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Critical Challenges. Practical Solutions.

LIFE CYCLE ANALYSIS FOR CCS AND CCUS: LESSONS LEARNED AND CHANGING PARADIGMS

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Nick Azzolina, Ph.D., Principal Hydrogeologist and Statistician

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A Few Topics to Stimulate Our Panel Discussion

- What do we know about life cycle greenhouse gas (GHG) emissions for transportation fuels and power generation when integrating CO_2 capture and storage (CCS)?
  a) Ethanol
  b) Incremental oil produced via CO_2 enhanced oil recovery (EOR)
  c) Power production from coal-fired or natural gas power plants
- How does (c) compare to alternative sources of electric power generation?
- Shortcoming of the current life cycle analysis (LCA) decision framework.
- Changing paradigms – broadening our comparative assessments.

What Do We Know About Life Cycle GHG Emissions for Transportation Fuels and Power Generation When Integrating CO_2 Capture and Storage?

For the LCA, It Is Important to Distinguish Between Dedicated and Associated CO_2 Storage

Dedicated CO_2 Storage

- Mitigation of GHG emissions is the primary purpose of underground injection.
- Storage of CO_2 in a deep saline formation.
- There are no additional products to consider in the system, which simplifies the LCA calculations.

Associated CO_2 Storage

- GHG mitigation is a secondary aspect of injection operations, typically at EOR sites.
- Storage of CO_2 in an oil reservoir incidental to the EOR process.
- *Associated storage produces incremental oil, which affects the LCA calculations because we must allocate the emission reductions to both the upstream source and the oil producer.*

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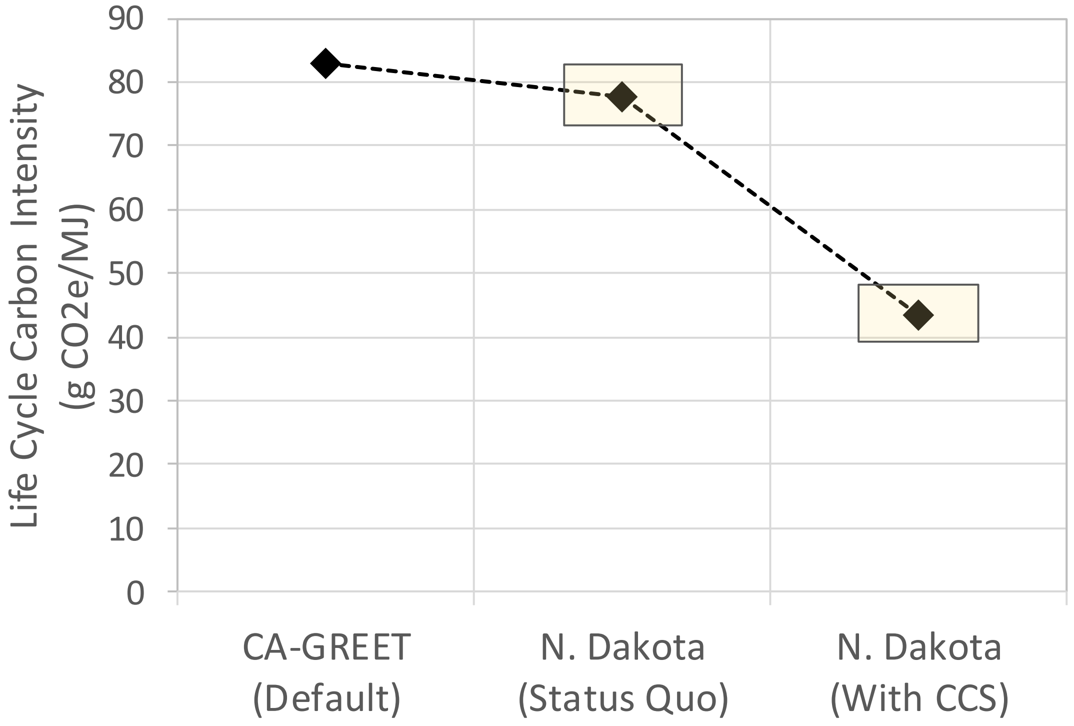
Ethanol Produced with CO_2 Capture Results in a Significant Reduction in the Ethanol Carbon Intensity

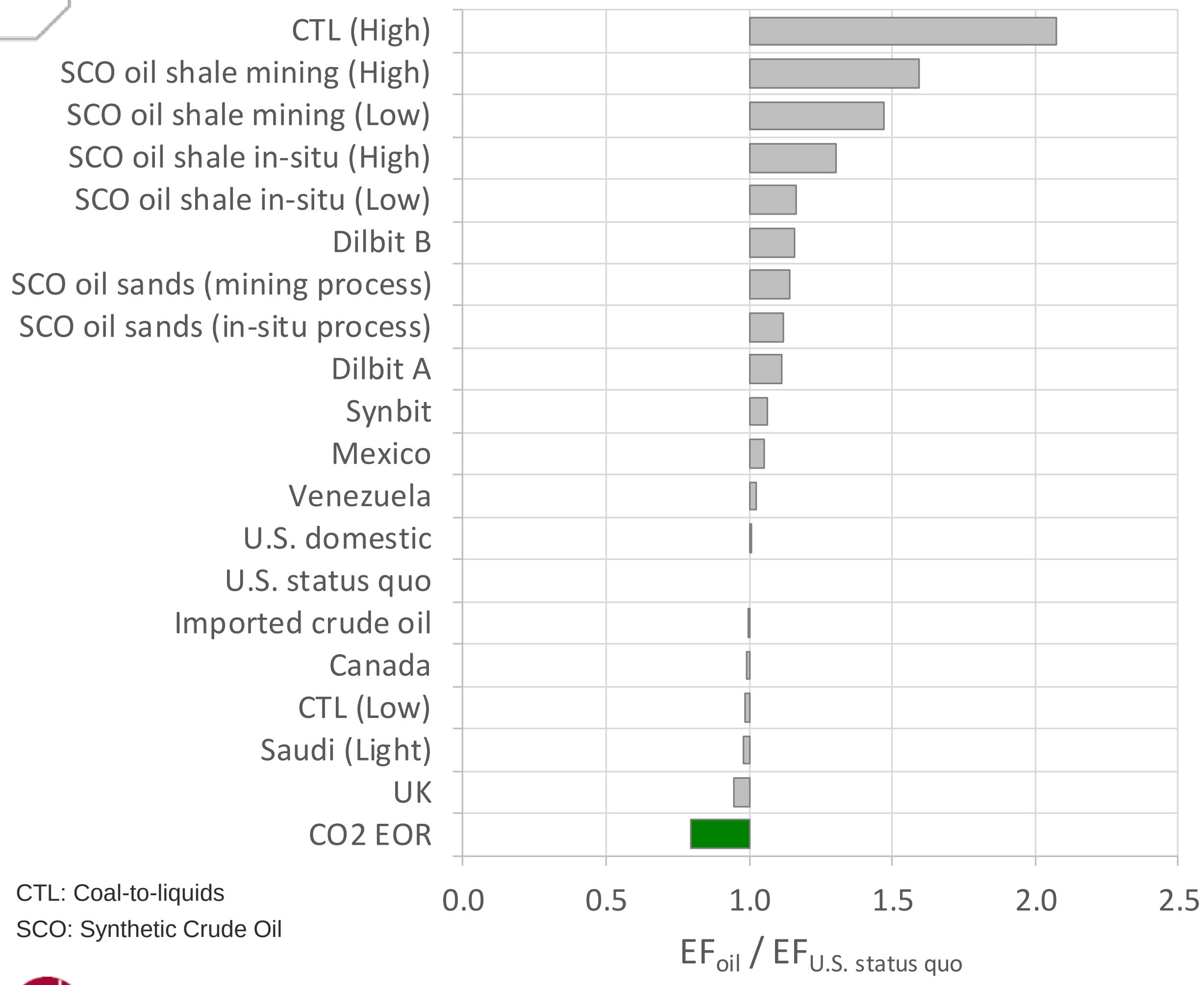


- Example of <u>dedicated</u> CO_2 storage.
- The CO_2 generated at this facility contains minimal impurities (>99% CO_2), requiring nominal processing for injection.
- An LCA showed >40% potential net reduction of CO_2 emissions for ethanol-CCS at this facility.

Adapted from:

Leroux, K.M. and others, 2017, Integrated carbon capture and storage for North Dakota ethanol production: Final Report (November 1, 2016 – May 31, 2017) for North Dakota Industrial Commission and Red Trail Energy, Grand Forks, North Dakota, Energy & Environmental Research Center, May.

CO_2 EOR with CO_2 Capture Results in a Significant Reduction in the GHG Emission Factor for Oil Production



CTL: Coal-to-liquids

SCO: Synthetic Crude Oil

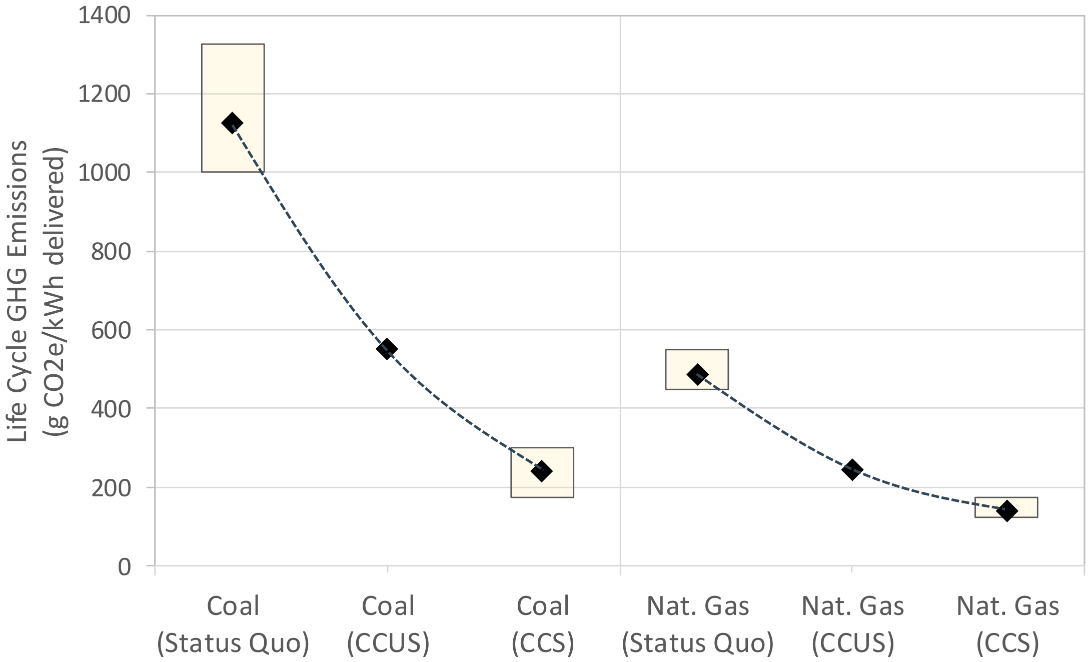
- Example of <u>associated</u> CO_2 storage.
- CO_2 captured from a lignite coal-fired power plant.
- Displace electricity from the MRO NERC Region (Midwest Reliability Organization, North American Electric Reliability Corporation), which spans the Canadian provinces of Saskatchewan and Manitoba and all or parts of the U.S. states of Illinois, Iowa, Michigan, Minnesota, Montana, Nebraska, North Dakota, South Dakota, and Wisconsin.
- **Oil via CO_2 EOR ~20% lower emission factor (EF).**

Adapted from:

Mangmeechai, A., 2009, Life cycle greenhouse gas emissions, consumptive water use and levelized costs of unconventional oil in North America: Dissertation, Pittsburgh, Pennsylvania, Carnegie Mellon University.

Azzolina, N.A., Peck, W.D., Hamling, J.A., Gorecki, C.D., Ayash, S.C., Doll, T.E., Nakles, D.V., and Melzer, L.S. How green is my oil? A detailed look at greenhouse gas accounting for CO_2-enhanced oil recovery (CO_2-EOR) sites. International Journal of Greenhouse Gas Control, v. 51, p. 369–379.

CO_2 Capture and Storage Results in a Significant Reduction in the GHG Emission Factor for Power Production



The CCUS scenarios assume displacement of crude oil. There is a strong case for displacement of natural dome CO_2 production. Under this assumption, CCUS ≈ CCS.

- Examples of <u>both</u> dedicated (CCS) and associated (CCUS) CO_2 storage.
- CCS → CO_2 stored in a deep saline formation. No coproducts.
- CCUS → CO_2 utilized for EOR, and the system produces both power and crude oil. GHG burdens are assigned to power using displacement of crude oil.

Adapted from:

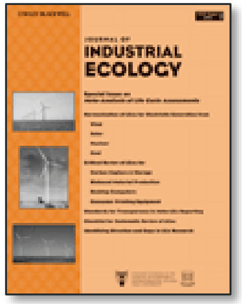
Skone, T., 2015, A life cycle analysis perspective of CCUS – goal and scope definition: Strategic Energy Analysis and Planning, International Energy Agency, London, England. November 12.

U.S. Department of Energy National Energy Technology Laboratory, 2014, Life cycle analysis of natural gas extraction and power generation: DOE/NETL-2014/1646, May 29.

How Does Power Generation with CO_2 Capture Compare to Alternative Sources of Electric Power Generation?

Good Resources for Life Cycle Assessments

- Journal of Industrial Ecology, Special Issue: Meta-Analysis of Life Cycle Assessments, April 2012, v. 16, p. S1–S205.
  - http://onlinelibrary.wiley.com/doi/10.1111/jiec.2012.16.issue-s1/issuetoc

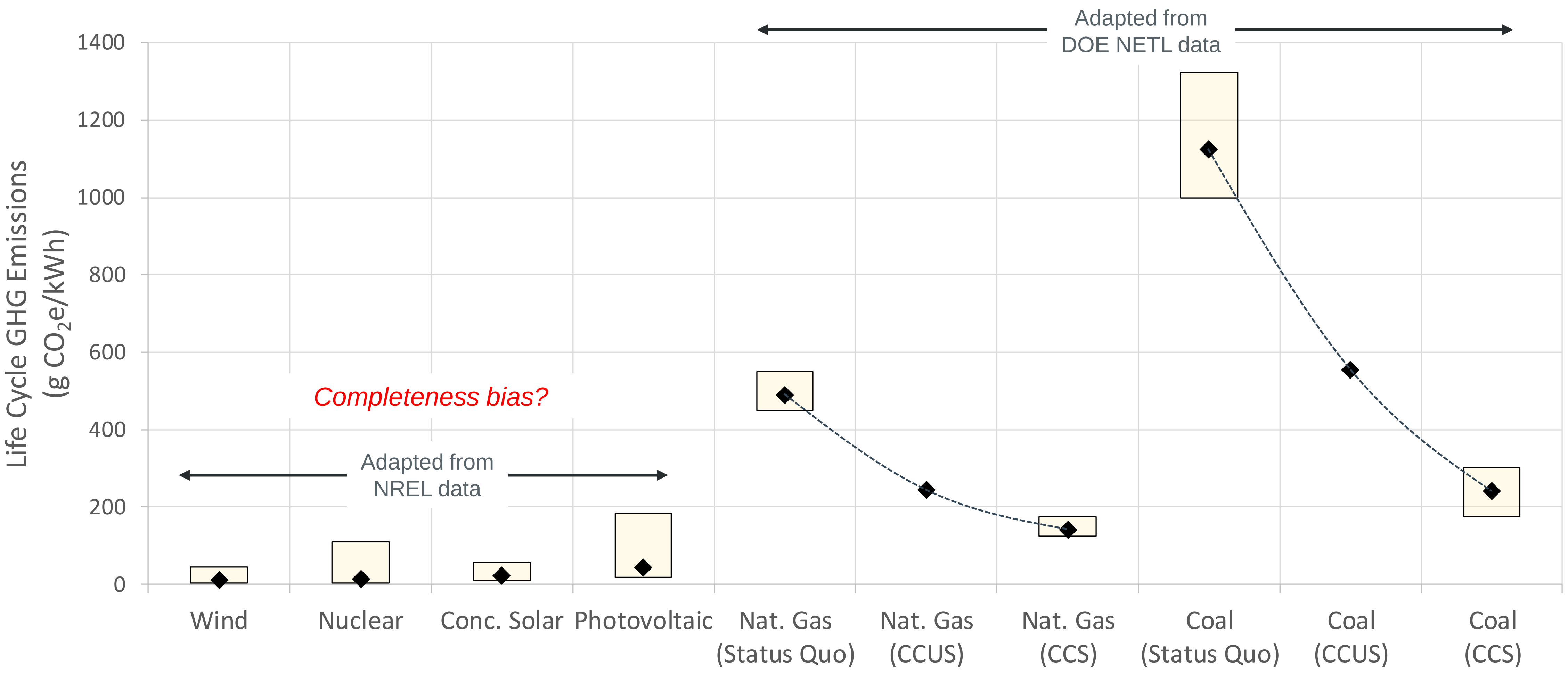


- National Renewable Energy Laboratory (NREL)
  - https://www.nrel.gov/analysis/life-cycle-assessment.html

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

- Harmonized to standardize methods, such as
  - Global warming potentials (GWPs) of methane (CH_4) and nitrous oxide (N_2O).
  - Lifetime (years).
  - Capacity factor (ratio of actual to potential electricity generation).
  - System boundary.

Life Cycle GHG Emissions for Different Sources of Electric Power Generation



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Shortcomings of the Current LCA Framework

LCA Assigns Ownership of Environmental Burdens to a Single Product (e.g., oil or electricity)

- In the current LCA framework, the sole focus is on GHG emissions.
- No other metrics are included in the analysis?! What about:
  - Supply
  - Reliability
  - Implementability
  - Cost
  - Etc.
- How can policy makers make sound decisions about investments in the energy sector when our analyses provide them with woefully incomplete information?

Changing Paradigms –
Broadening Our Comparative Assessments

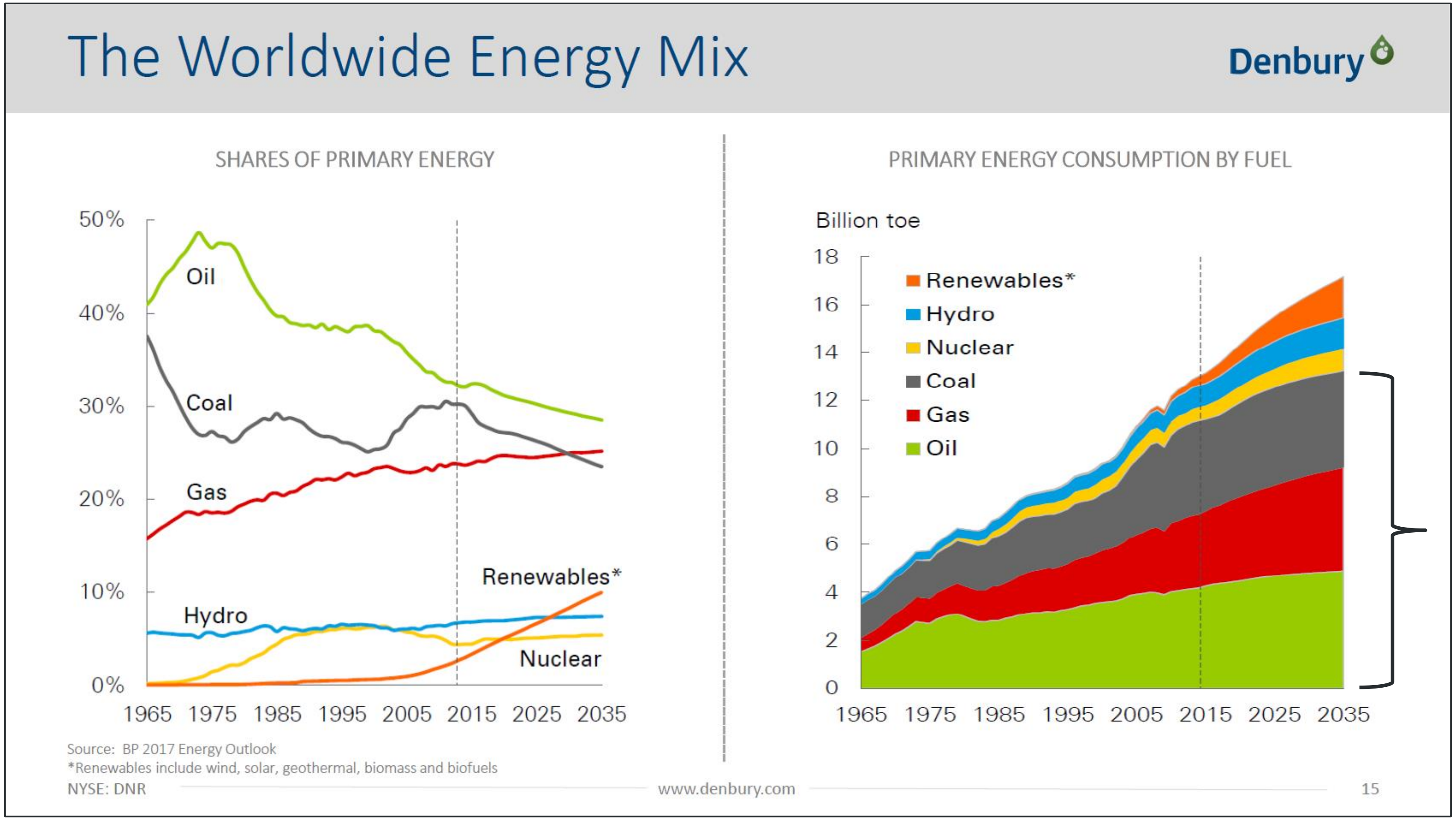
Broader Assessments that Account for Multiple Components Are Needed to Guide Data-Driven Decision Making

- We have sufficient data and tools to derive accurate LCAs of GHG emission for various sources of electric power and transportation fuels.
- We lack sufficient data and tools to integrate multiple factors such as supply, reliability, implementability, and cost into a more comprehensive evaluation.
- A multimetric index is needed, which will provide the type of information required to appropriately plan and prioritize investments in energy over the next half-century.
- For example:

Index = GHGs + Supply + Reliability + Implementability + Cost

The current LCA approach treats these terms as zeros.

Primary Energy Consumption of Oil, Gas, and Coal Must Increase to Meet Growing Energy Demand



Must increase to meet growing energy demand

Summary and Conclusions

- LCAs show that CCUS implemented in an electric power–crude oil system generates both products (electricity and crude oil) with lower GHG emissions. However, even with CO_2 capture, alternative sources of electric power like wind, nuclear, and concentrated solar will likely have lower-life-cycle GHG emissions.
- The current LCA framework, which focuses on GHGs as the sole metric for comparison across sources of primary energy, fails to account for a multitude of factors that should influence our policy decision making. Consequently, the current LCA framework is of limited utility to plan and prioritize investments over the next half-century.
- A broader comparative assessment is needed that integrates multiple factors such as supply, reliability, implementability, and cost, in addition to GHGs, into a more comprehensive evaluation.

CONTACT INFORMATION

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
www.undeerc.org

Nick Azzolina
Principal Hydrogeologist and Statistician
nazzolina@undeerc.org
701.777.5120

Charlie Gorecki
Director of Subsurface R&D
cgorecki@undeerc.org
701.777.5355

THANK YOU!

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