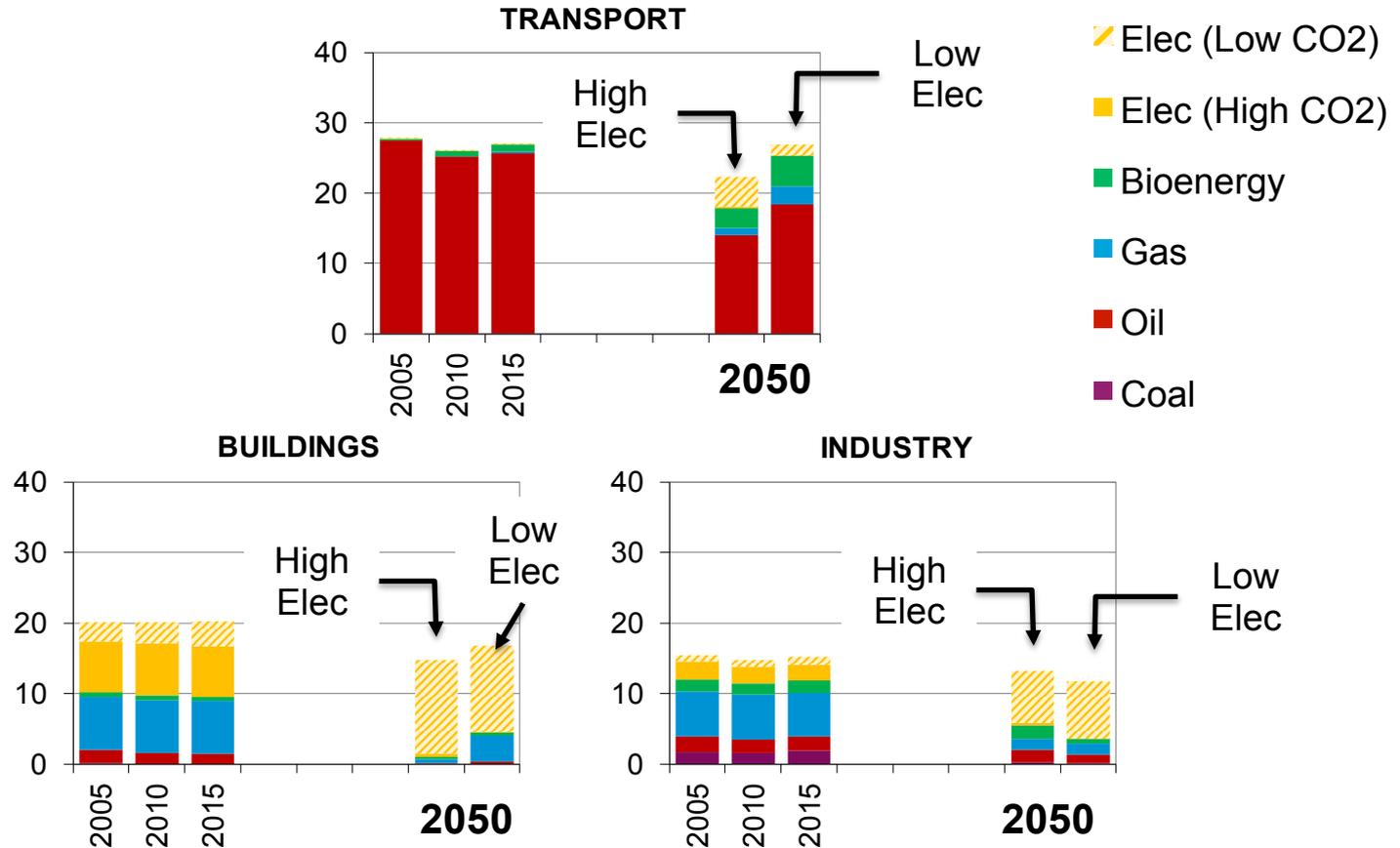
REF	Reference (No Policy)
STN	Standard
GAS	High Gas

- geothermal
- solar
- wind
- hydro
- nuclear
- biomass w/o CCS
- biomass w/CCS
- oil w/o CCS
- oil w/CCS
- gas w/o CCS
- gas w/CCS
- coal w/o CCS

Source: Jones, McJeon, et al. Early Retirements or Carbon-Capture Retrofits Required for Natural Gas as Bridge to Deep Decarbonization. Under review.

Electrification of end-use sectors will be an important strategy

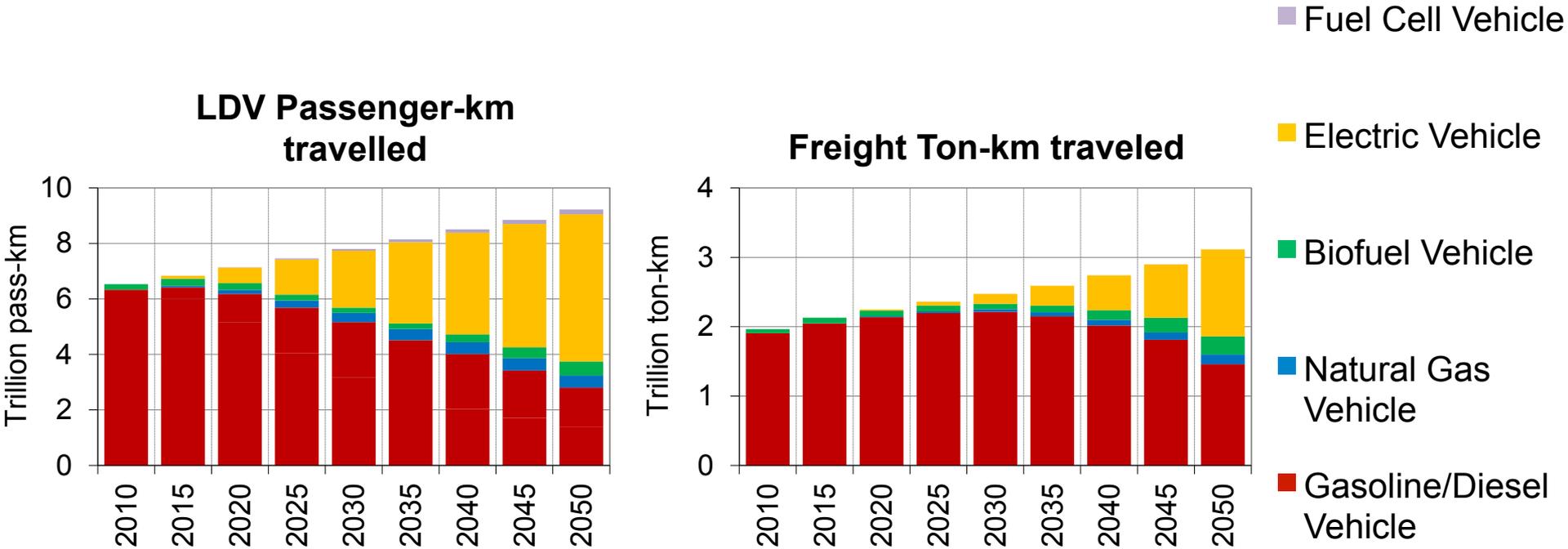
Energy consumption [EJ]



❖ Increased use of electricity for electric cars, heat pumps, and other end uses served by liquid or gaseous fuels will be important

Transport is a particularly challenging sector because of its reliance on liquid fuels

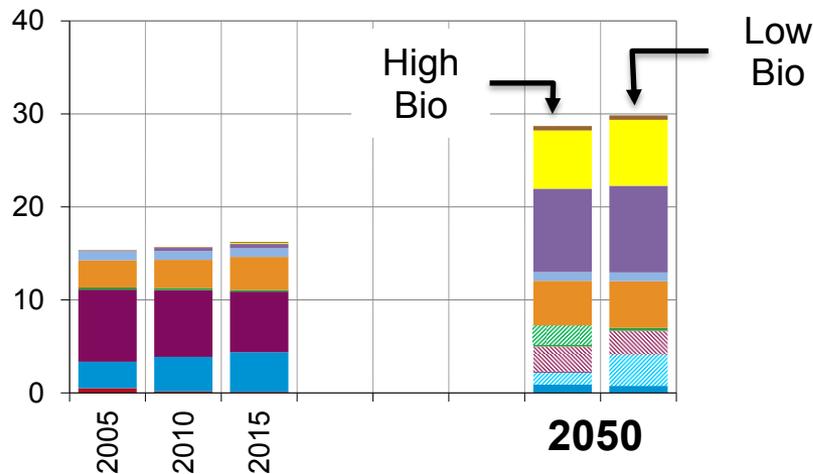
Transport service by fuel type



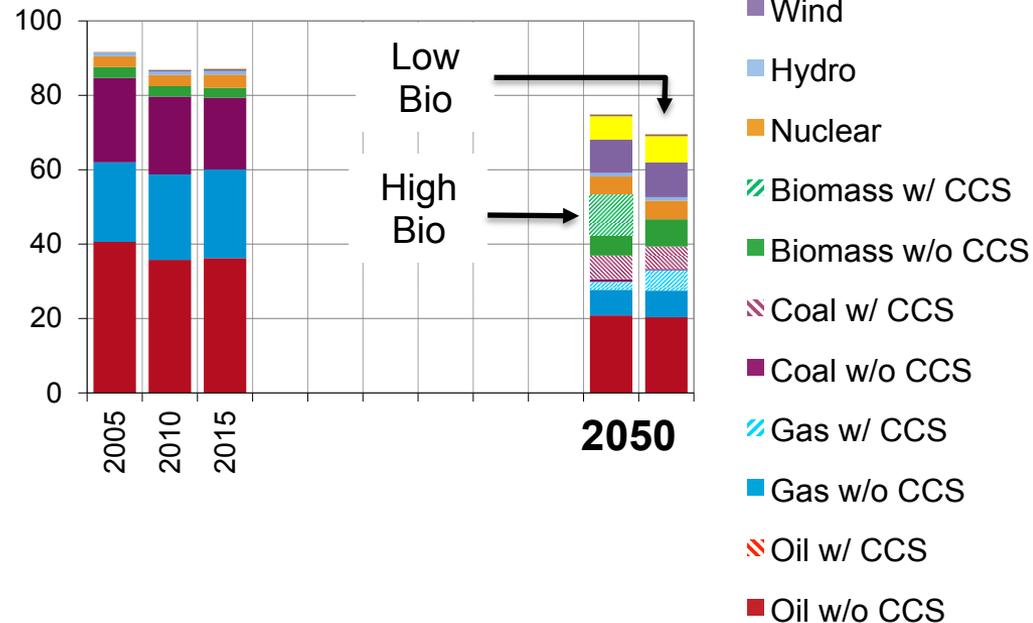
- ❖ Getting last bit out will require decarbonization of transport
- ❖ Options to decarbonize transport include electricity, biofuels, and hydrogen.
- ❖ Increased vehicle efficiency and methods to increase the use of public transportation and high-efficiency modes will be critical

The availability and use of bioenergy will be important

Electricity Generation [EJ]



Primary Energy [EJ]



- ❖ These scenarios assume 1 billion tonne of bioenergy in the U.S.
- ❖ BECCS in electricity and refining will be a key use of bioenergy
- ❖ Biofuels are a natural substitute for liquid fuels in transportation, including heavy-duty vehicles.

Further issues to consider

- ▶ Improvements in energy efficiency
- ▶ Similar to electricity generation, there are many decarbonize strategies for transport apart from electrification
 - Hydrogen
 - Public transportation
- ▶ Trade of bioenergy

Broader questions to think about

- ▶ We've tried to articulate some themes in the context of the U.S.
- ▶ A key question is to what extent would these talk to other national circumstances?
- ▶ What will be the role of infrastructure and institutions both for the U.S. and the rest of the world?
- ▶ What would be the role of technology spillovers and technology transfer?



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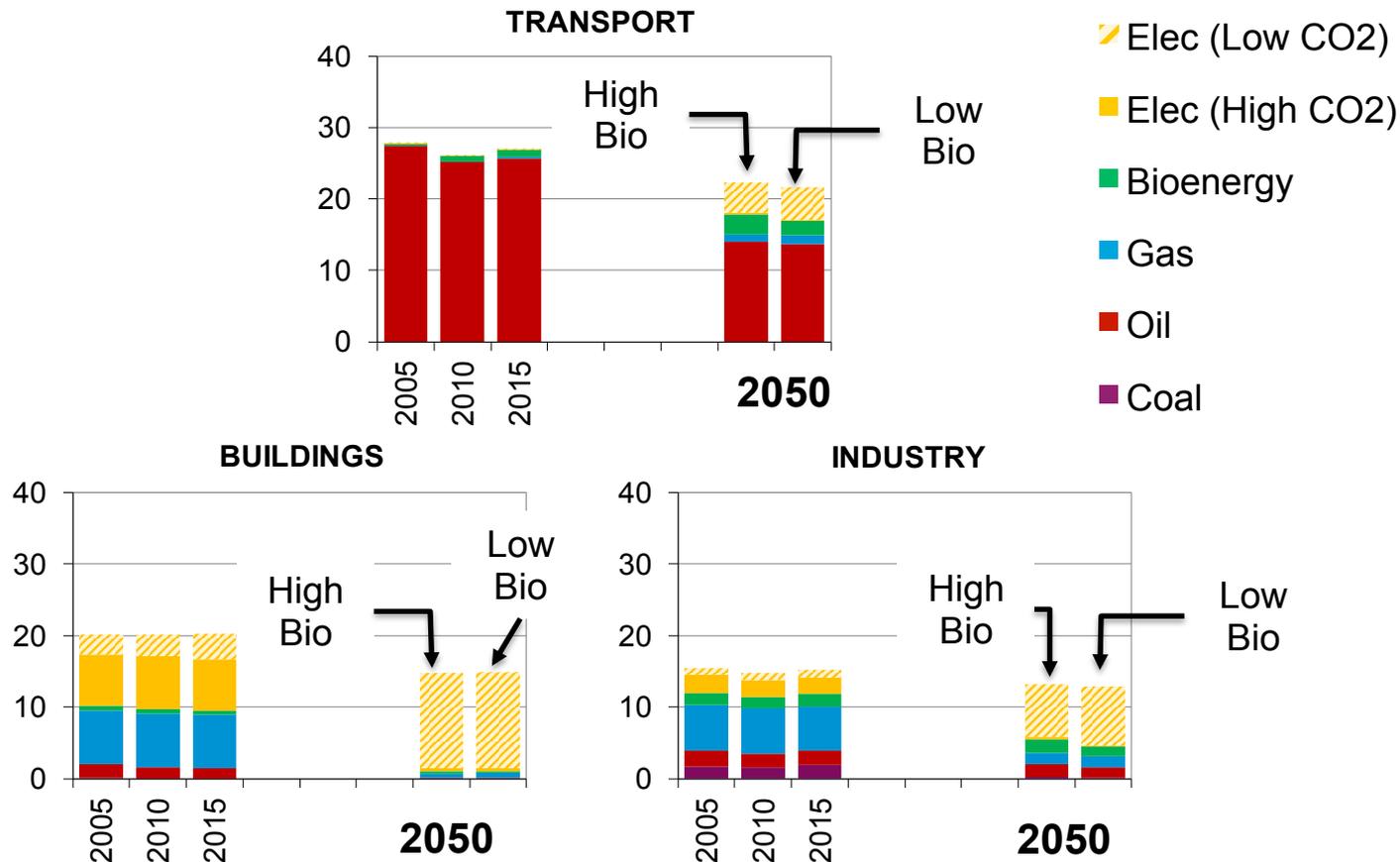
Thank You



Additional

The availability of bioenergy will have enormous implications for U.S. mid-century pathways

Energy consumption [EJ]



- ❖ U.S.'s mid-century strategy is based on the goal of obtaining 1 billion tonnes of domestic biomass production.
- ❖ Biofuels are a natural substitute for liquid fuels in transportation, including heavy-duty vehicles.

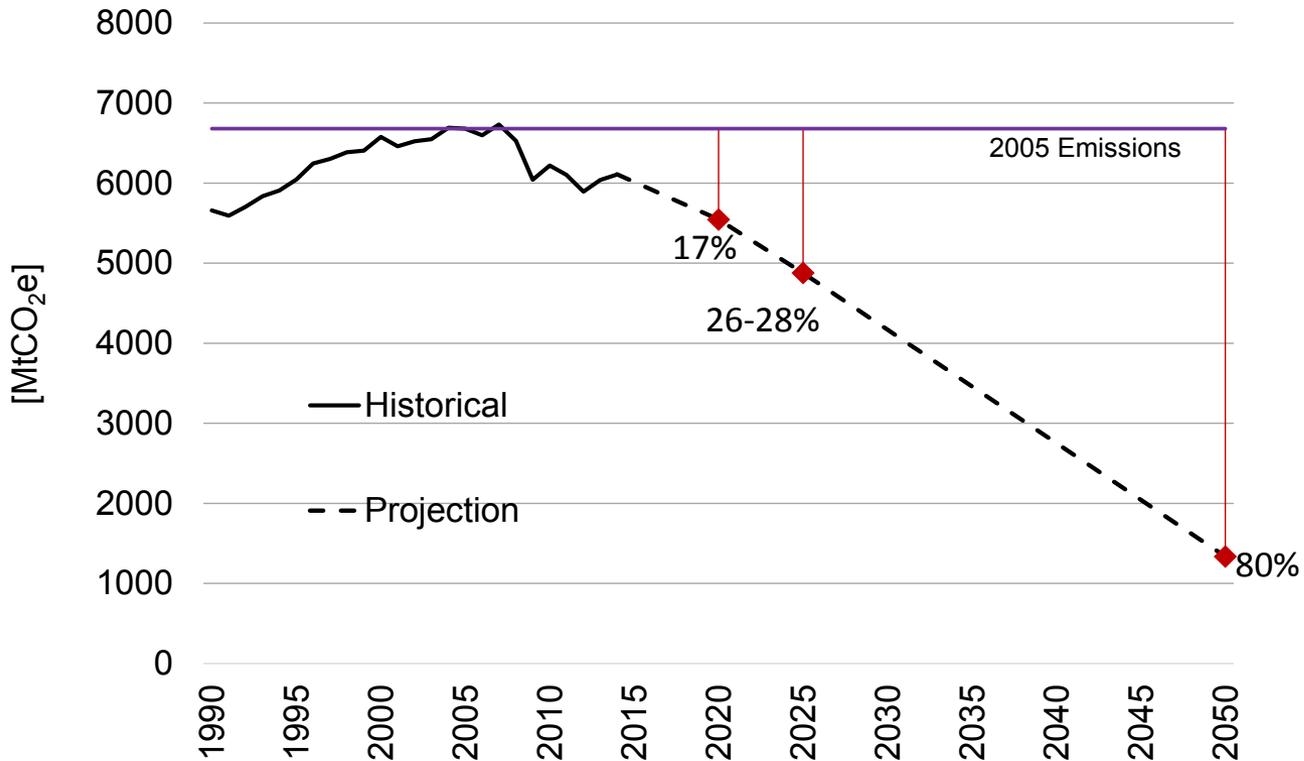
The Paris Agreement invites countries to articulate mid-century goals

- ▶ Mid-century strategies are a key component of international efforts to put the world on a track toward lower greenhouse gas emissions.
- ▶ Paragraph 35 of the Paris Agreement ***“(i)nvites Parties to communicate, by 2020, to the secretariat mid-century, long-term low greenhouse gas emission development strategies;”***
- ▶ In Article 4, paragraph 1 of the Paris agreement Parties aim to, ***“undertake rapid reductions ... so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century,”***

in order to achieve the long-term temperature goals

U.S. as an example of national-level mid-century analysis

Net Greenhouse Gas Emissions (Includes all sources and sinks)



- ▶ The U.S. INDC states that the 2025 target,

“is consistent with a straight line emission reduction pathway from 2020 to deep, economy-wide emission reductions of 80% or more by 2050.”