

TESTIMONY OF KARL HAUSKER, Ph.D.

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U.S. HOUSE OF REPRESENTATIVES, ENERGY AND COMMERCE COMMITTEE

SUBCOMMITTEE ON ENVIRONMENT AND CLIMATE CHANGE

HEARING ON "BUILDING AMERICA'S CLEAN FUTURE: PATHWAYS TO DECARBONIZE THE ECONOMY"

JULY 24, 2019

My name is Karl Hausker, and I am a Senior Fellow in the U.S. Climate Program at the World Resources Institute (WRI). WRI is a nonprofit, non-partisan environmental think tank that goes beyond research to provide practical solutions to the world's most urgent environment and development challenges. We work in partnership with scientists, businesses, governments, and non-governmental organizations across the globe to provide information, tools and analysis to address problems like climate change, the degradation of ecosystems and their capacity to provide for human well-being. I also bring to the Committee my expertise as the Chief Economist of the Senate Energy and Natural Resources Committee (1987-1992), Deputy Assistant Administrator of EPA's Policy Office (1993-1995), and many years of consulting to Federal and state governments in the areas of climate change and energy policy.

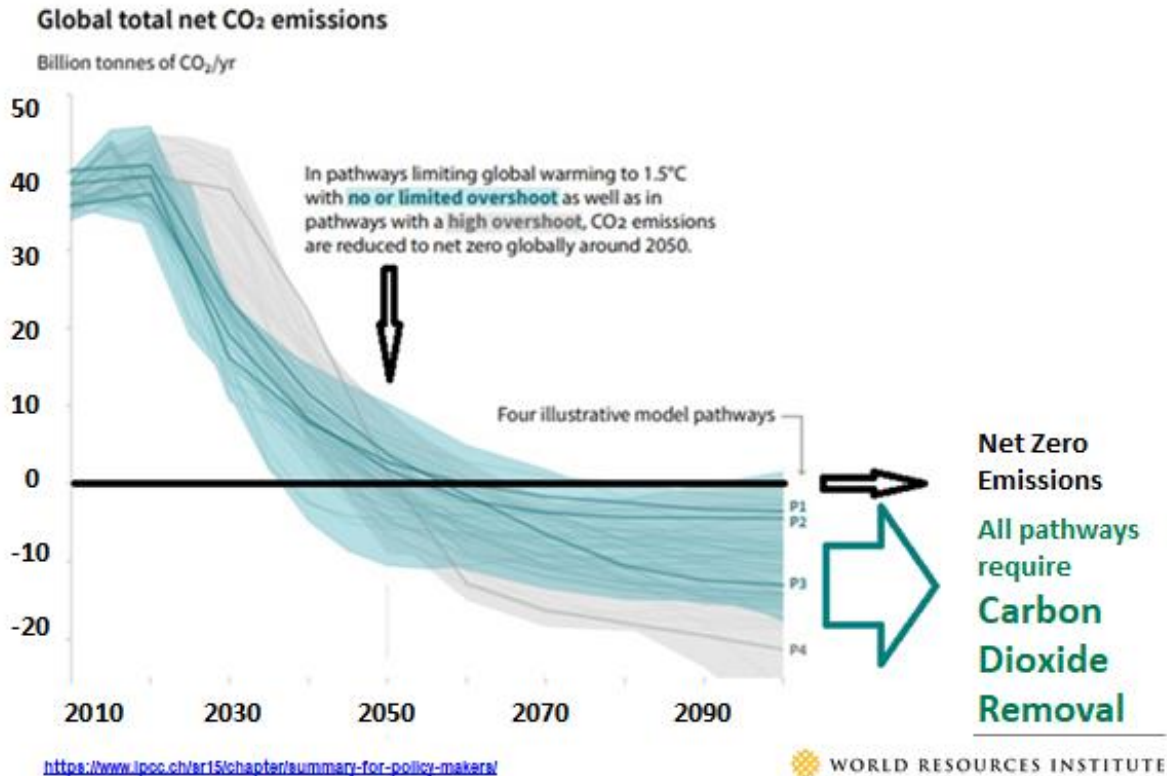
I thank the Committee for the opportunity to testify on America's Clean Energy Future. In addition to this written testimony, I have attached a presentation I gave to Chairman Tonko and the Sustainable Energy and Environment Coalition last February that expands on some of the themes in my testimony.

The evidence that climate change is underway grows stronger every year, along with the evidence that it is largely attributable to human activities. Climate change is already damaging human health, our economic well-being, our national security, and the ecosystems that underpin our food production and water supplies. Climate change is contributing to the destruction of countless plant and animal species. It is a problem that calls for U.S. action and for U.S. leadership in technology innovation and in diplomacy (because it requires collective action by nations).

To avoid the worst effects of climate change, the United States, and the world as a whole, must dramatically reduce greenhouse gas (GHG) emissions over the next 30 years. I'm going to focus on CO₂ in my testimony, which drives roughly 80 percent of global warming, but we should not lose sight of the need to reduce the other greenhouse gases, such as methane, nitrous oxide, and certain industrial gases.

The Intergovernmental Panel on Climate Change (IPCC) issued a report last year that laid out various emission pathways that could limit average global warming to 1.5 degrees Celsius. Figure 1 presents the IPCC pathways, with global emissions of CO₂ in billions of tons on the vertical axis, and years from present out to 2100 on the horizontal axis. Of the many model projections examined, the IPCC has indicated 4 "illustrative pathways" (P1, P2, P3, P4) as representative of the broader range of pathways.

Figure 1. IPCC Pathways Limiting Warming to 1.5 Degrees



There are two key takeaways from the IPCC pathways:

1. **Net-Zero By Mid Century.** Global emission reductions must begin a sharp descent in the coming decade. Major transformations will be required across the economy: in electricity generation, buildings, transport, and industry. CO₂ emissions should reach net-zero by roughly 2050, i.e., our gross emissions minus CO₂ removed from the atmosphere by natural means and technical means.
2. **Carbon Dioxide Removal After Mid Century.** The IPCC pathways indicate a very strong likelihood that we will overshoot GHG concentrations limits consistent with 1.5 degrees warming, and that we will need to begin removing up to 10 billion tons of CO₂ from the atmosphere each year. Some of this can be done by natural means (e.g., planting trees and improving soil health) but it is also highly likely to require technical means (e.g., bioenergy power plants with carbon capture and storage (BECCS) and/or direct air capture and storage of CO₂ (DACs)).¹

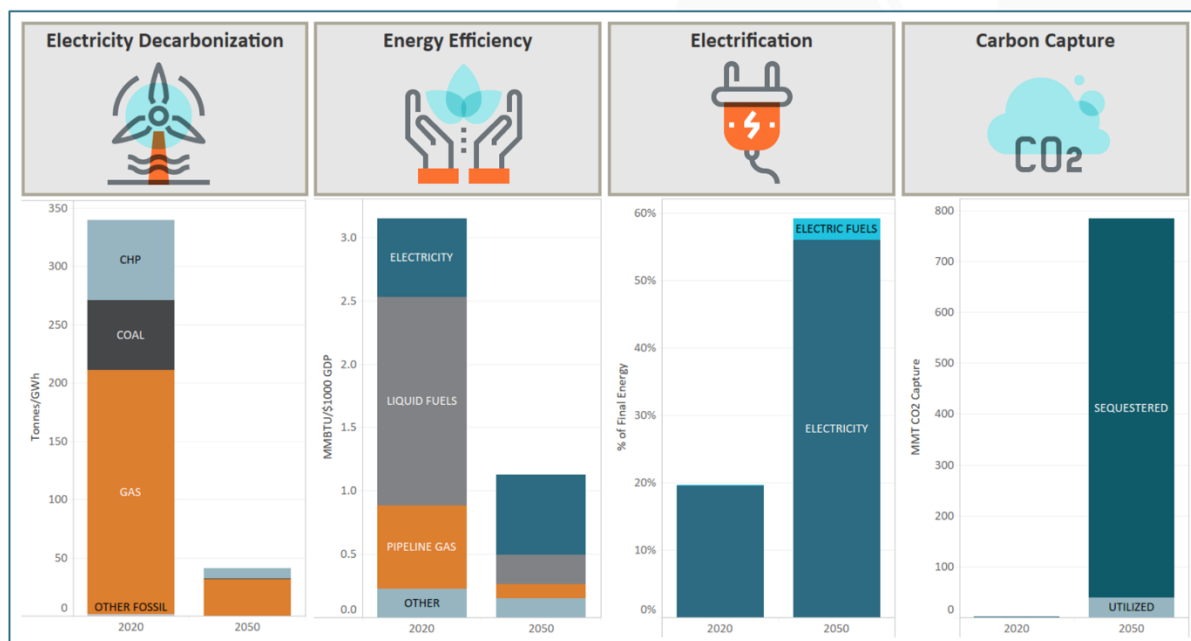
This has an important implication for the further development of carbon capture and storage (CCS) technology: regardless of whether one believes that CCS technology will be needed for electricity

¹ See WRI's working papers on these topics: CarbonShot: Creating Options for Carbon Removal at Scale in the United States. Available at: <https://www.wri.org/publication-series/carbonshot-creating-options-carbon-removal-scale-united-states>

generation, the technology is very likely to be needed for the job of carbon dioxide removal. Similarly, CCS is very likely to be needed to reduce process emissions from certain industrial sources (e.g. cement, iron and steel, chemicals and refining).

These transformations across all sectors in how we use energy will be challenging in many ways, but the transformations are technologically feasible and affordable. There are four basic strategies for achieving a clean energy future. These strategies are quite consistent across IPCC studies and other studies of how to achieve a clean energy economy. Figure 2 is from a recent US study conducted as part of the Deep Decarbonization Pathways Project.

Figure 2. Four Strategies for a Clean Energy Future.



Source: Evolved Energy Research, *350 ppm Pathways for the United States*, 2019.

<https://www.evolved.energy/single-post/2019/05/08/350-ppm-Pathways-for-the-United-States>

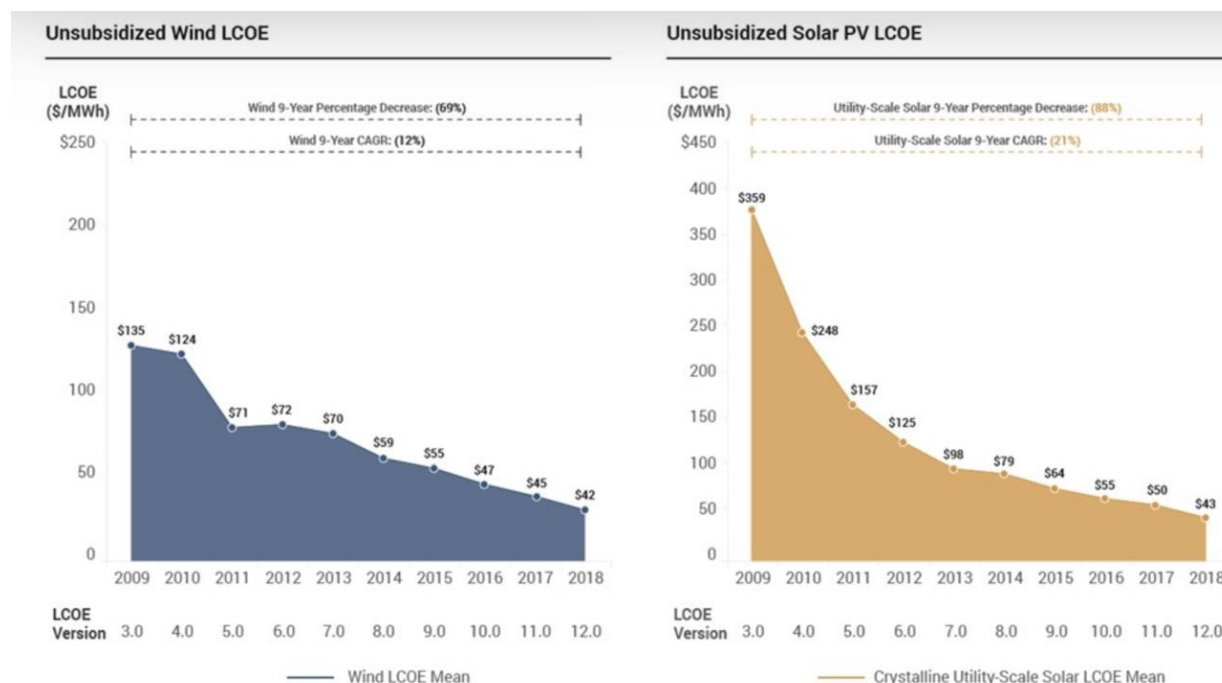
The four strategies are:

- **Energy efficiency:** aggressive improvements in across all sectors.
- **Electrification** of end-uses across all sectors, wherever feasible, and adoption of zero- or near zero-carbon fuels in certain end-uses.
- **Clean generation of electricity** from zero-carbon or near zero-carbon sources.
- **Carbon capture and storage** (from power plants, industrial operations, and/or direct air capture facilities), along with some utilization of CO2 capture in production processes.

There are encouraging signs of progress related to all of these strategies: the success of LED light bulbs, the growing market for electric vehicles, the potential for low-emission cement production, just to name a few. However, the most significant development of the past decade has been the jaw-dropping reductions in the cost of renewable electricity generation (see Figure 3). Through a combination of public and private R&D, supportive policies, and achievement of economies of scale, wind and solar

photovoltaic (PV) costs have decreased dramatically over the last decade as measured by the metric of the “Levelized Cost of Energy” (LCOE). The LCOE per MWh decreased by nearly 70% for wind and by nearly 90% for utility-scale solar PV (Lazard 2018). With these decreases, wind and utility-scale solar PV are now the least expensive sources of new generation in many parts of the U.S. Customer demand for renewable or “green” electricity can now be met at a fraction of the cost ten years ago.

Figure 3. Recent Cost Decreases in Wind and Solar PV Electricity Generation (LCOE)



Source: Lazard, *Levelized Cost of Energy and Levelized Cost of Storage 2018*, November 8, 2018
<https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/>

These cost reductions for wind and solar PV lead most analysts to project that renewables will become the largest source of electricity as we transition to clean energy. For example, in the IPCC pathways, renewables grow to represent roughly 60 to 80 percent of total generation globally by 2050, with most the remainder generated by hydro power, nuclear power, and fossil or bioenergy with CCS. Most of the modeling of clean energy pathways for the US shows similar high market shares for renewables by 2050. However, there are important caveats to the LCOE metric – one cannot conclude simplistically that wind and solar PV are “cheapest”, period, end of story. Power system dynamics are much more complex.

There are some calls for 100% renewable electricity (or even 100% renewable sources for all energy), and there are a few modeling studies that suggest this would be feasible. But power systems that become highly dependent on solar and wind (“variable renewables”) would be likely to face reliability and affordability challenges when their share of the total generation mix crosses certain thresholds.²

² Variable (or “intermittent”) renewables (wind and solar) present more challenges than other renewables such as hydro power, geothermal, or bioenergy that can operate in baseload and/or load-following modes. However, the quantity of wind and solar generation can be scaled up dramatically to reduce CO2 emissions, in contrast to other renewables that face constraints on their expansion (e.g., suitable locations, competition for food production and preservation of biodiversity).

The level of that threshold can be modeled, but when and how it actually might be crossed in the years and decades ahead is impossible to predict with certainty. It will depend on many factors that affect the “integration costs” of variable renewables:

- the resource mix of the particular power system;
- the degree to which transmission expansion can enable aggregation of diverse resources across large geographic areas; and
- the roles demand response, load-shifting, and storage technologies can ultimately play.

These integration costs are likely to escalate as the share of solar PV and wind increases, and that is why one cannot simply conclude they are “cheapest” based on LCOE, and that we should commit to a 100% renewable grid.

The good news is that, in the U.S., we can build out solar PV and wind aggressively for many years to come, make operational changes as variable generation increases, and reliably manage our power systems. At the same time, we should strive to fully commercialize other near zero-carbon technologies. The good news here is that NetPower and other companies are developing promising approaches to CCS that capture nearly 100% of CO₂ emissions from fossil plants. In addition, NuScale and other companies are developing small modular reactors and other designs that may allow new nuclear power plants to play a role in America’s clean energy future.

Our strategies for limiting global warming should be resilient in the face of the many ways that various zero-carbon technologies could develop.

- Technical and economic feasibility could change over time (e.g., with R&D and scale-up in production)
- Various political and institutional factors could change over time (e.g., the political acceptability of large-scale renewables deployment, nuclear power, CCS technologies and infrastructure, and large-scale transmission expansion)

Leading states, such as California, New York, Nevada, and Washington, appear to be setting policies in a resilient and pragmatic way. They are boosting their Renewable Portfolio Standards to 50 or 60 percent in the mid-term (e.g., 2030 or 2035). However, in setting long-term goals, they are taking a technology-neutral approach, calling for zero carbon or net-zero carbon energy systems.

It’s risky to “bet the climate” on any single set of technologies. The United States should greatly expand its zero-carbon generation now with low-cost wind and solar, while aggressively investing in research, development, and demonstration of a broad portfolio of zero-carbon electricity options, given the many uncertainties related to the evolution of any single technology. Let’s keep our focus on the problem – carbon emissions -- not the market share of any particular technology.³

³ See also: Woolard, John. 2019. “Beyond Renewables: How to Reduce Energy-Related Emissions by Measuring What Matters.” WRI Commentary. <https://www.wri.org/news/beyond-renewables-how-reduce-energy-related-emissions-measuring-what-matters>



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PATHWAYS TO A SAFE CLIMATE

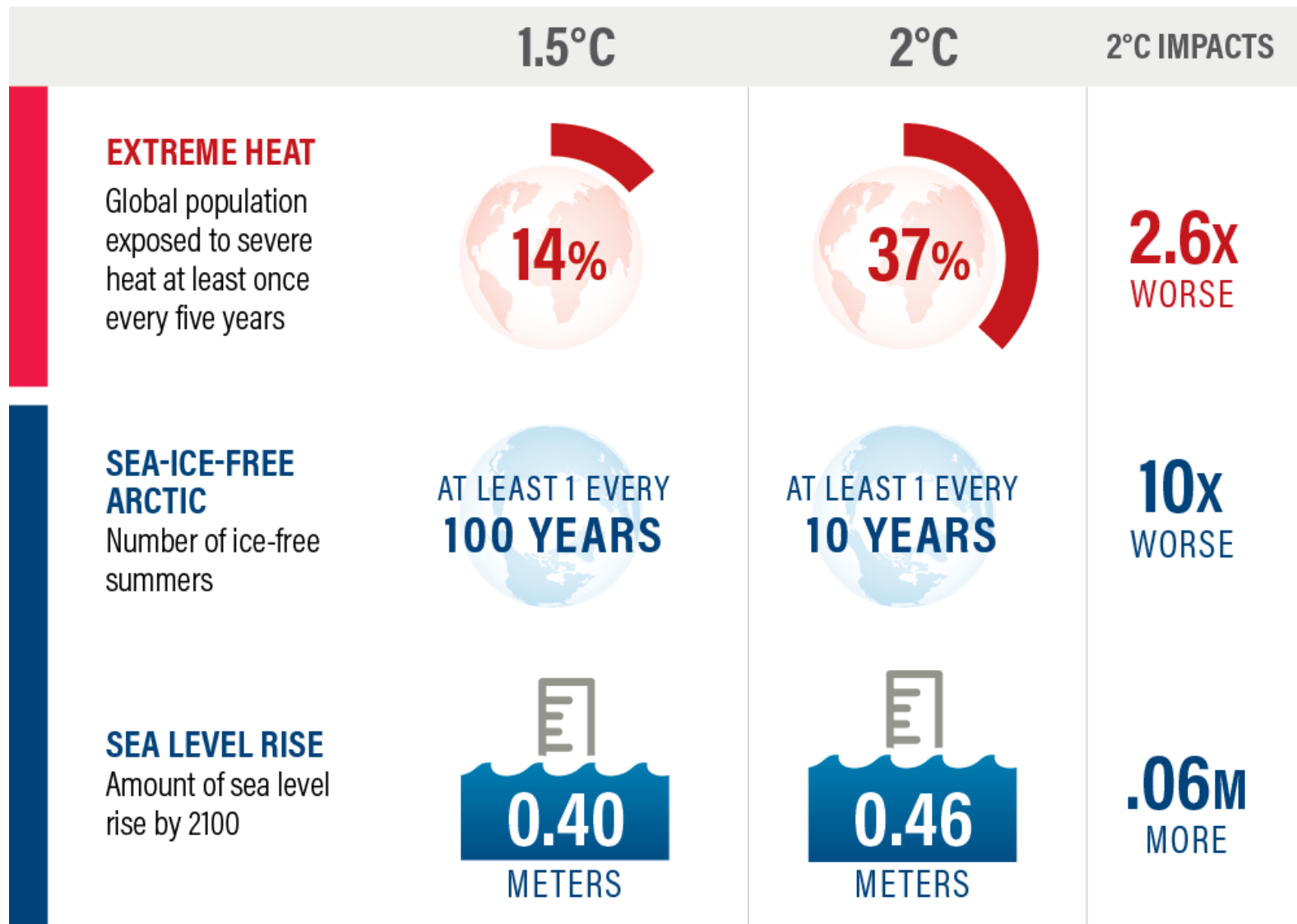
DAN LASHOF, PH.D.
DIRECTOR, WRI-U.S.

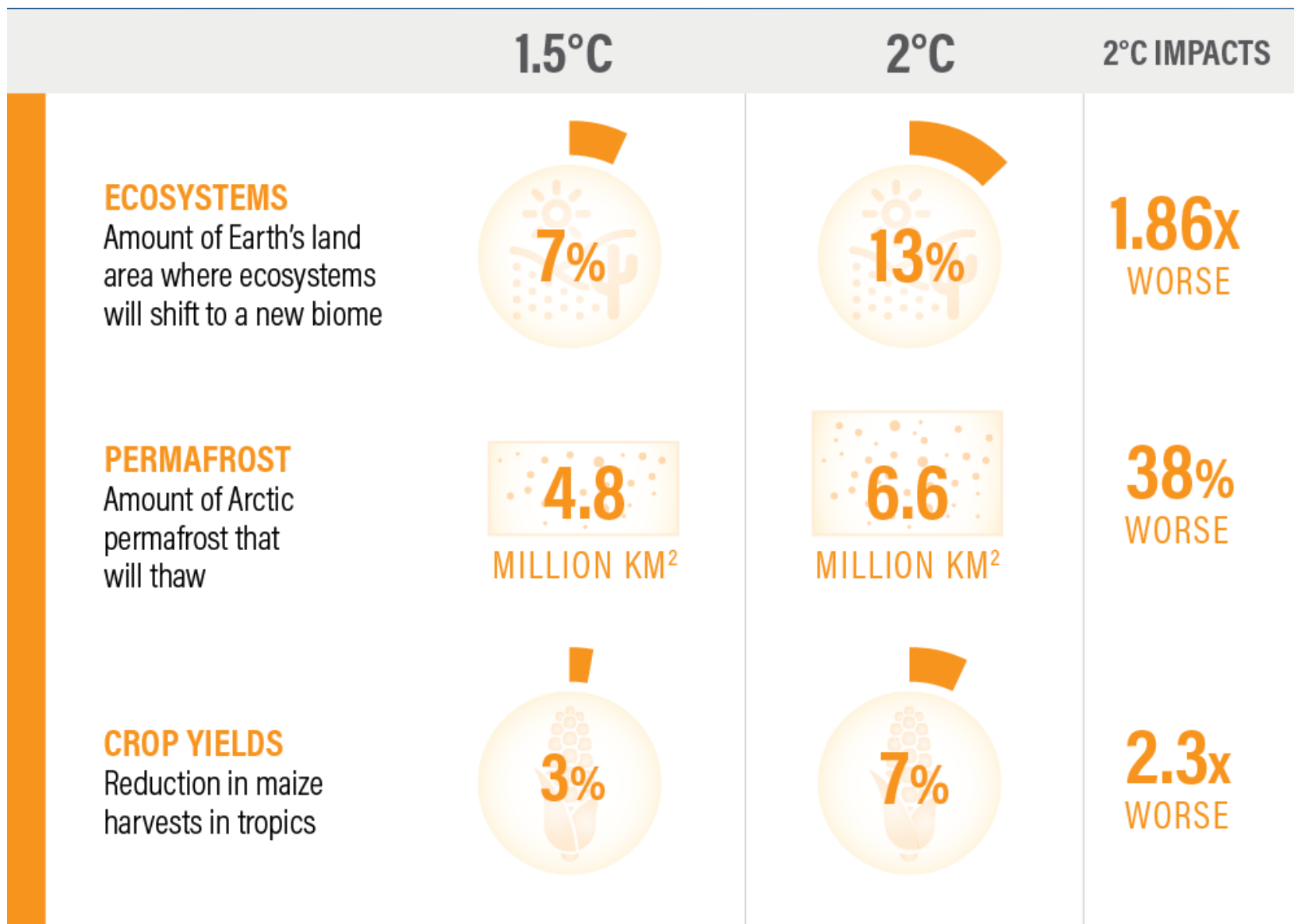
KARL HAUSKER, PH.D.
SENIOR FELLOW

FEBRUARY 2019

Briefing for the Sustainable Energy and Environment Coalition

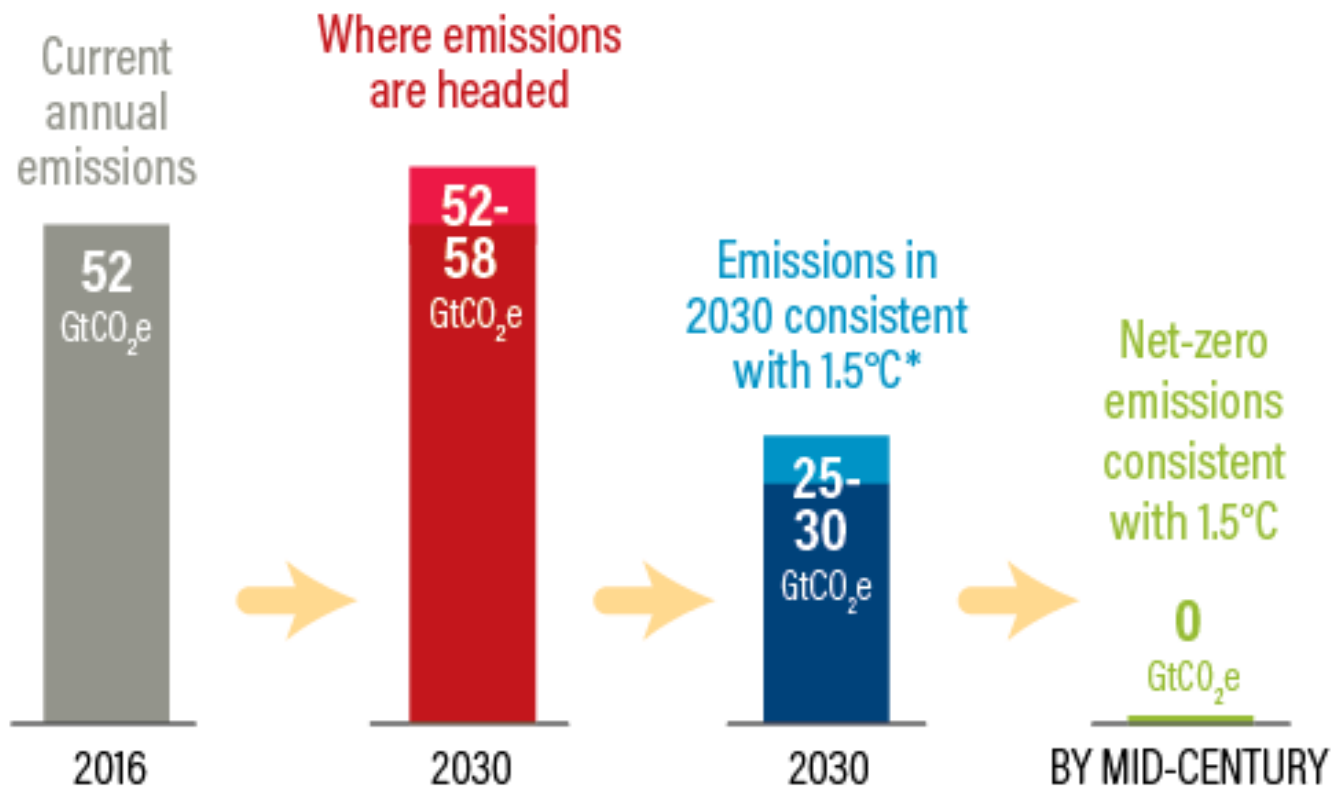
HALF A DEGREE AND A WORLD APART: RISKS MUCH HIGHER AT 2°C RATHER THAN 1.5°C





LIMITING WARMING TO 1.5°C REQUIRES MAJOR AND IMMEDIATE TRANSFORMATION

The World Is Not on Track to Limit Temperature Rise to 1.5°C



Notes: *on average, no or low overshoot.

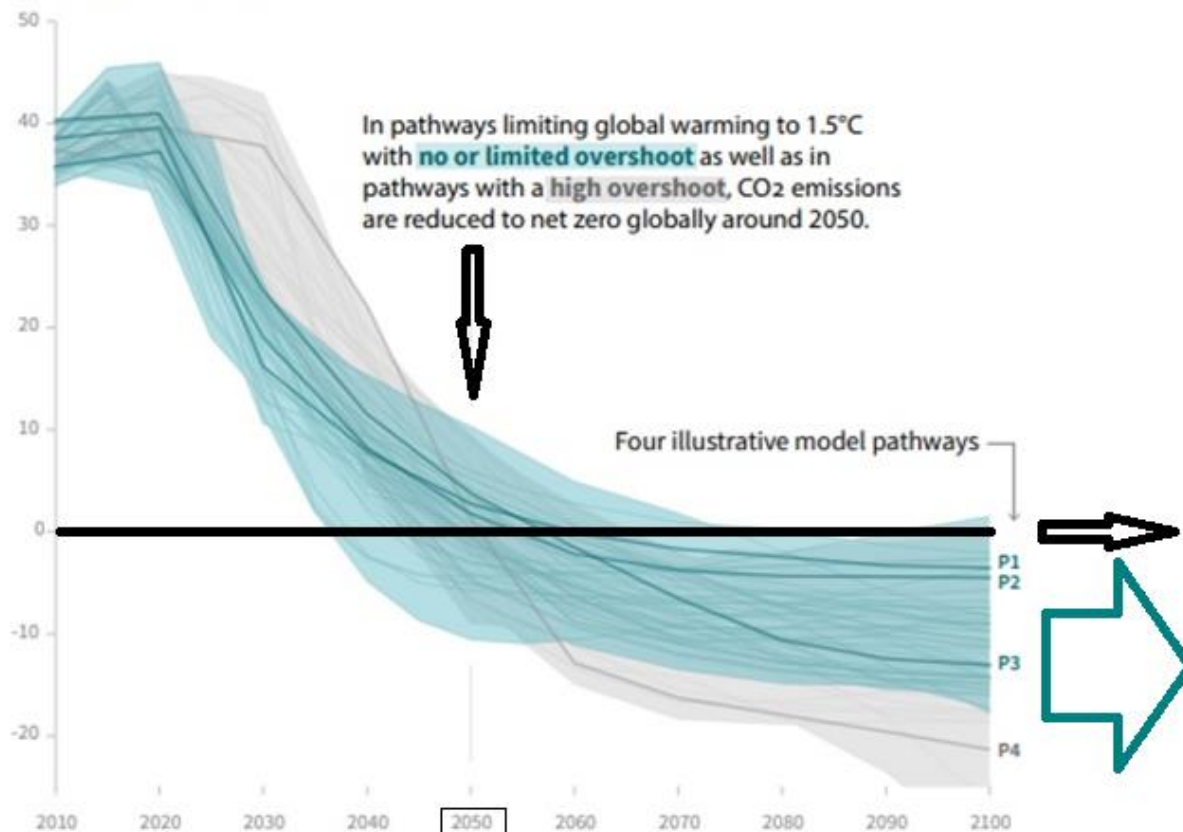


WORLD RESOURCES INSTITUTE

1.5°C PATHWAYS REQUIRE NET-ZERO BY MID-CENTURY

Global total net CO₂ emissions

Billion tonnes of CO₂/yr

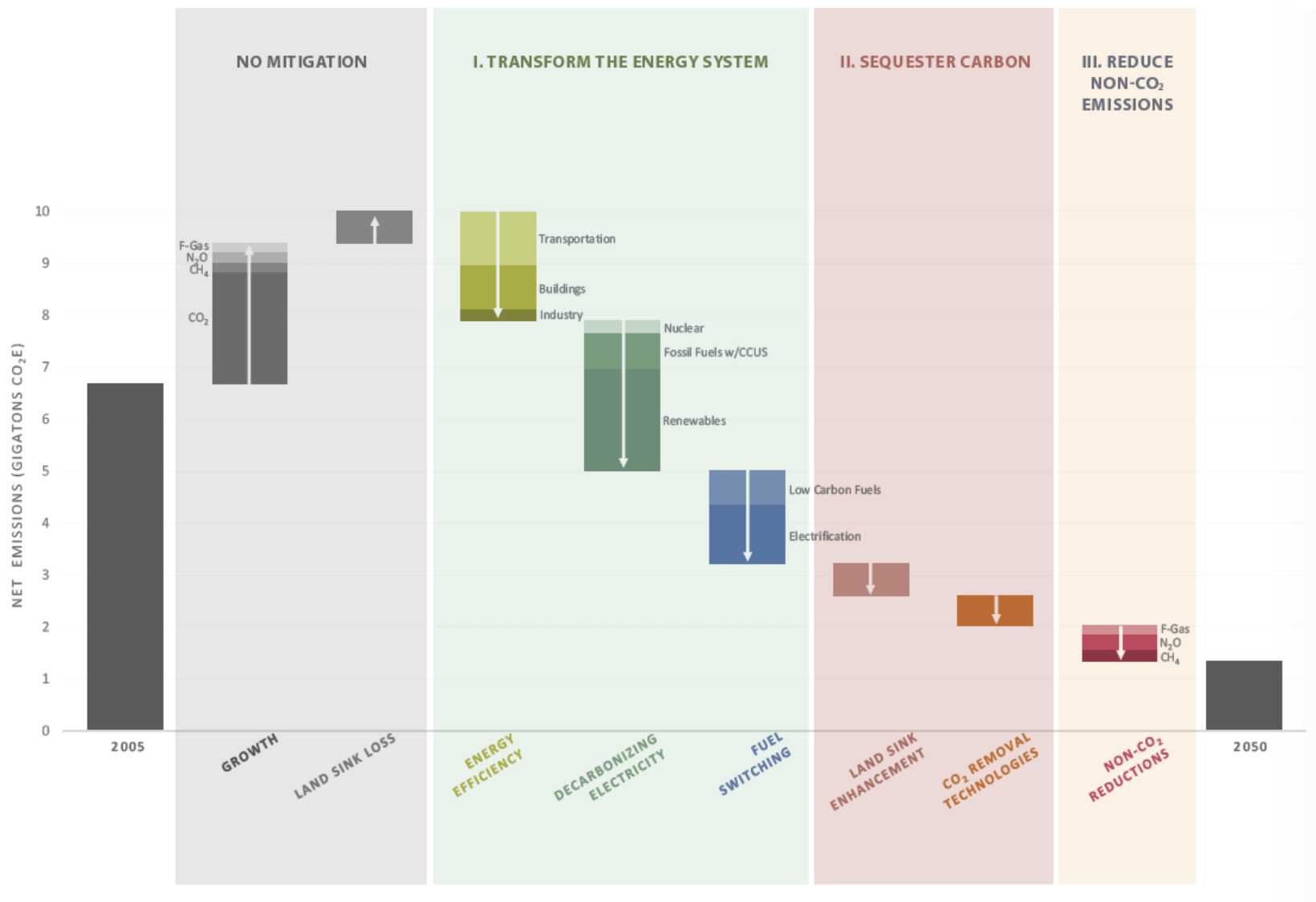


Timing of net zero CO₂

Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

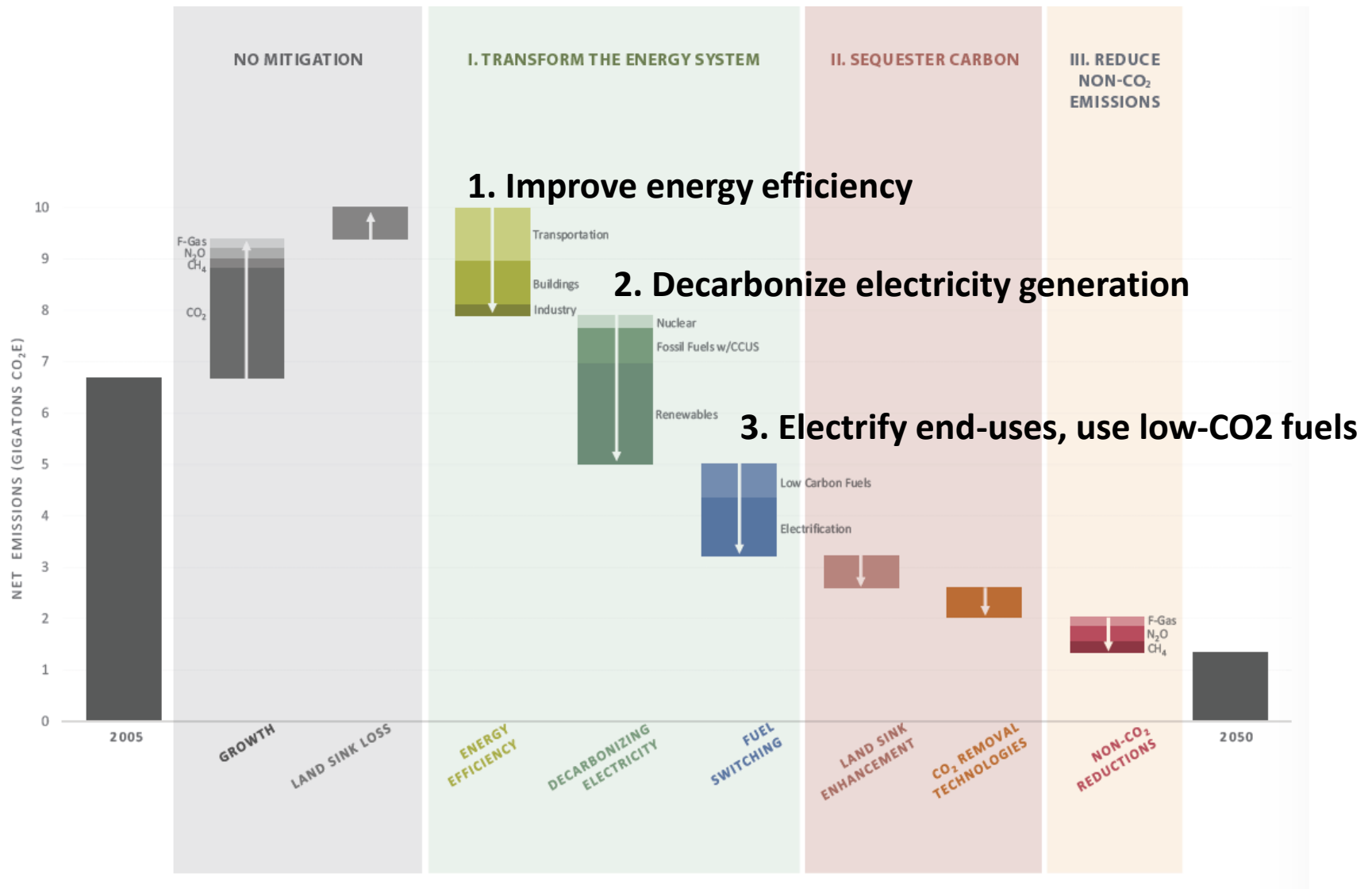


U.S. MID-CENTURY STRATEGY REPORT



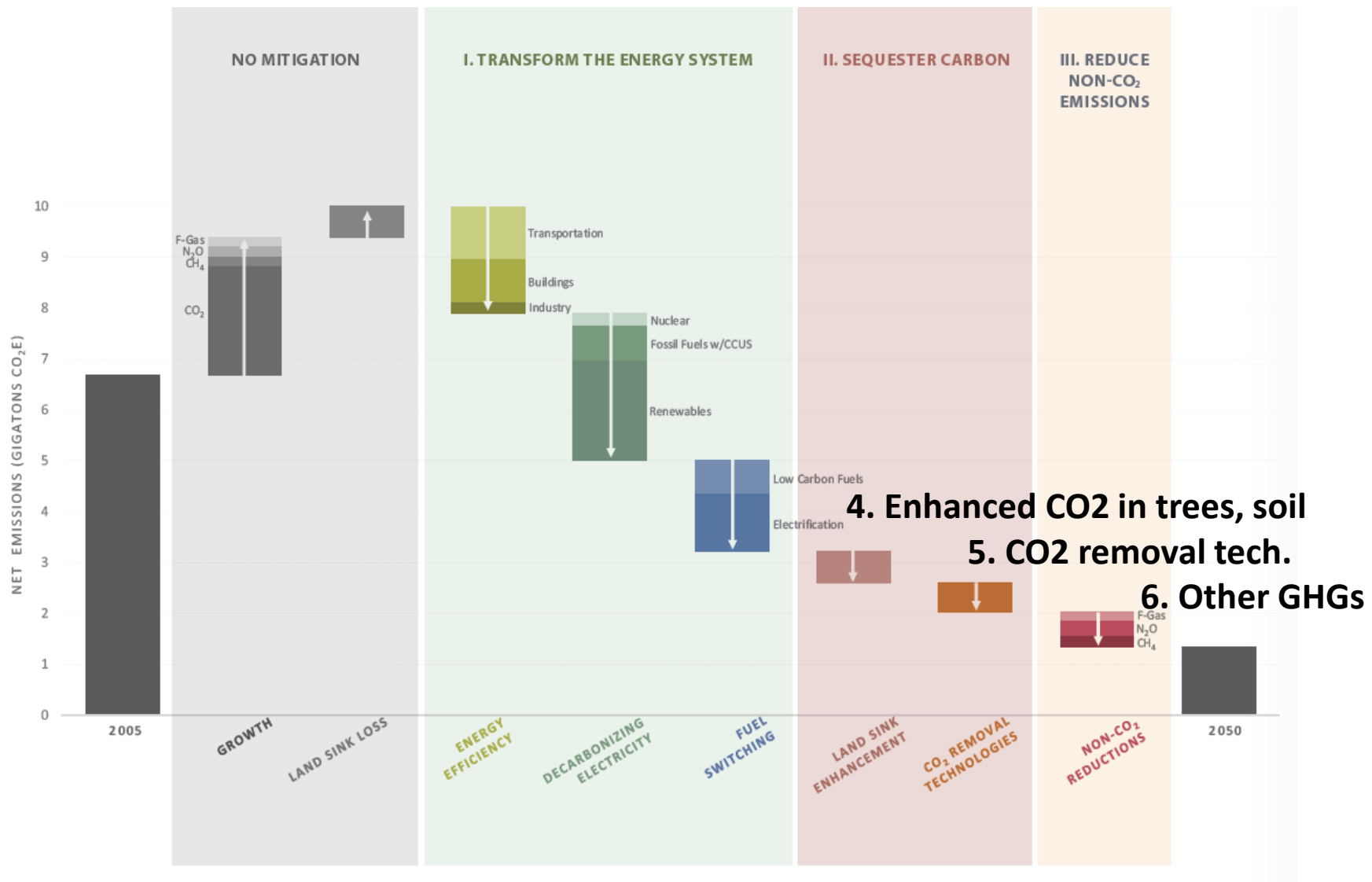
Source: *United States Mid Century Strategy for Deep Decarbonization*, November 2016

U.S. MID CENTURY STRATEGY REPORT



Source: *United States Mid Century Strategy for Deep Decarbonization*, November 2016

U.S. MID CENTURY STRATEGY REPORT

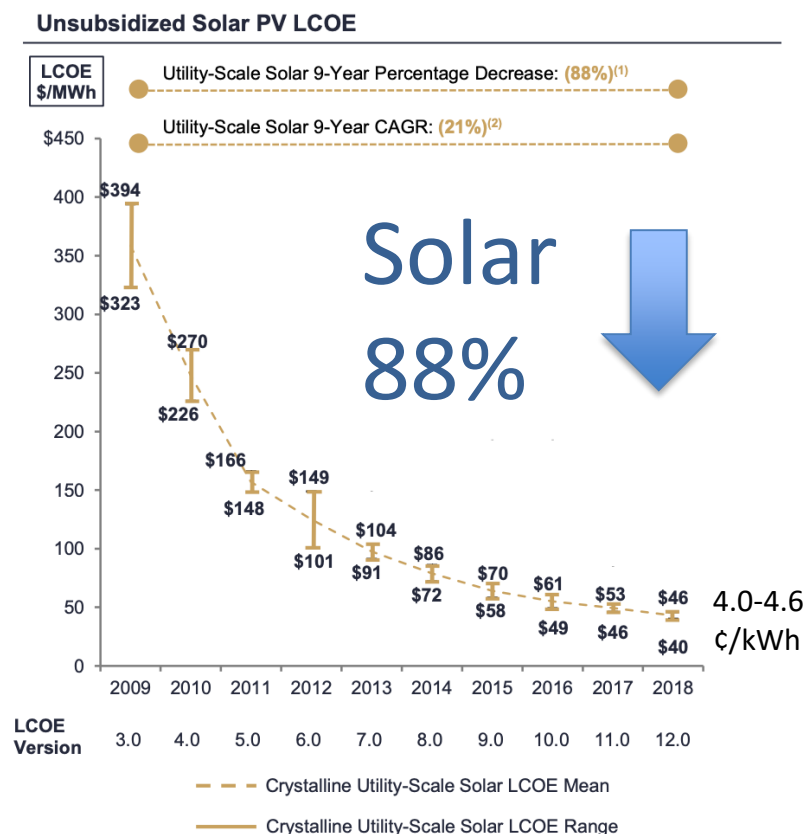
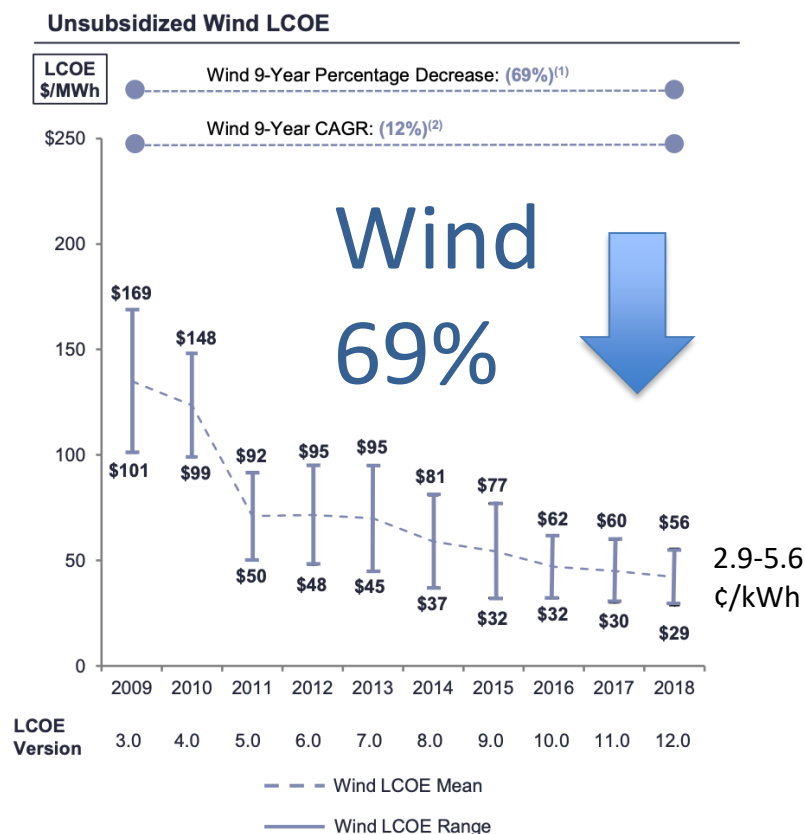


Source: *United States Mid Century Strategy for Deep Decarbonization*, November 2016

RENEWABLES REVOLUTION

Dramatic cost decreases in wind and solar PV over the past 10 years

Wind: 3 – 6 cents/kWh. Solar PV: 4 – 5 cents/kWh (Utility-Scale).



EXAMPLES OF FEDERAL AND STATE GOALS: 100% RENEWABLE AND 100% CLEAN

100% Renewable

100% Clean

Federal

- **By 2035:** Climate Solutions Act, H.R. 330, Rep. Lieu, 2019.
- **By 2035:** OFF Act, H.R. 3671, Rep. Gabbard, 2017.

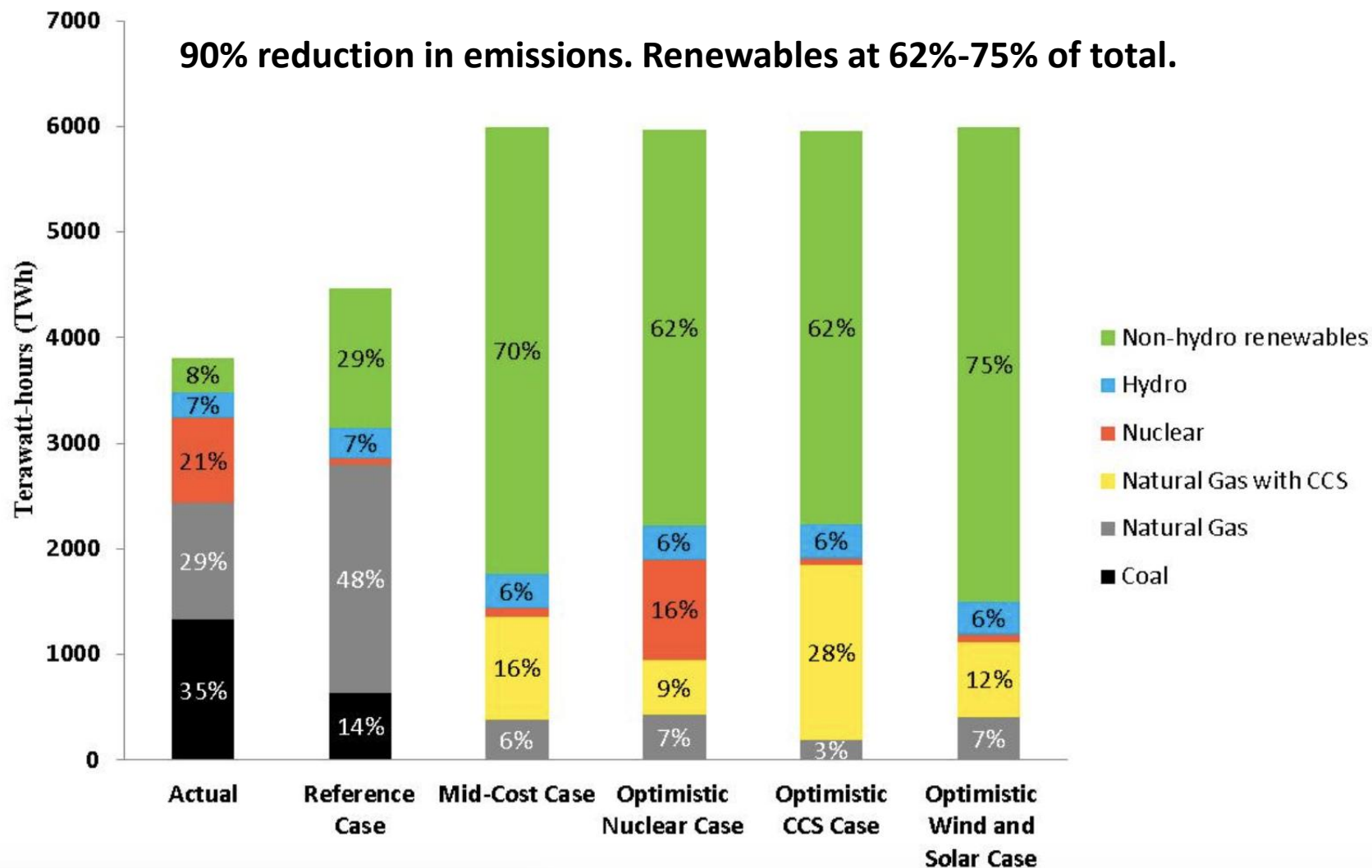
- **By 2030:** AOC-Markey GND Resolution, 2019.
- **By 2050:** 100 By '50 Act, S.987 Sen. Merkley, 2017.

State

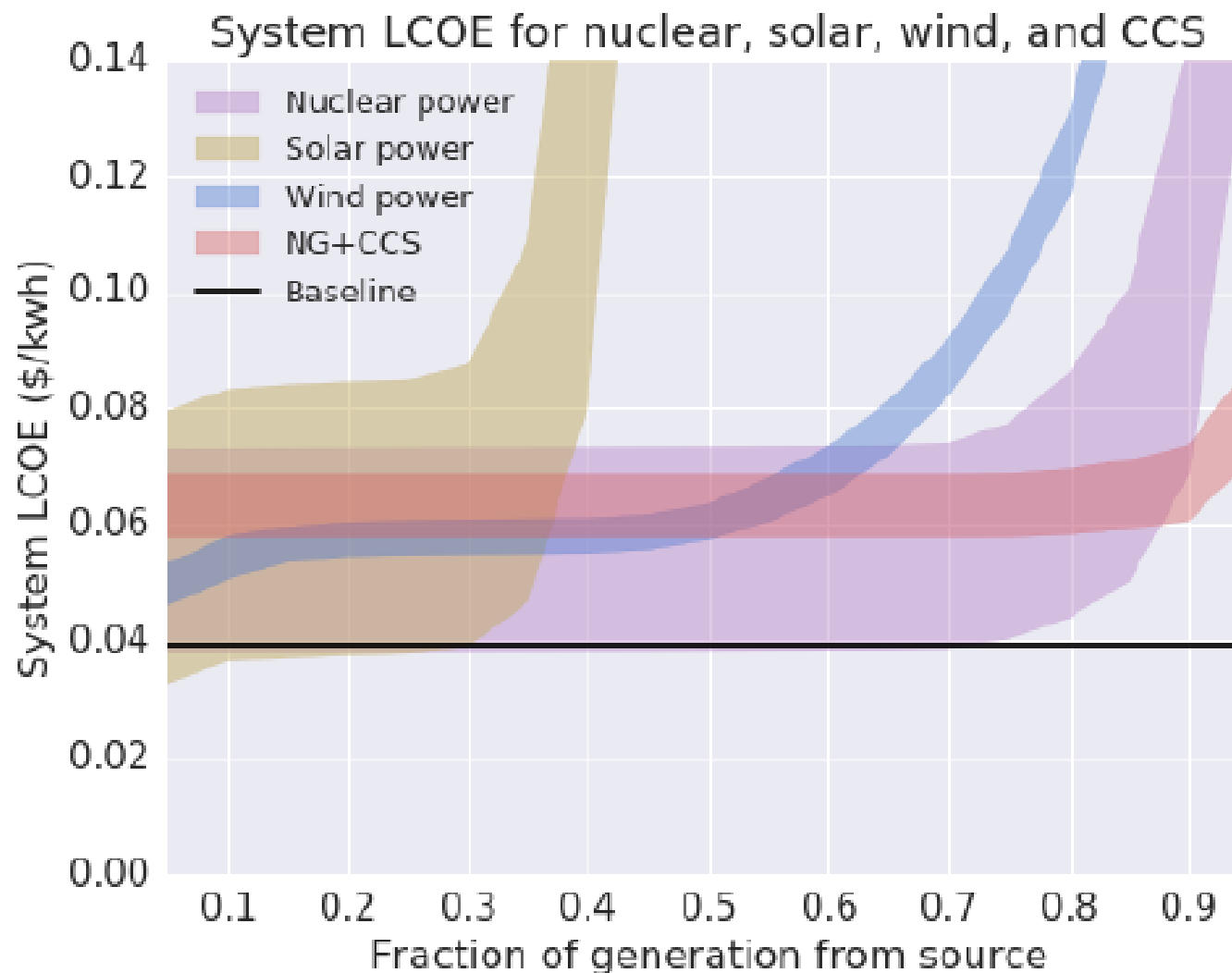
- **By 2045:** Hawaii, H.B. 623 (enacted), 2015.
- **By 2040:** Colorado, Governor's proposal for 100% renewable electricity

- **By 2045:** California S.B.100 (enacted), 2018.
- **By 2040:** New York, Governor's Green New Deal proposal, 2019
- **By 2050:** New Jersey, Governor's E.O. #28 on Energy Master Plan
- **By 2050:** Campaign commitments from governors in WA, CT, IL, ME, MI, WI

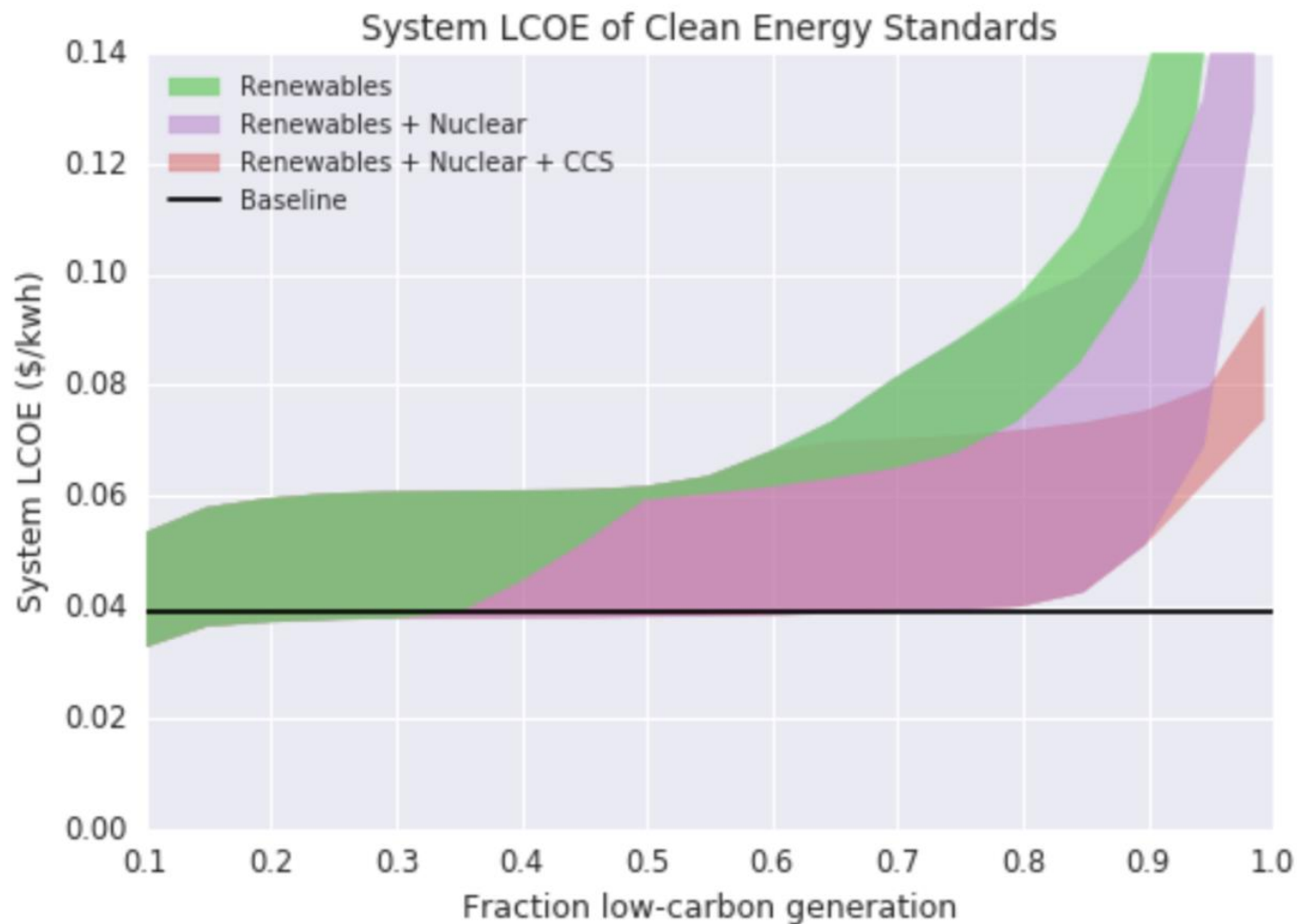
EXAMPLE OF ELECTRICITY GENERATION MIX: FOUR SCENARIOS, UNION OF CONCERNED SCIENTISTS



THE RIDDLE OF “CHEAP RENEWABLES” AND “HIGH SYSTEM COSTS”



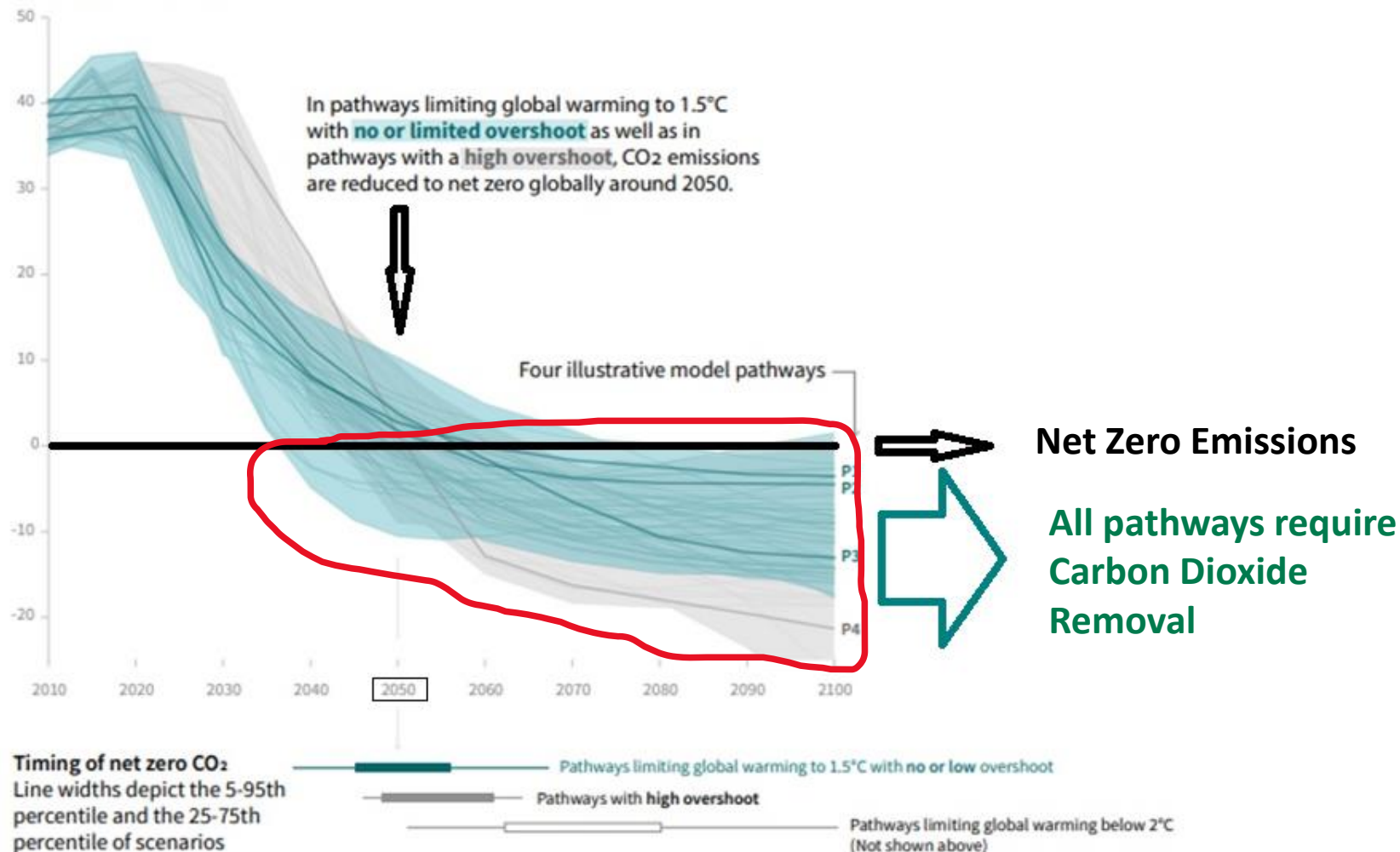
TOTAL SYSTEM COSTS MINIMIZED BY DIVERSE PORTFOLIO



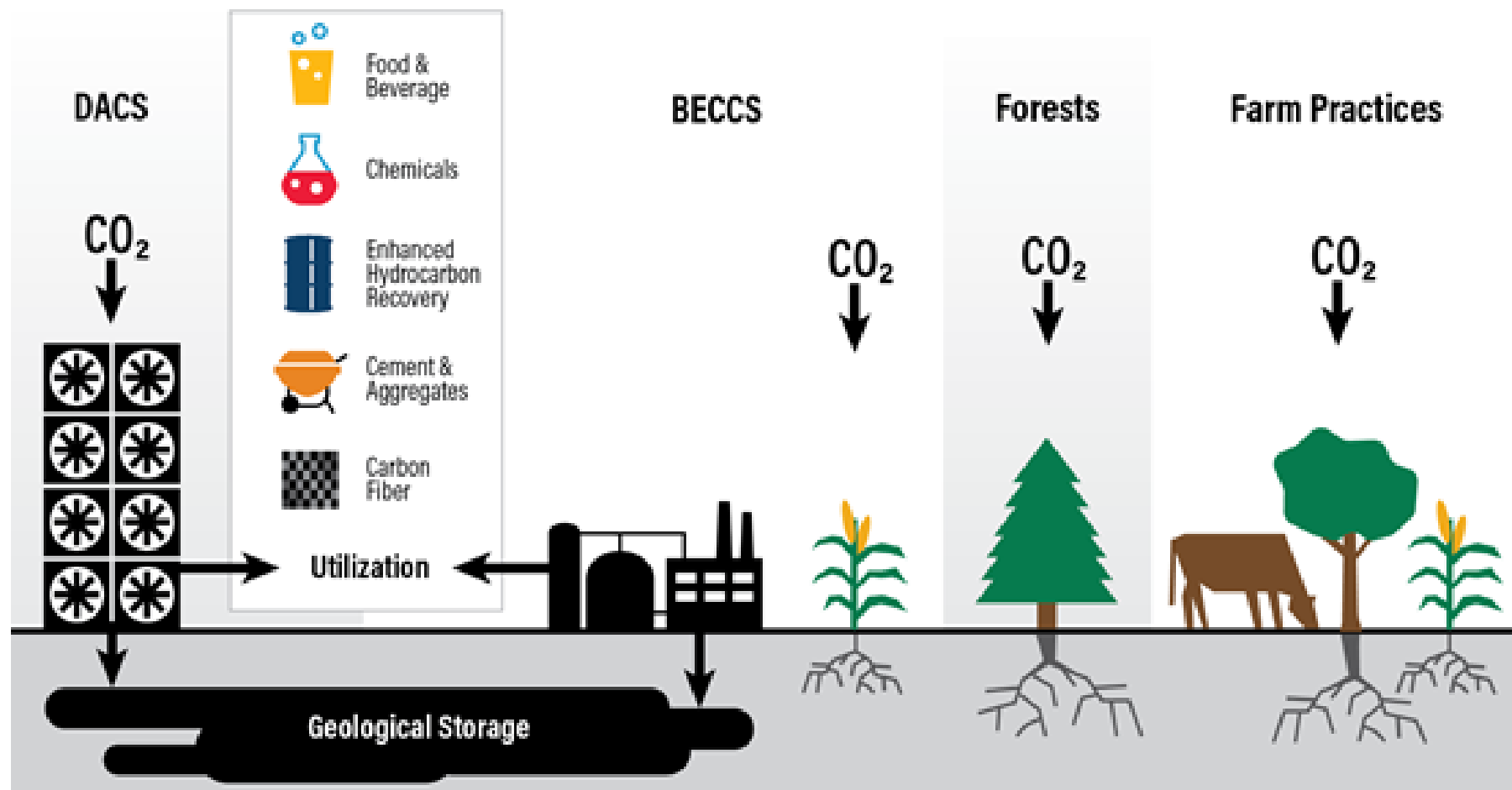
WHAT ARE OUR OPTIONS FOR CARBON DIOXIDE REMOVAL AT LARGE SCALE (BILLIONS OF TONS/YEAR)

Global total net CO₂ emissions

Billion tonnes of CO₂/yr



CARBON DIOXIDE REMOVAL OPTIONS



Also at research stage: Enhanced weathering of rocks/minerals, and seawater capture

NEAR-TERM CARBON DIOXIDE REMOVAL POLICY NEEDS

- Federal cross-cutting RD&D program
- Federal & state deployment-support policies
- Cross-cutting enabling investments in infrastructure and data systems

KEY TAKEAWAYS

- Damages increase sharply if warming goes from 1.5 to 2 degrees C (and beyond)
- Need to achieve zero net emissions by midcentury to limit warming to 1.5°C
- Broad technology portfolio can significantly cut cost to decarbonize electricity generation.
- Fully developing carbon dioxide removal approaches preserves pathways to 1.5°C

ADDITIONAL SLIDES

EXAMPLE OF INTERPLAY OF TRANSMISSION, LOAD-SHIFTING, AND STORAGE IN HIGH RE PATHWAYS

- Study by NREL researcher
- Modeled RPS of 20/40/60/80/100%
- Modeled 6 pathways with variations related to transmission expansion, growth in plug-in electric vehicles (PEVs), and a path dependent feature.
 - Two pathways labeled “Indep.” always had similar results, and assumed the current transmission system
 - The other four pathways always had similar results.
 - Estimated least cost mix, system costs, and “overgeneration”





IMPACTS OF 20%-100% RENEWABLES

- With current transmission system, costs and overgeneration escalate sharply as system reaches 60/80/100% renewables.
- Storage costs drive up cost (batteries). Total system costs increase 4x.

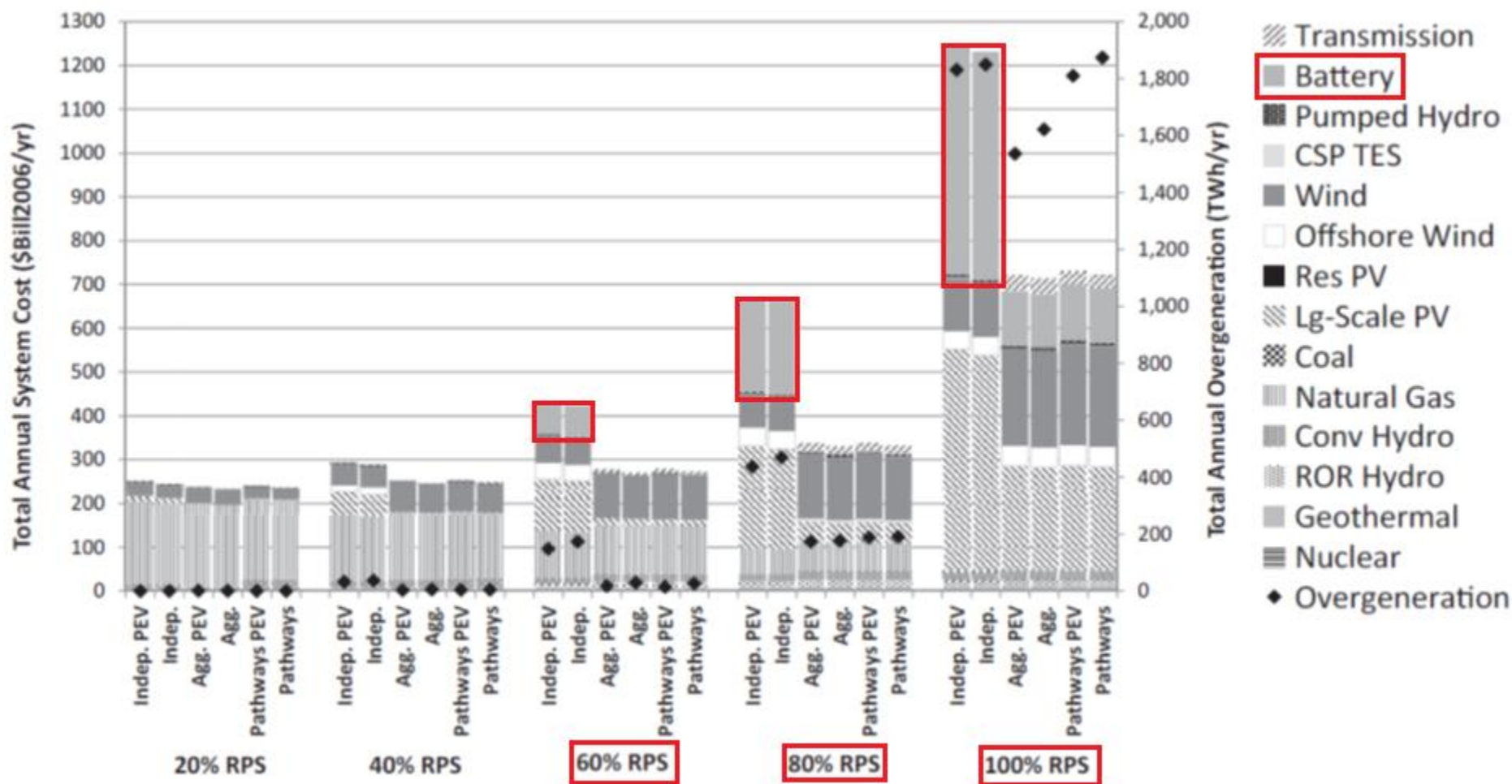


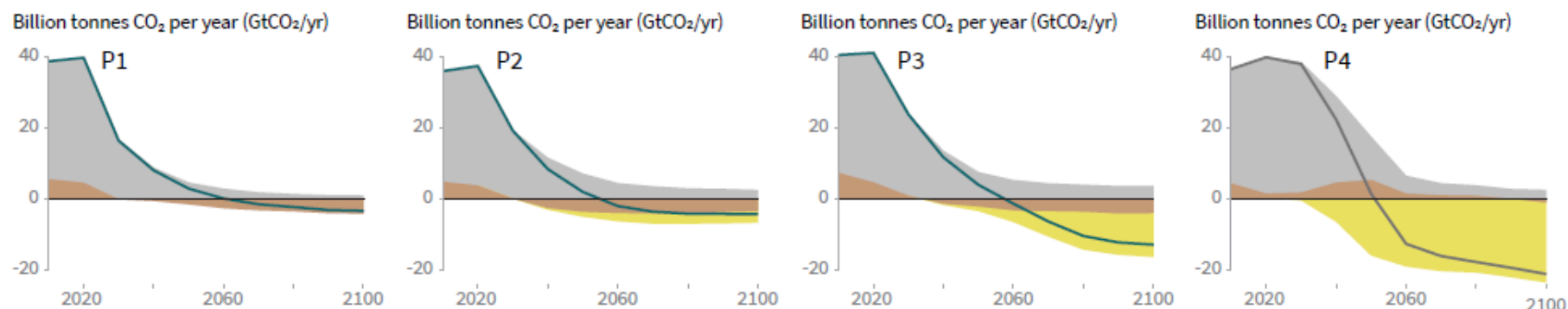
Figure 10 is a dual-axis chart showing Total Annual System Cost (\$/MWh/yr) on the left y-axis and Total Annual Overgeneration (TWh/yr) on the right y-axis. The x-axis represents different Renewable Portfolio Standard (RPS) scenarios: 20% RPS, 40% RPS, 60% RPS, 80% RPS, and 100% RPS. For each RPS scenario, there are five stacked bar graphs representing different system configurations: Indep. PEV, Indep., Agg. PEV, Agg., and Pathways. The bars are color-coded by energy source: Transmission (light blue), Battery (dark blue), Pumped Hydro (light green), CSP TES (medium green), Wind (dark green), Offshore Wind (light yellow), Res PV (dark yellow), Lg-Scale PV (light orange), Coal (medium orange), Natural Gas (dark orange), Conv Hydro (light brown), ROR Hydro (medium brown), Geothermal (dark brown), and Nuclear (black). Overgeneration is represented by black diamonds. A blue line connects the overgeneration points for the 100% RPS scenarios. The chart shows that as the RPS increases, the total annual system cost generally increases, and the total annual overgeneration also increases, particularly for the 100% RPS scenarios.

FOUR ILLUSTRATIVE PATHWAYS – CO₂

- Major transformations needed in power, buildings, transport, industry
- Carbon dioxide removal (CDR) needed via afforestation, BECCS, and/or other technologies and processes

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways

● Fossil fuel and industry ● AFOLU ● BECCS



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

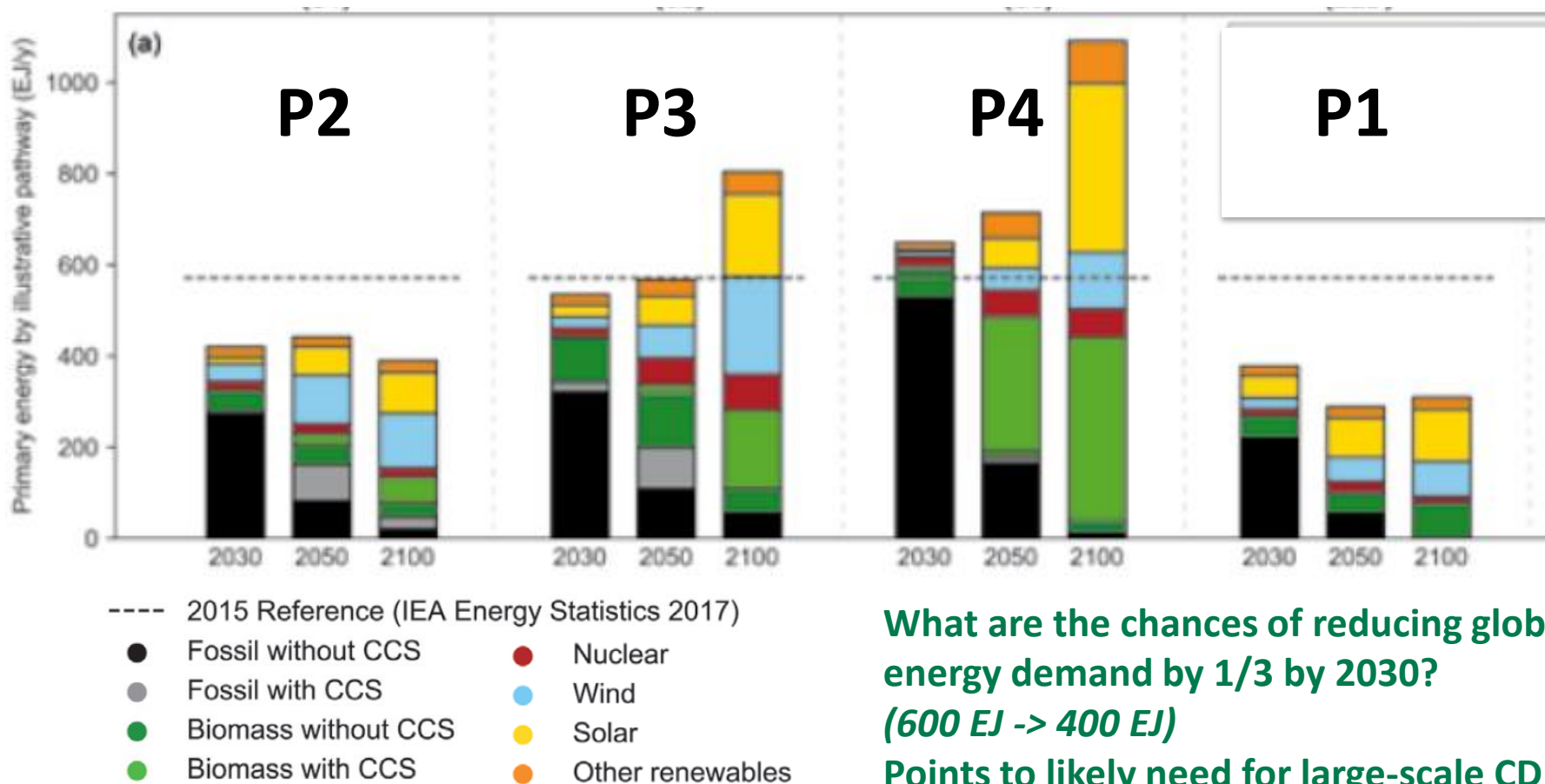
P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Renewables grow exponentially. CCS and nuclear play key roles.

P1 and P2: primary energy decreases from ~600 EJ/yr to ~400 EJ/yr by 2030

P3: slight decrease by 2030; back to ~600 EJ/yr by 2050.

P4: slow growth through 2050



Storage of 12 hours of load can balance daily variation in solar, and the storage can be cycled nearly every day.

VARIABLE OUTPUT: DAILY, SEASONAL, AND “UH-OH’S”...

“dunkelflaute”
dark doldrums

