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DECARBONIZATION PATHWAYS TO MEET OUR CLIMATE IMPERATIVE

2022 NASEO ENERGY POLICY OUTLOOK CONFERENCE

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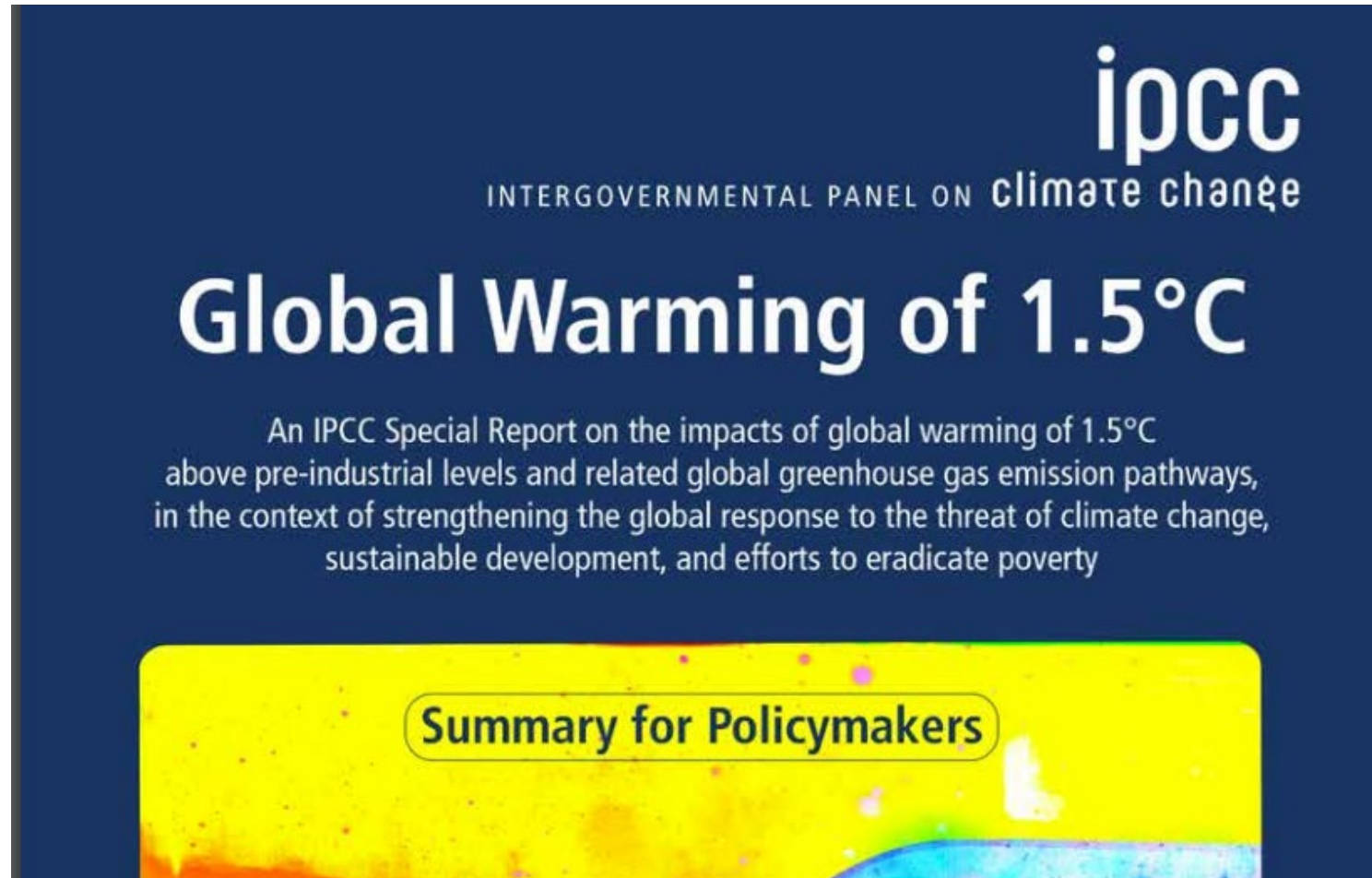
FEBRUARY 9, 2022

TOPICS

- The net-zero emissions challenge: the IPCC perspective
- Five key strategies to achieve net-zero GHG emissions
 - 1] Efficiency
 - 2] Electrification,
 - 3] Clean electricity
 - 4] Carbon capture
 - 5] *reduce non-CO2 gases*
- Illustration: new U.S. Long-Term Strategy (Nov. 2021)
- Clean electricity:
 - Why not 100% renewable electricity?
 - Focus on system costs, not LCOE
- Carbon capture: the imperative
 - And dissenting views
- Betting on climate solutions:
 - The case for “spreading our chips” at the casino...

*See web links
throughout*

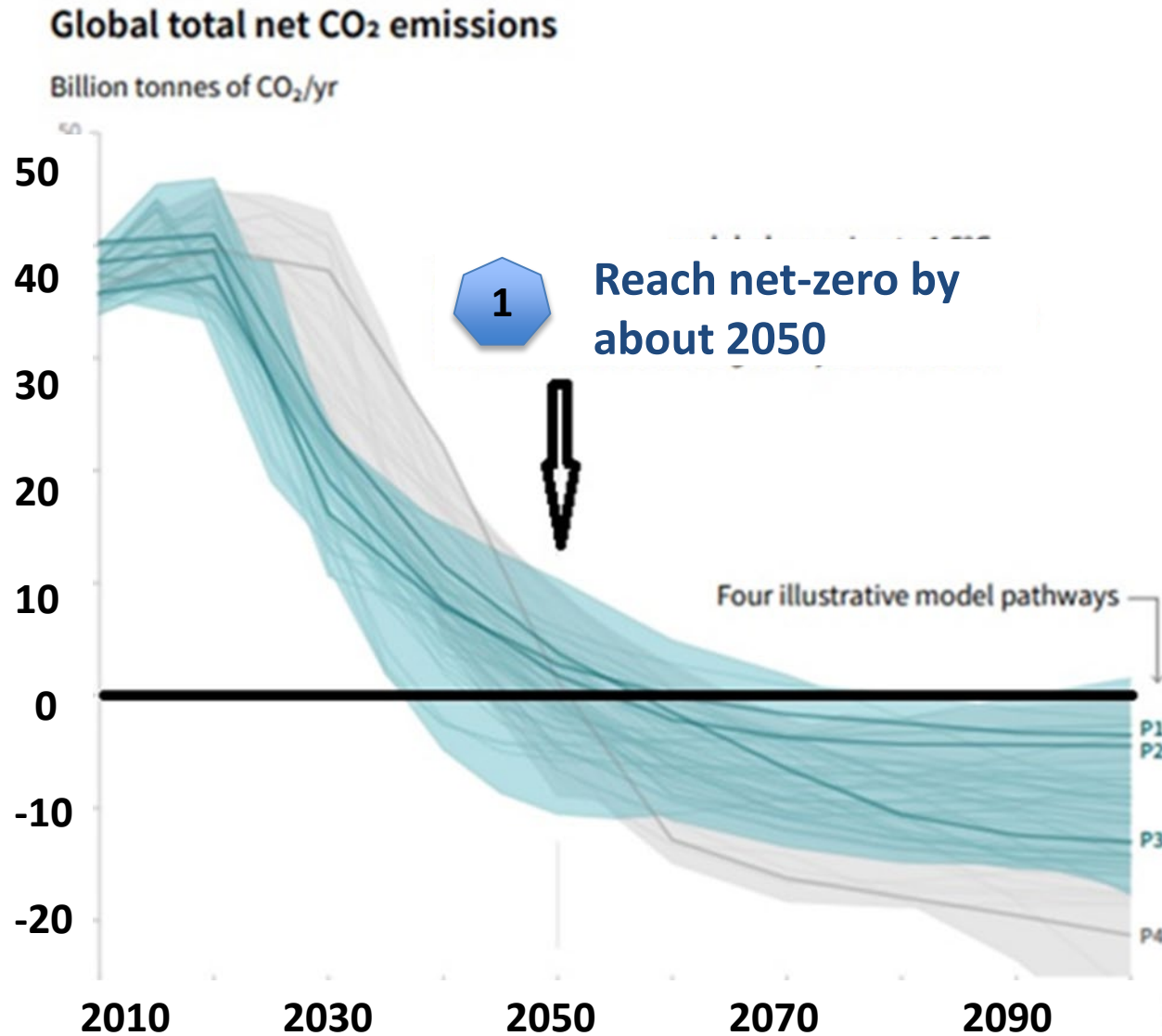
IPCC REPORT RELEASED IN OCT. 2018 LAYS OUT GLOBAL PATHWAYS TO A SAFE CLIMATE



Updates coming soon in Sixth Assessment Report (AR6):

- Science report (WG1) released August 2021
- Impacts report (WG2) & Mitigation report (WG3) to be released in 2022.

1.5°C PATHWAYS: GLOBAL EMISSION TRAJECTORIES (IPCC, 2018)



2

Emissions must steeply decline ASAP and reach net-zero by mid-century. Transformations needed across all economic sectors. Efficient policies can keep costs to 1%-2% of GDP.

3

Overshoot of safe concentrations is very likely, so “net negative emissions” will be necessary.

4

Four pathways: P1, P2, P3, P4



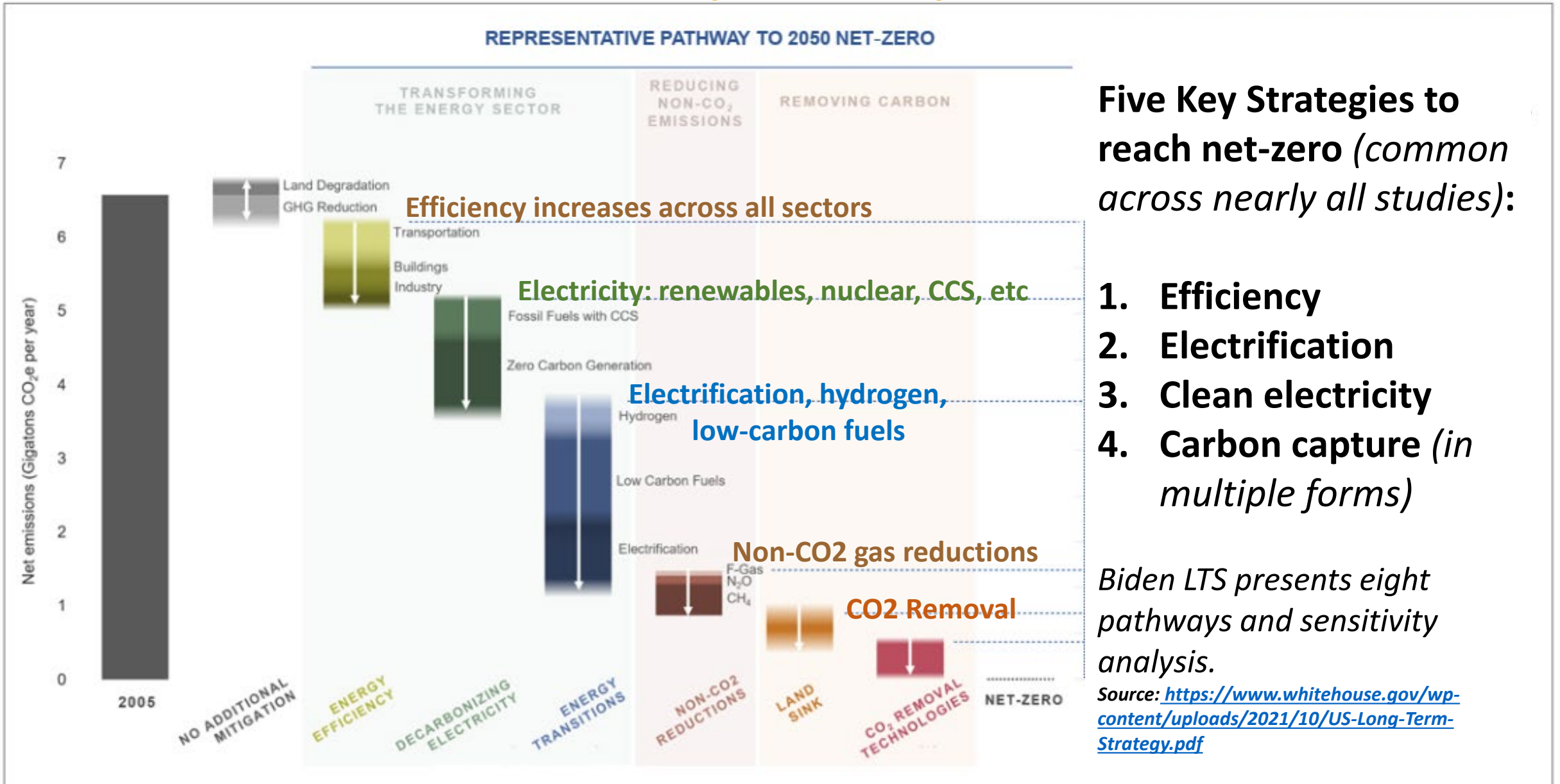
Net Zero



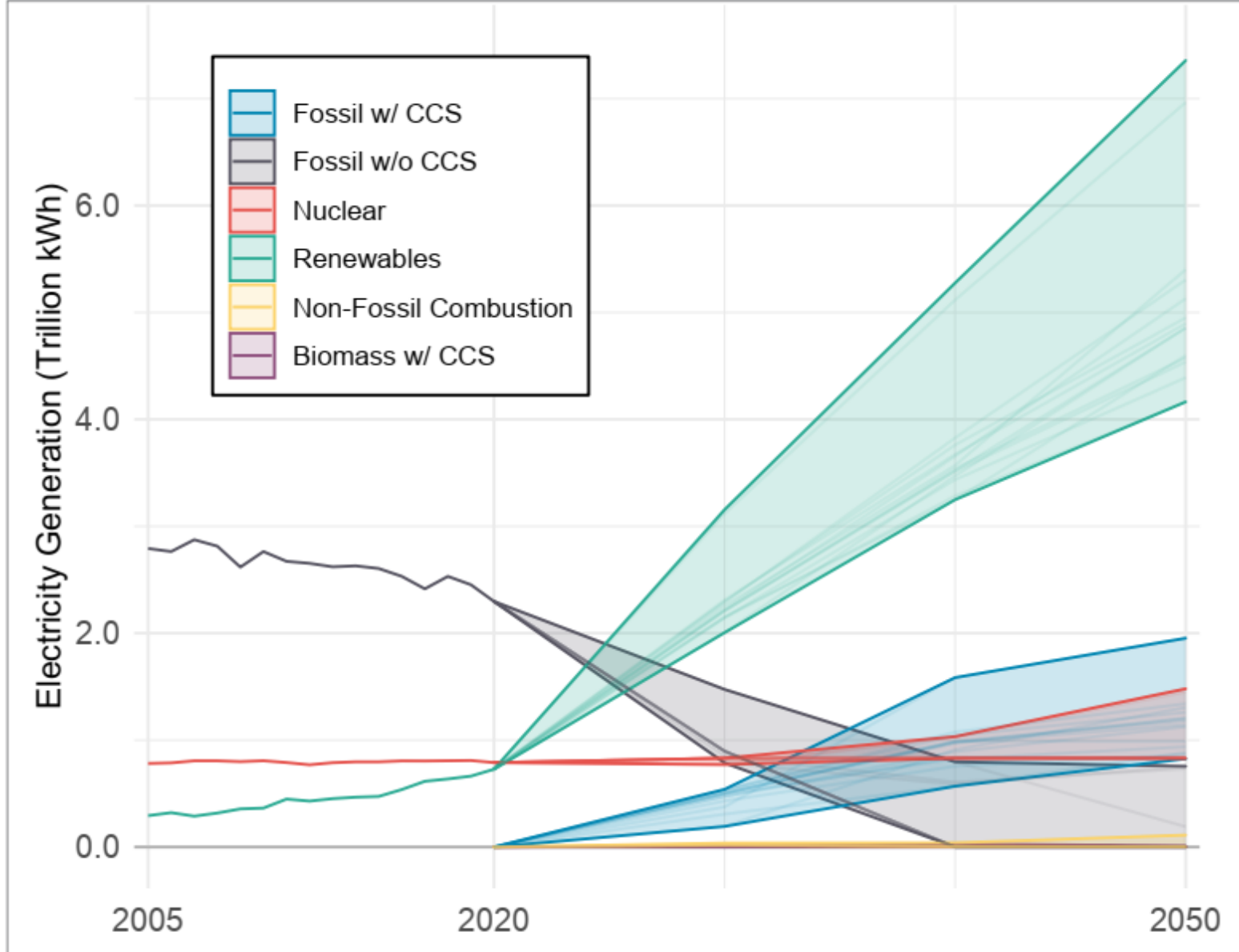
Net Negative Emissions

Requires Carbon Dioxide Removal (CDR) by nature-based and/or technological means

U.S. "LONG-TERM STRATEGY" (NOV. 2021) – PATHWAYS TO NET-ZERO



U.S. LTS: PATHWAYS TO CLEAN (ZERO-CARBON) ELECTRICITY



- Electrification: generation increases from ~4 T-kWh to ~6-11 T-kWh
- Renewables (includes hydro):
 - RE increases ~4x-7x, and accounts for ~70% of total
 - Common across credible studies (60% - 90%)
 - Reflects huge cost drops
- Renewables complemented by:
 - Nuclear, stable at <1 T-kWh or increases ~50%
 - Fossil generation with CCS provides ~1-2 T-kWh by 2050
 - Fossil generation w/out CCS drops to range of 0 - <1 T-kWh
- Hydrogen and biomass with CCS are de minimus

WHY NOT 100% RENEWABLE? CHEAP, CHEAPER, CHEAPEST?

Renewables are winning the economics battle against new coal and gas, stunning study shows

By 2030, wind and solar will "undercut existing coal and gas almost everywhere."

JOE ROMM JUN 18, 2019 1:47 PM

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Solar Costs & Wind Costs So Low They're Cheaper Than *Existing* Coal & Nuclear — Lazard **LCOE** Report

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Ad Chester County Solar Installer

SOLAR

WoodMac: Solar Plants Cheaper Than Natural Gas 'Just About Everywhere' by 2023

The days of new gas-fired plants keeping up with utility solar on a **levelized cost basis** may soon be over. But the rise of competitive renewables auctions means profits will be hard to come by, even in an expanding market.

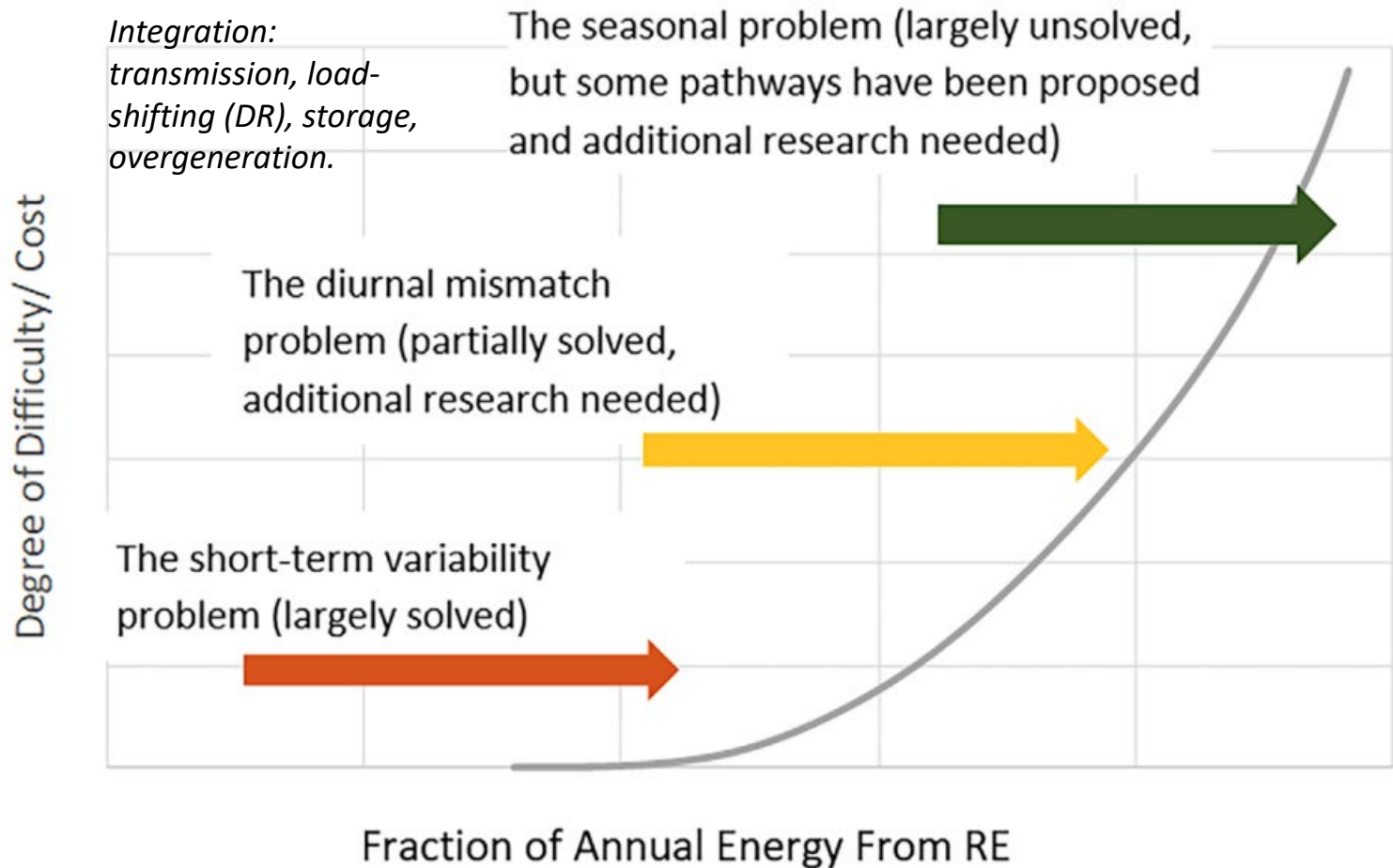
KARL-ERIK STROMSTA | MAY 14, 2019

FOCUS ON “SYSTEM COSTS”, NOT LCOE (a misused metric)

- Levelized Cost of Energy (LCOE) = average cost of a MWh from a standalone power plant.
- System cost is the average cost of a power system, including ALL plants and technologies needed to maintain a reliable grid.
- Credible modeling indicates that as a power system approaches 100% renewables, system cost will increase sharply and maintaining reliability will be more difficult.
- Widely accepted:
 - Credible net-zero studies show a generation mix of 60%-90% wind and solar in 2050
 - Nearly all states that have set a goal of a zero-carbon for their utilities define it in terms of 100% clean electricity, not 100% renewable
 - Biden Administration goal for 2035 is 100% clean electricity

NON-LINEAR NATURE OF COST AND DIFFICULTY: 16 NREL AUTHORS

The challenge of balancing supply and demand, 24/7 – Three “zones”



Zone 3: approaching 100%. Likely requires long-term storage. Must also address “dunkelflaute.”

Zone 2: up to ~80%. Likely requires storage measured in many hours, other integration steps.

Zone 1: Zero to XX%. [Currently ~20% in U.S.] Renewables are integrated at low cost; legacy dispatchable plants, batteries.

Figure 1. A simple framework for discussing the degree of difficulty and cost of increased RE deployment associated with the balance challenge

In my view...

“REQUIRED READING”-

A case for “spreading our chips”

Joule

CellPress

The challenges of achieving a 100% renewable electricity system in the United States

Paul Denholm,^{1,*} Douglas J. Arent,¹ Samuel F. Baldwin,² Daniel E. Bilello,¹ Gregory L. Brinkman,¹ Jaquelin M. Cochran,¹ Wesley J. Cole,¹ Bethany Frew,¹ Vahan Gevorgian,¹ Jenny Heeter,¹ Bri-Mathias S. Hodge,^{1,3} Benjamin Kroposki,¹ Trieu Mai,¹ Mark J. O'Malley,¹ Bryan Palmintier,¹ Daniel Steinberg,¹ and Yingchen Zhang¹

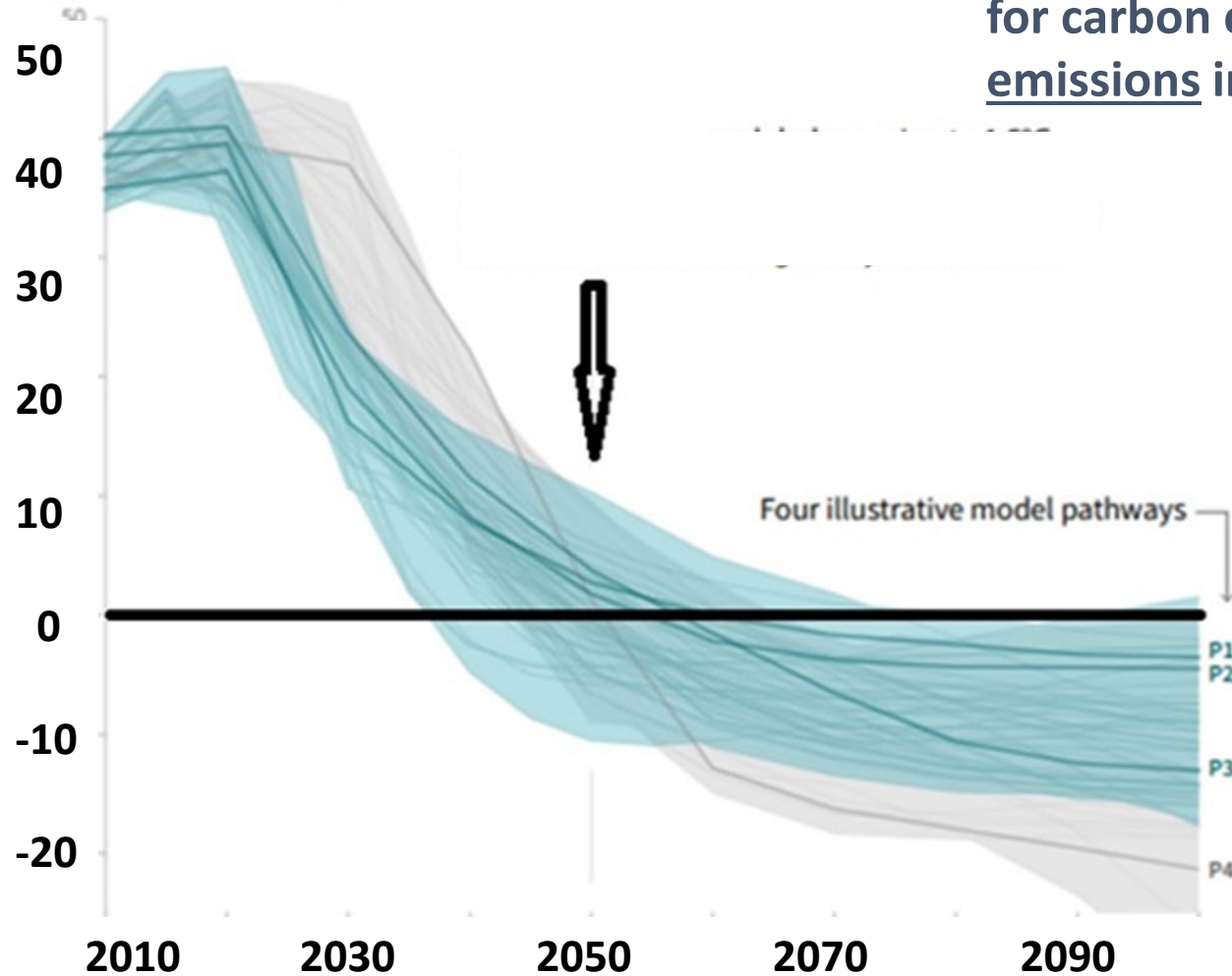
“Significant unanswered questions remain regarding moving toward or achieving 100% RE at a national scale for all hours of the year. There is no simple answer to how far we can increase RE penetration before costs rise dramatically or reliability becomes compromised.” [p.17]

“Reducing the costs of low-carbon generation in the electric sector, potentially by keeping non-RE options (including CCS and nuclear) available, enables electrifying and thus decarbonizing other sectors, reducing economy-wide carbon emissions.” [p.18]

1.5°C PATHWAYS: THE CARBON CAPTURE IMPERATIVE

Global total net CO₂ emissions

Billion tonnes of CO₂/yr



- IPCC and most credible modeling indicates likely need for carbon capture and storage (CCS) to reduce emissions in industry and/or power sector.

3 Overshoot of safe concentrations is very likely, so “net negative emissions” will be necessary.

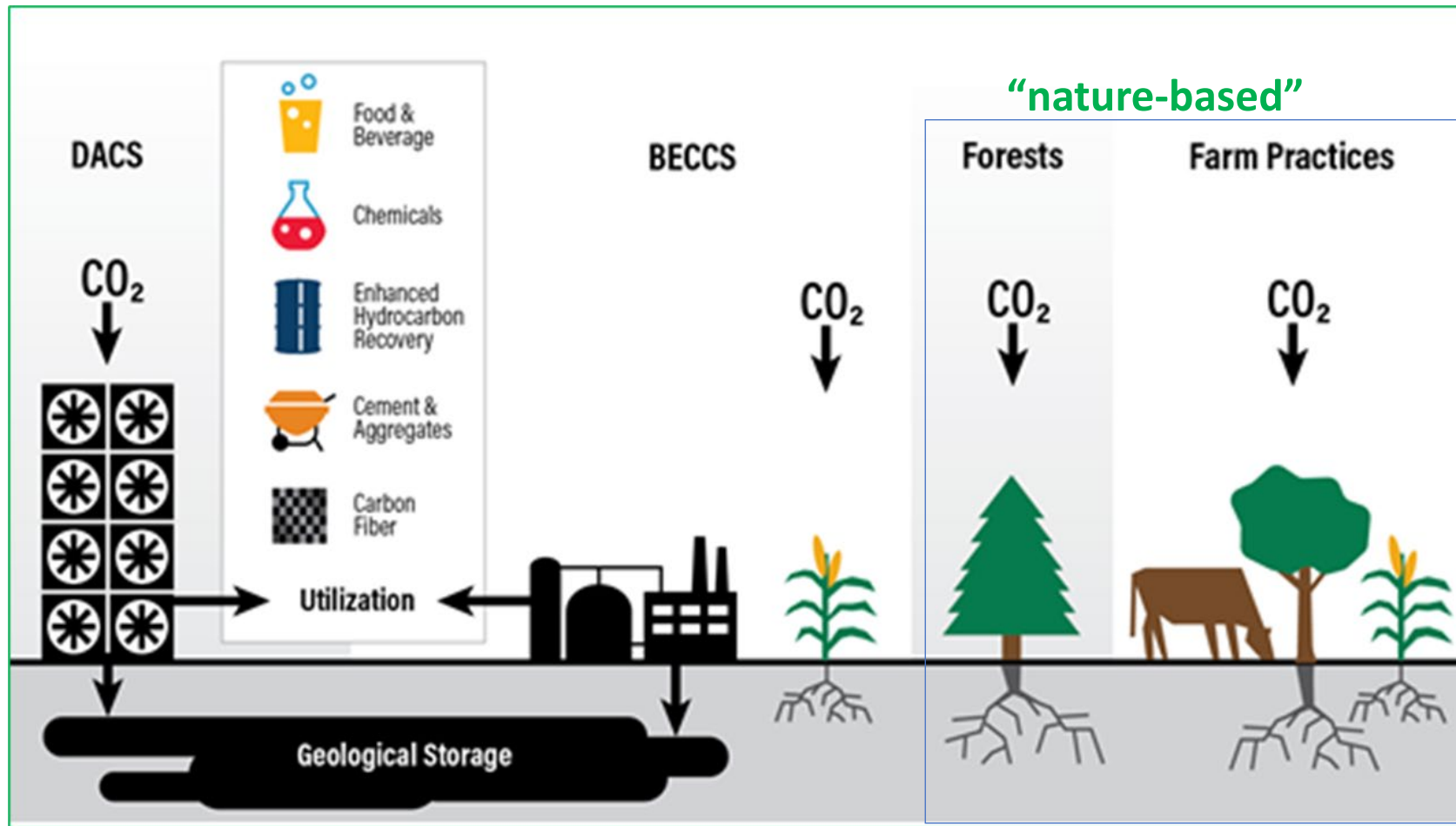
4 Four pathways: P1, P2, P3, P4

Net Zero

Net Negative Emissions

Requires Carbon Dioxide Removal (CDR) by nature-based and/or technological means

CARBON DIOXIDE REMOVAL OPTIONS



- “Nature-based”:
 - use of forests and soil management
 - Ready now
 - Large co-benefits
 - Risk of loss
- “Technology-based”:
 - Under development
 - Costs and risks uncertain
- Direct Air Capture & Storage (DACs)
- Bioenergy with Carbon Capture & Storage (BECCS), utilization strategies
- Research underway on other options

IPCC P1 might require only nature-based solutions (a few billion tons/year). However, P2, P3, and P4 could ultimately require 5, 10, 20 billion tons/year, exceeding the potential of nature-based solutions.

DISSENTING VIEWS ON THE CARBON CAPTURE IMPERATIVE



- ‘Doesn’t work’
- ‘Too expensive’
- ‘Too risky’
- ‘Prolongs dependence on fossil fuels’

The “moral hazard” question....

It’s Time to End Carbon Capture of Climate Policy *An Open Letter to US and Canadian Leaders*

On behalf of our millions of members and supporters across the United States and Canada, we call on policymakers to recognize that carbon capture and storage (CCS) is not a climate solution. It is a dangerous distraction driven by the same big polluters who created the climate emergency.



Say NO to two CO2 pipeline projects proposed in Iowa!

We want real climate solutions - not greenwashing schemes!

BETTING ON CLIMATE SOLUTIONS: SHOULD WE...

Place all our “chips” on renewables and nature-based CDR?



Are the risks of nuclear power unacceptable?
Should we “Leave It in the Ground”? No CCS?
Should technological CO2 removal be off the table?



... Or spread our chips on a broader portfolio?

MEETING THE CLIMATE IMPERATIVE: SUMMING UP ¹⁵

- Be extremely efficient
- “Electrify everything”
 - Make hydrogen and other low/zero-carbon fuels to fill niches
- Double or triple electricity generation. Convert to all zero-carbon.
 - Build out wind and solar aggressively – integration costs are still low.
 - Build more transmission, more batteries, use demand management
 - Keep existing nuclear plants operating -- if safe.
 - Create viable new nuclear, CCS, and other options, along with long-term storage. Deploy as needed.
- Commercialize carbon capture for industry and CO2 removal.
 - Capture technology, pipelines, injection sites, governance, public acceptance
- Spread your chips: need aggressive, well-designed RD&D programs with a broad portfolio of technologies.



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THANK YOU

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