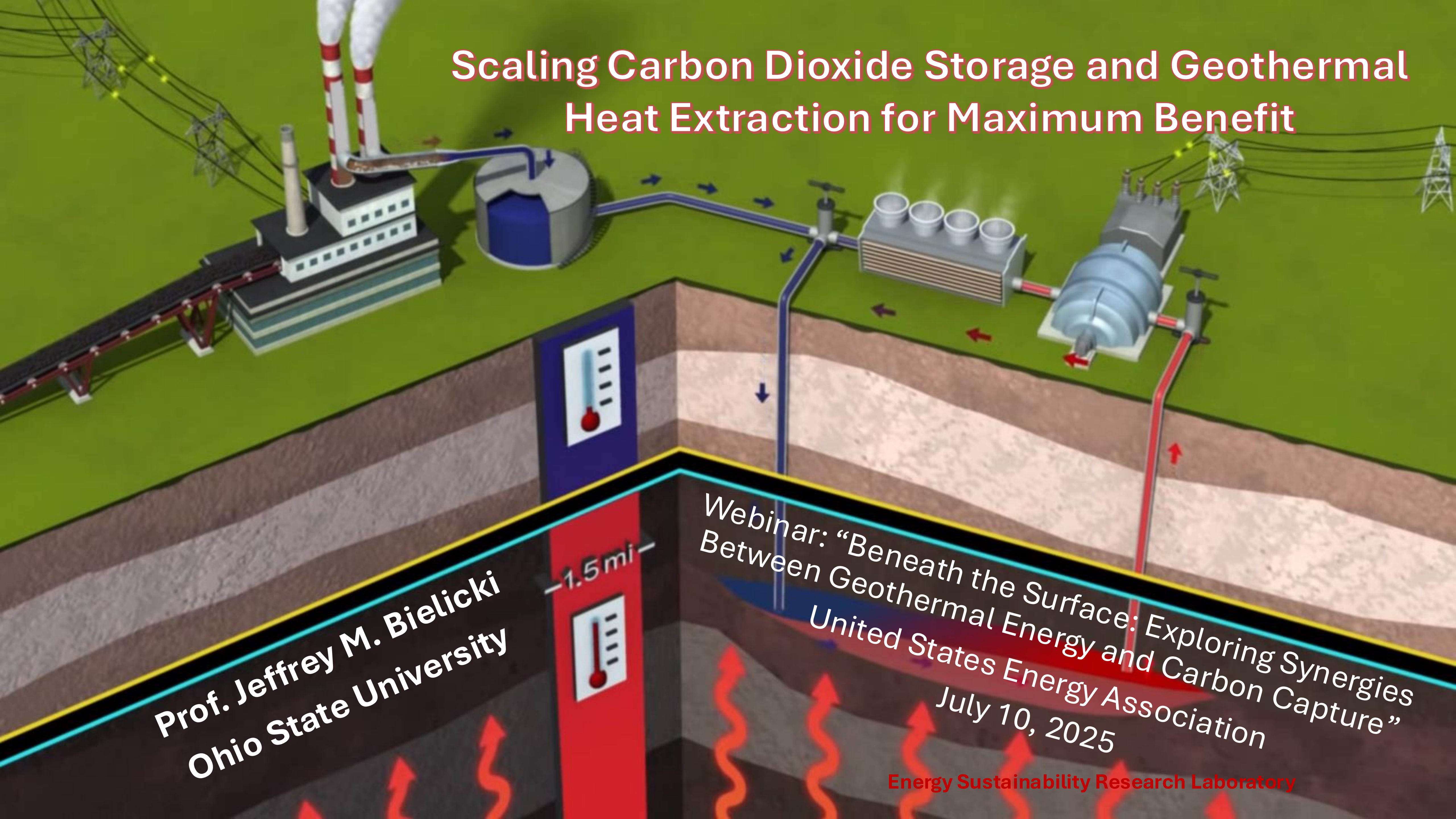
Scaling Carbon Dioxide Storage and Geothermal Heat Extraction for Maximum Benefit



Prof. Jeffrey M. Bielicki
Ohio State University

Webinar: “Beneath the Surface: Exploring Synergies Between Geothermal Energy and Carbon Capture”
United States Energy Association
July 10, 2025

Energy Sustainability Research Laboratory

A Little History and Background…
About Me

Associate Professor at Ohio State University

I direct this:

Ohio State EmPOWERment Program

A comprehensive interdisciplinary training experience in sustainable energy systems

Ohio State students completing a PhD program in any energy-related field are welcome to apply.

LEARN MORE ABOUT EMPOWERMENT

I run that…

I lead this other thing…

SUSTAINABLE ENERGY

Developing the technologies, infrastructure, institutions and behaviors needed to transition energy systems toward improved energy efficiency, a greater mix of renewable resources and an affordable, resilient and reliable power grid

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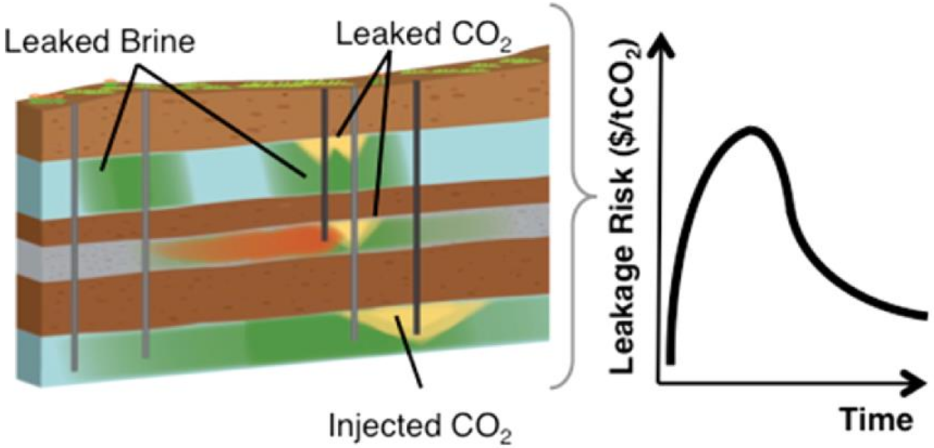
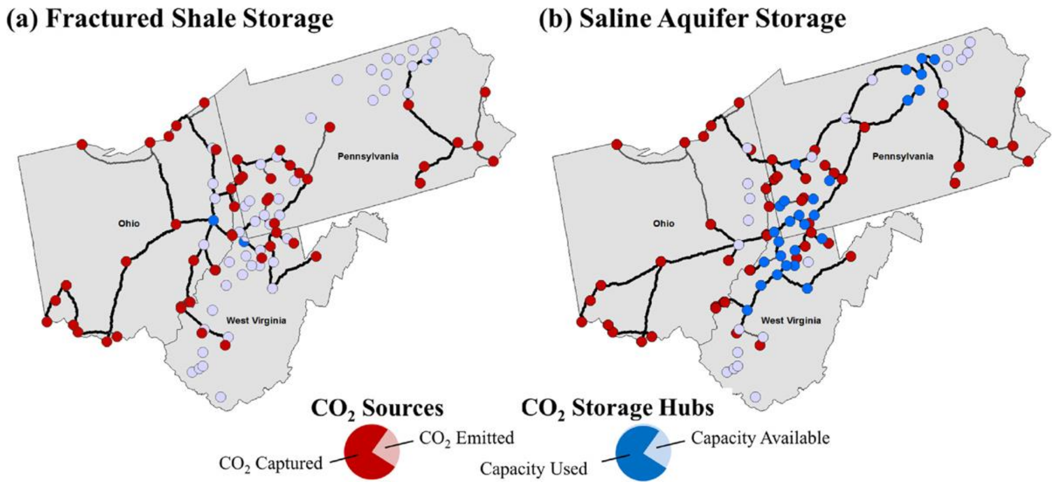
A Little History and Background…
About My Work



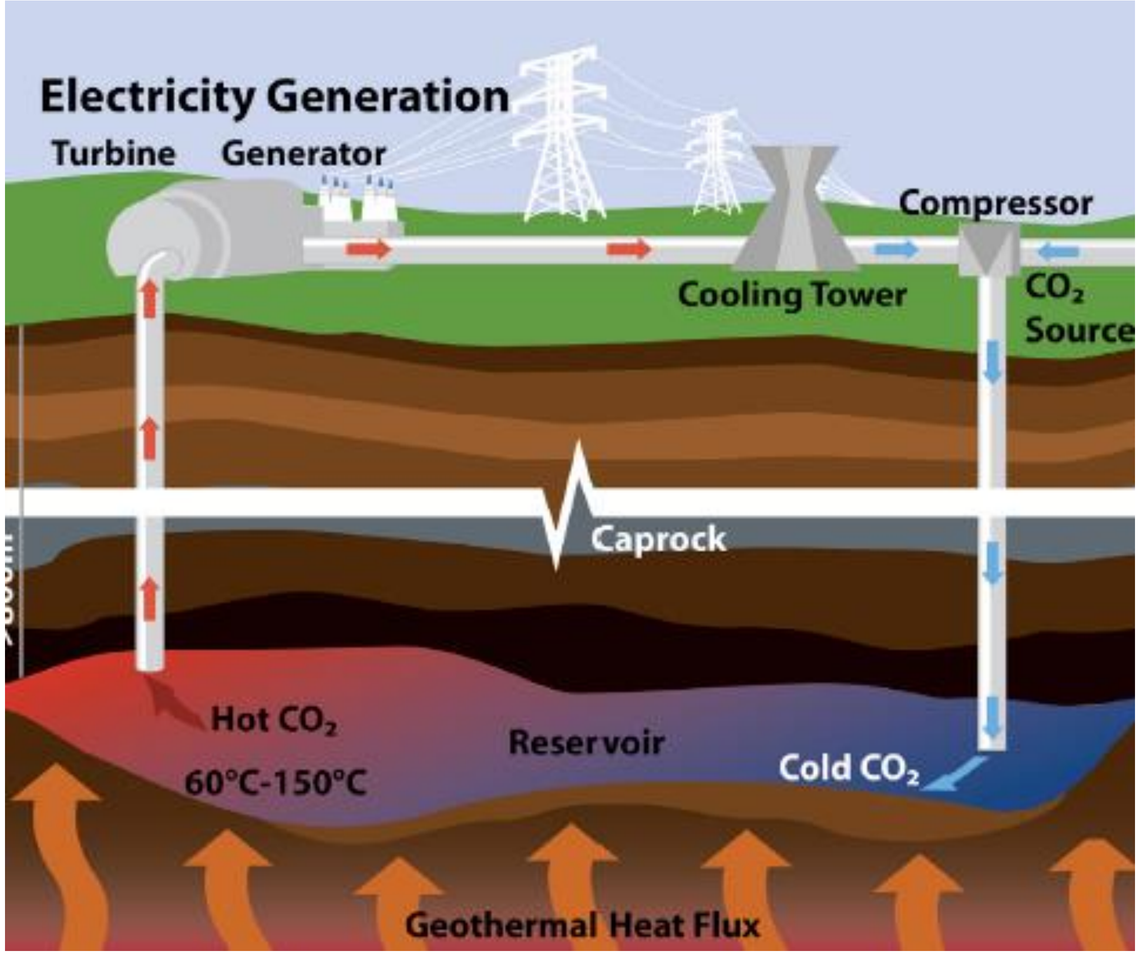


Various aspects of <u>Reservoir-Scale and Systems-Level Research</u> on:

- Carbon Dioxide Capture and Geologic Storage (since 2005)

Bielicki et al., (2016); Bielicki et al., (2018); Bielicki et al., (2023)

A Little History and Background… About My Relevant Work

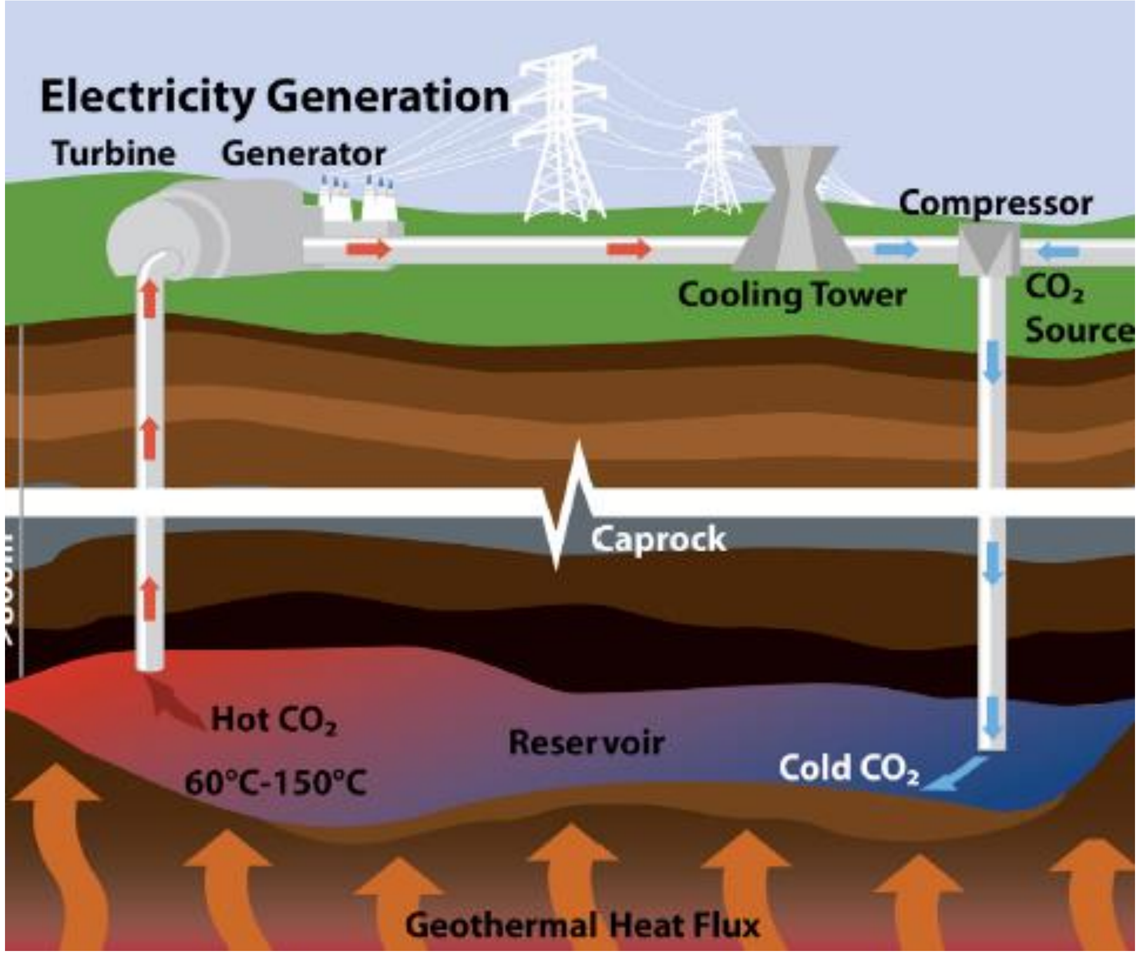


Various aspects of <u>Reservoir-Scale and Systems-Level Research</u> on:

- Carbon Dioxide Capture and Geologic Storage (since 2005)
- **Utilization** – beneficial use of emplaced CO_2 (since 2010)

Bielicki et al., (2016); Bielicki et al., (2018); Bielicki et al., (2023)

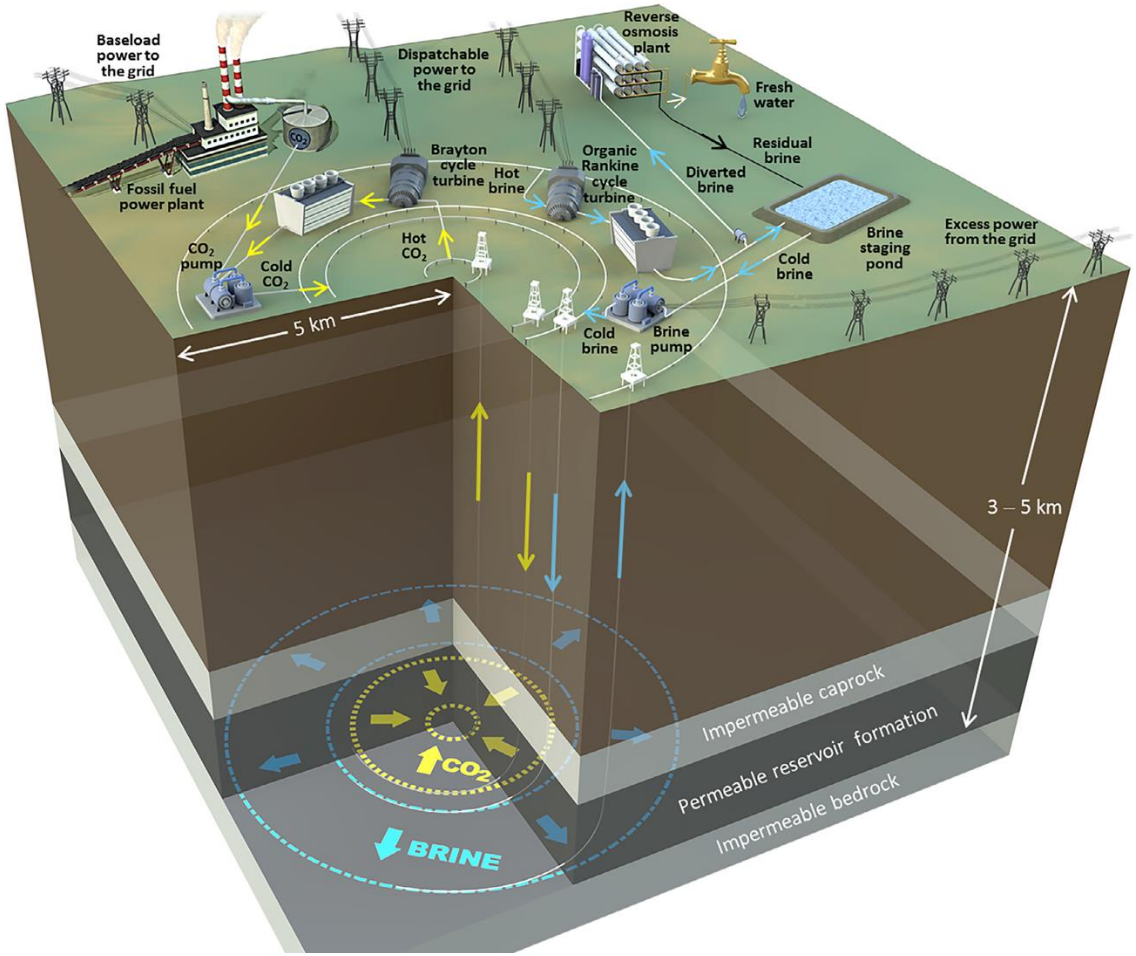
Three Main Utilization Approaches Will Underlie My Remarks



Carbon Dioxide Plume Geothermal (CPG) circulating emplaced CO_2 in sedimentary basin geothermal resources to extract geothermal heat.

Bielicki et al., (2023)

Three Main Utilization Approaches Will Underlie My Remarks



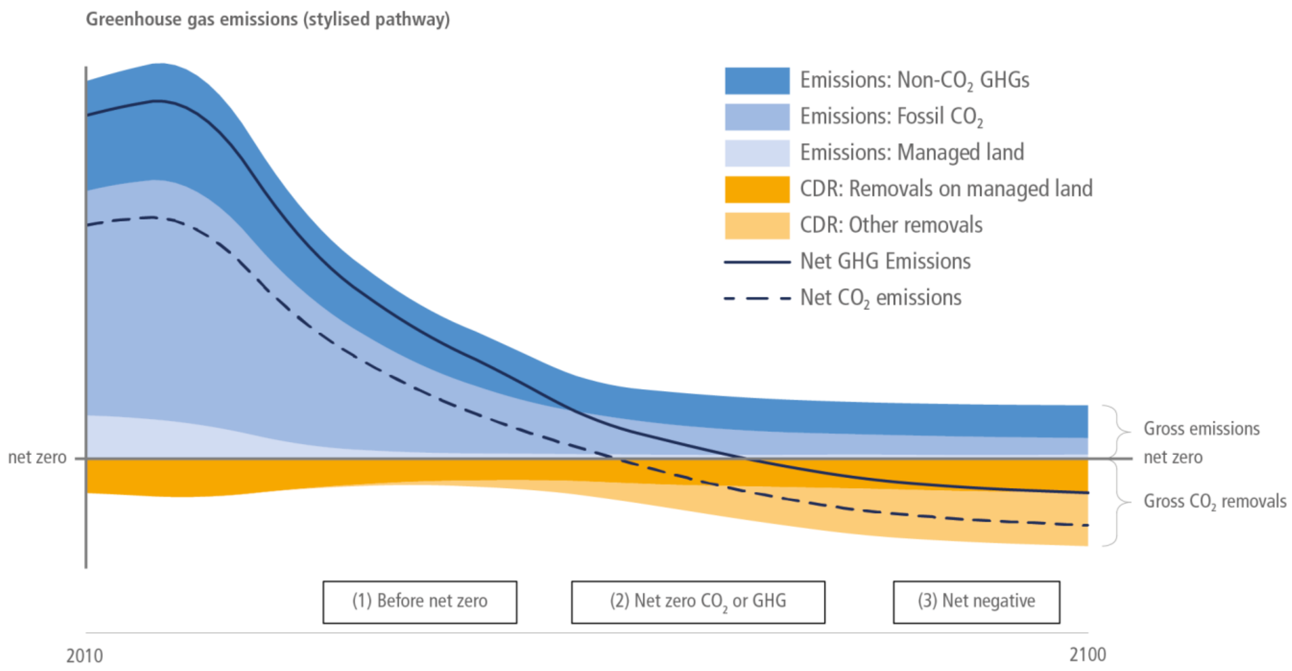
Carbon Dioxide Plume Geothermal (CPG)
circulating emplaced CO_2 in sedimentary basin geothermal resources to extract geothermal heat.

CO_2 Bulk Energy Storage

using emplaced CO_2 to store energy (e.g., pressure) and later produce stored, often with brine management as well.

Buscheck et al., (2016)

Three Main Utilization Approaches Will Underlie My Remarks



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Negative Emissions

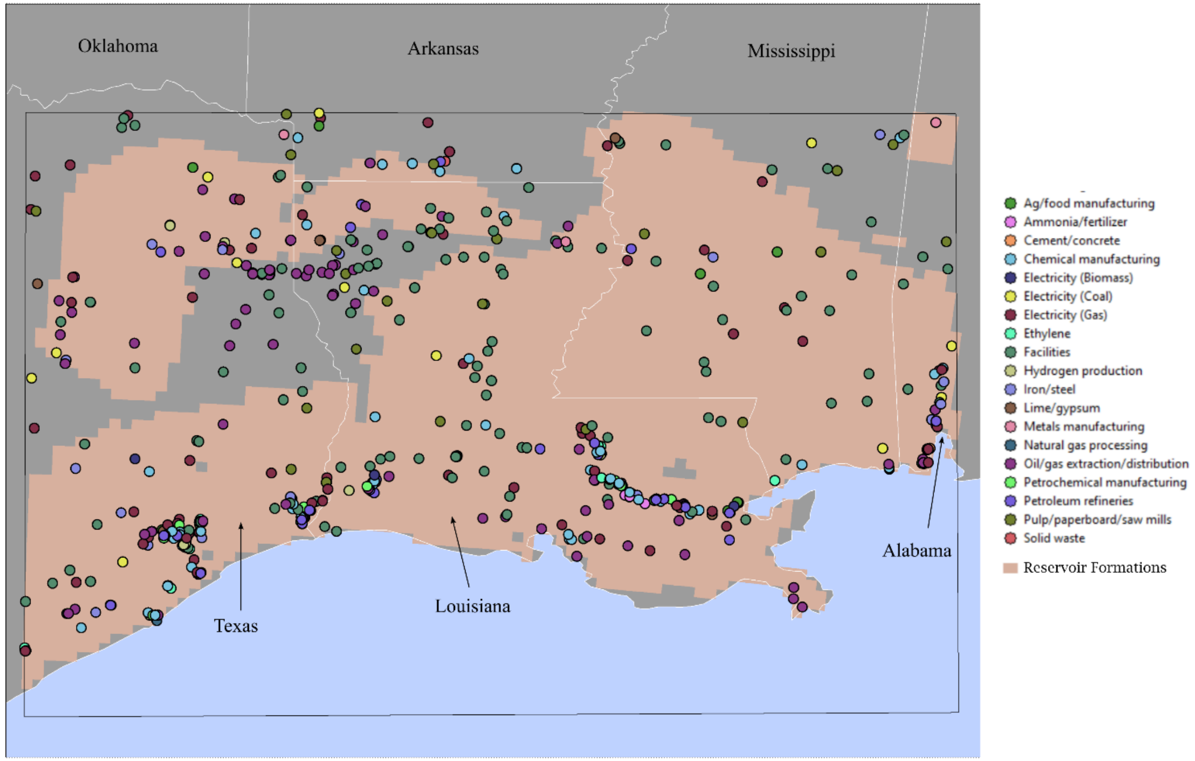
net removal of CO_2 from the atmosphere

IPCC (2022)

Systems-Level Perspective Require Matching CO_2 Sources with Prospective Locations for Geologic CO_2 Storage and Geothermal Heat Mining

Geospatial Considerations at Regional Scale:

- U.S. Gulf Coast Region
- Points = Various CO_2 Sources*
- Tan Shading = Deep Saline Aquifers for Geologic CO_2 Storage



*See Jonathan Ogland-Hand's presentation involving SCO_2T and CO_2NCORD

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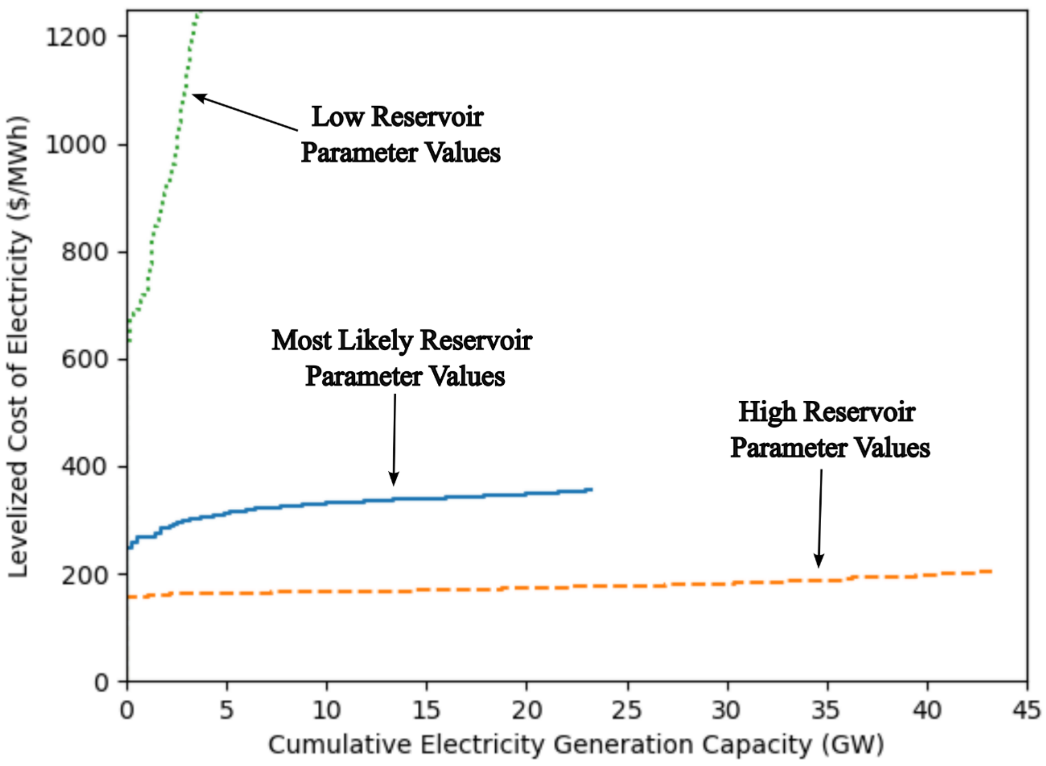
Miranda (2023)

The Subsurface is Opaque and Reservoir Characteristics are Uncertain



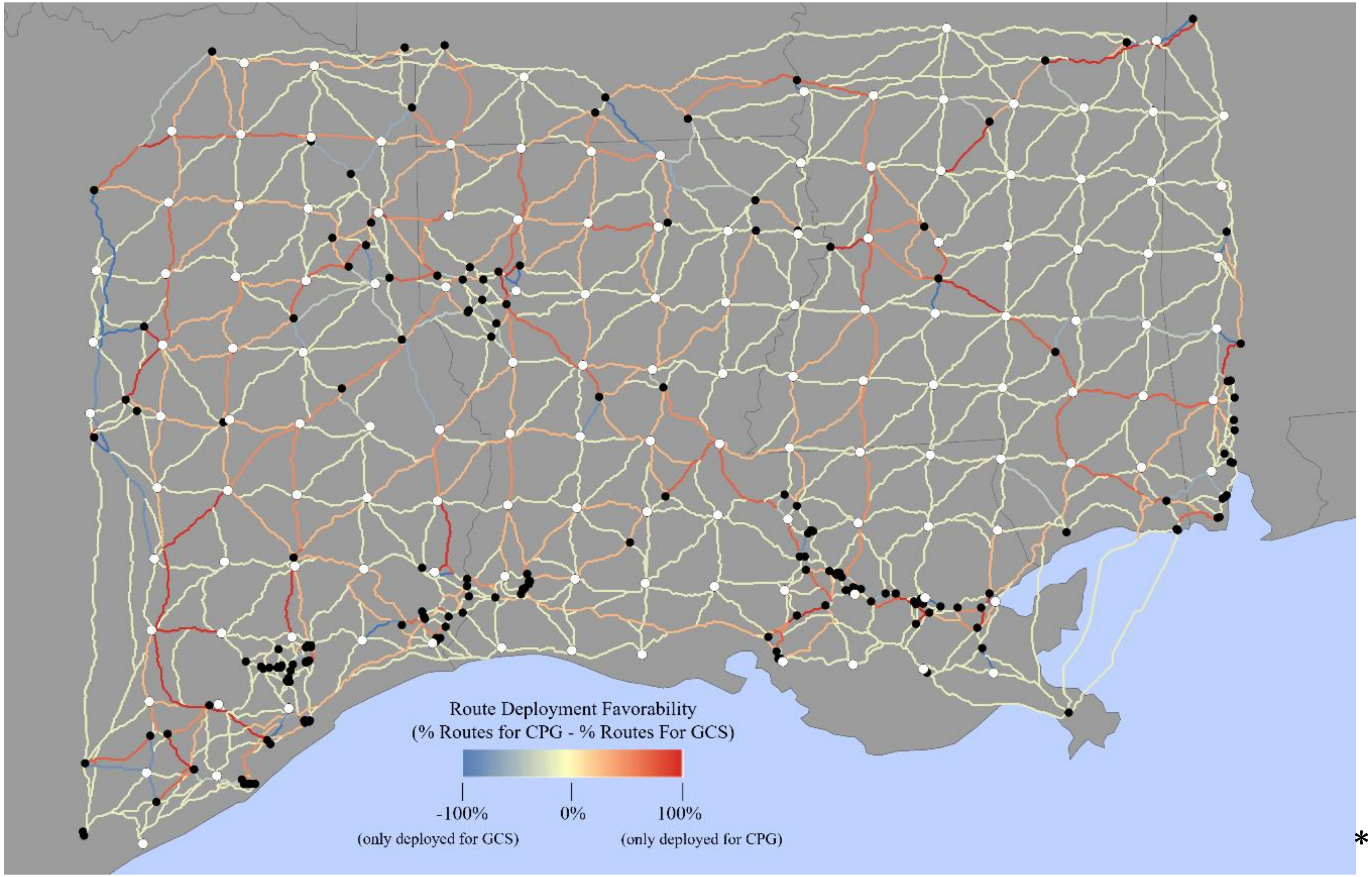
Reservoir Uncertainty Affects CPG Cost and Capacity

- Early estimates* of CPG Electricity Generating Capacity in the U.S. Gulf Coast

*See Jonathan Ogland-Hand's presentation involving SCO_2T and CO_2NCORD

Miranda (2023)

Reservoir Uncertainty Affects Desired Pipeline Routes*



*Using $SimCCS^{PRO}$ model

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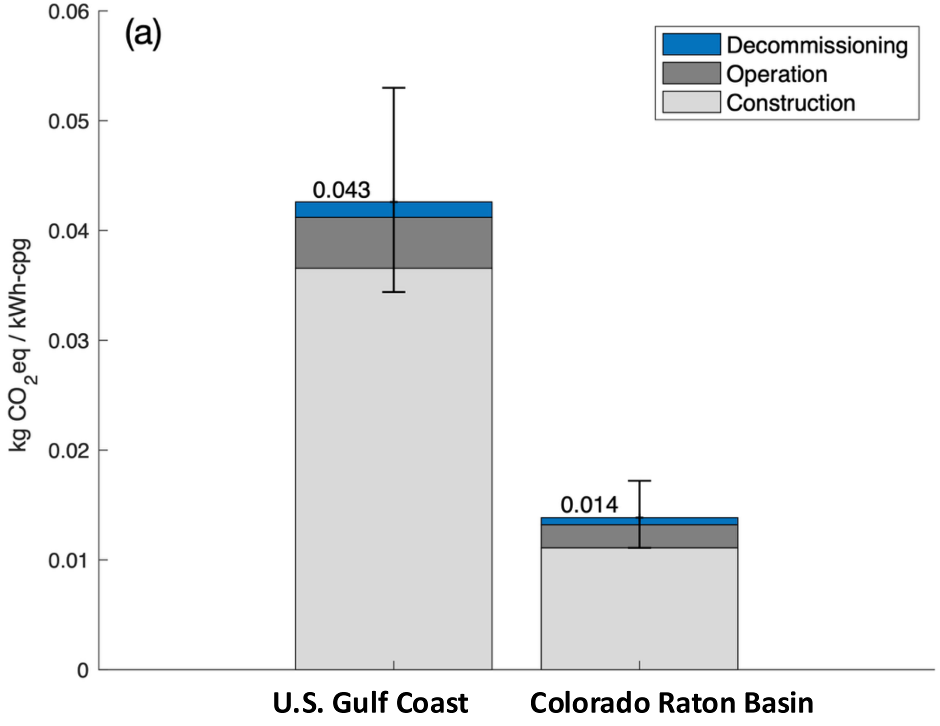
*[e.g., Middleton and Bielicki (2019), Middleton et al. (2020)]; Miranda (2023)

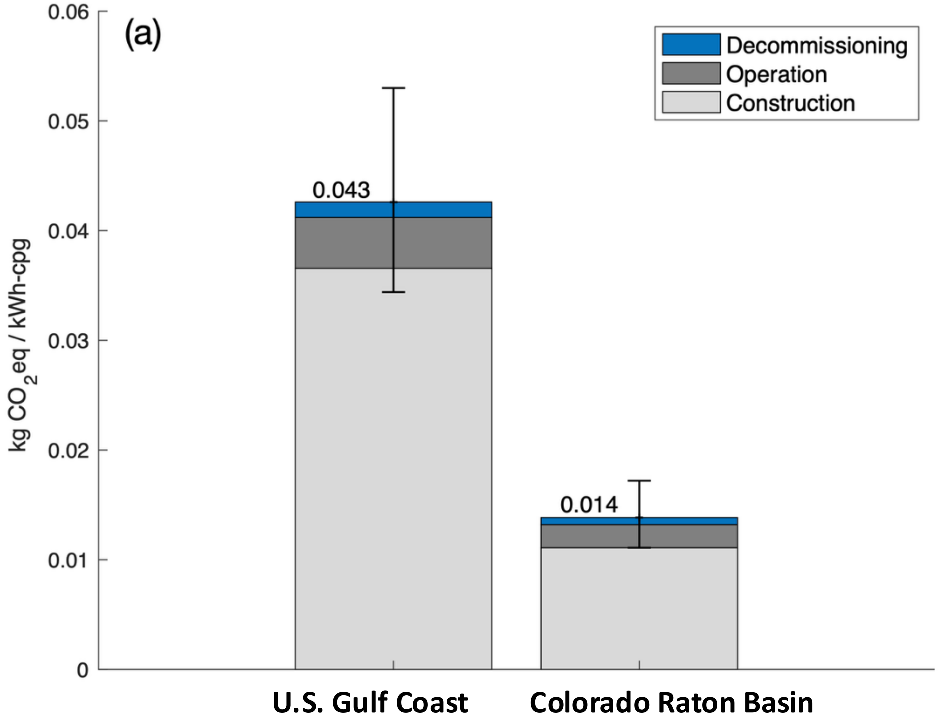
Of Course, We Need to Consider CO_2 Emissions Throughout the Lifetime and Supply Chain



Lifecycle Stages

Liu et al., (2024)

Of Course, We Need to Consider CO_2 Emissions Throughout the Lifetime and Supply Chain



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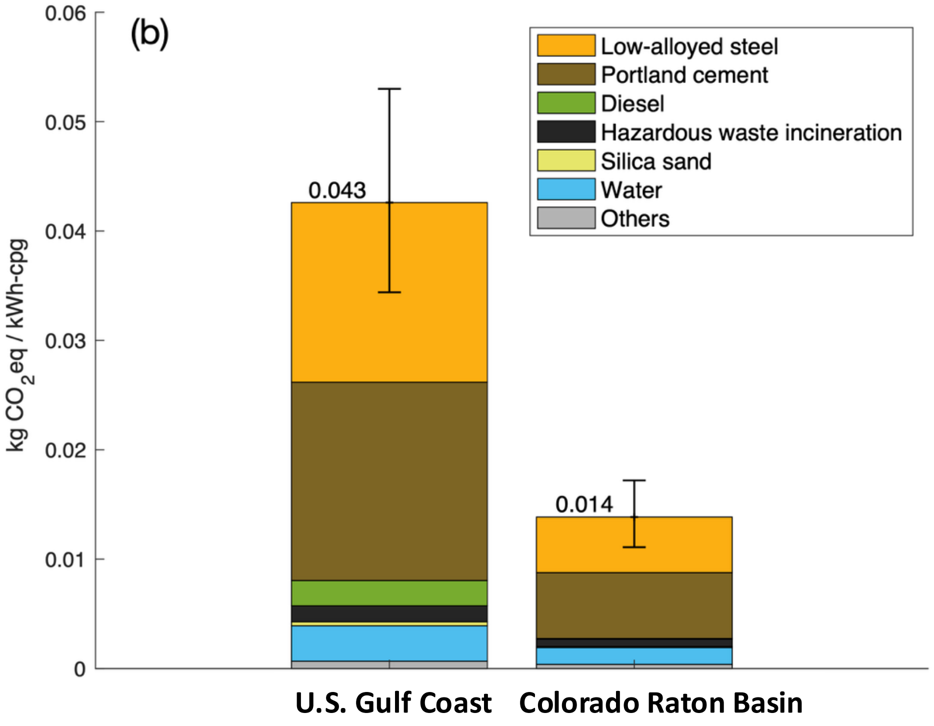
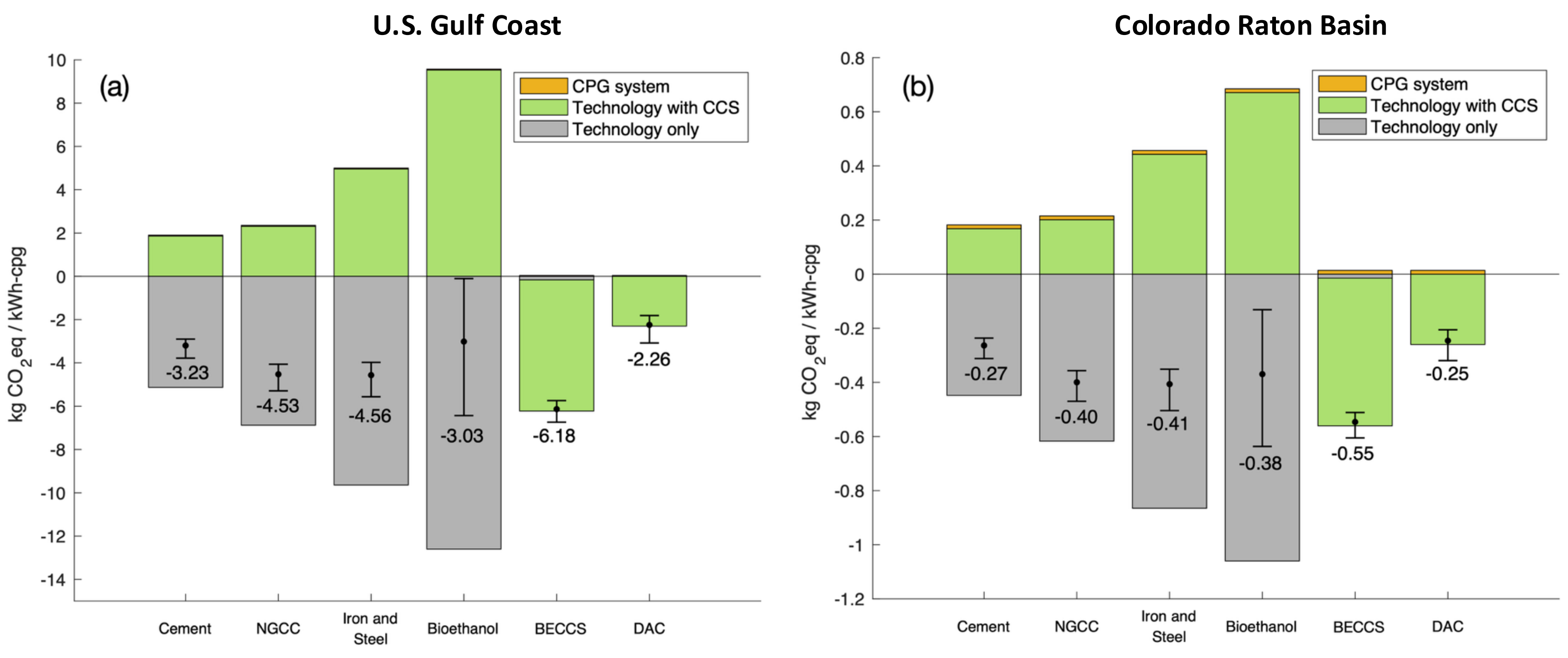


Material and Energy Contributions

Location, Location, Location: Reservoir Parameters and Geothermal Resource Matter!!!

Liu et al., (2024)

There is Potential for Negative Emissions



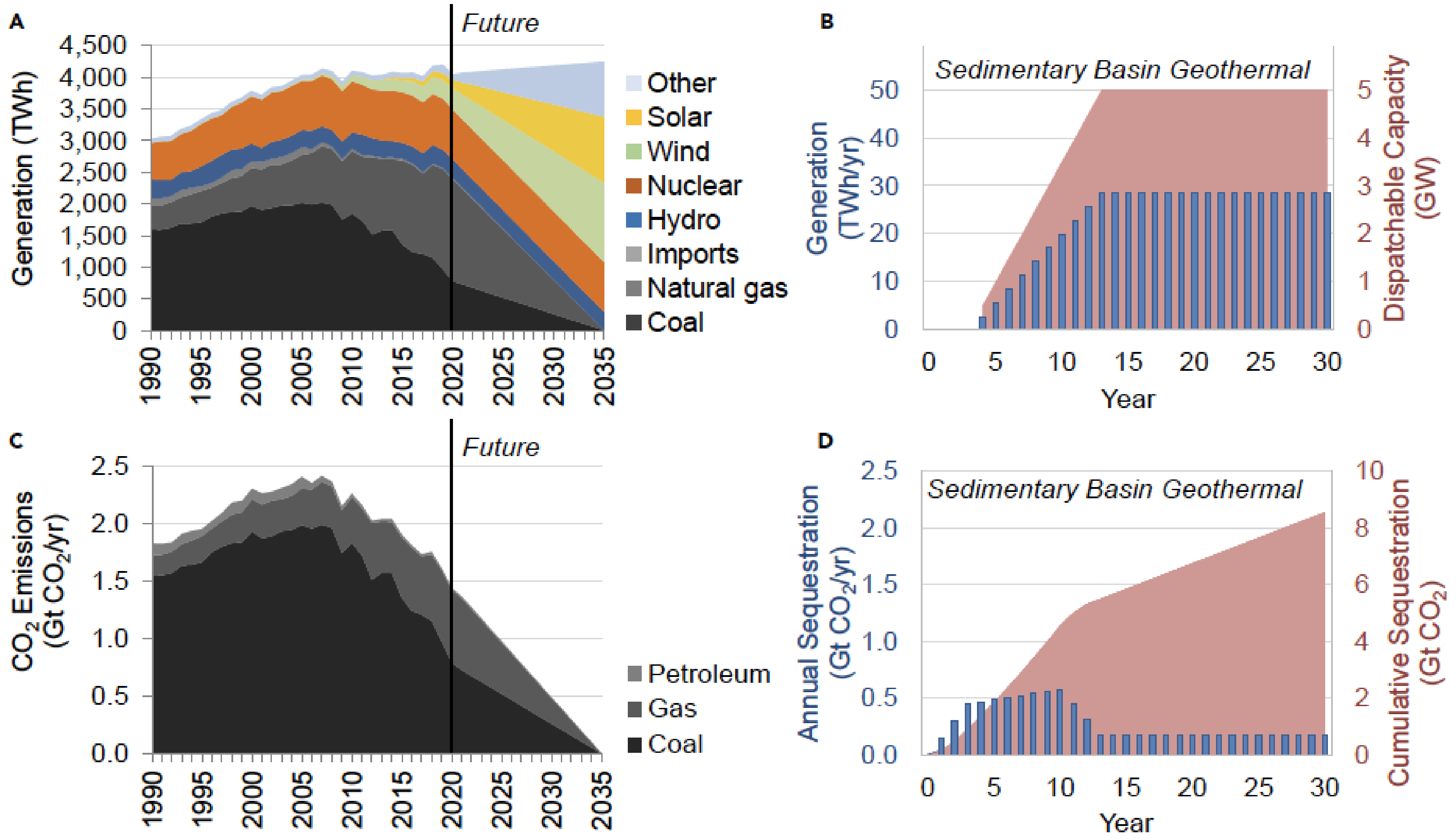
life cycle emissions of CPG systems when combined with one of the six CO_2 feedstocks

Characteristics of CO_2 Sources Matter As Well!!!

Ambitious Scaling: Possibility to Provide Gigatonne Reductions in CO_2 Emissions and Gigawatts of Power

mix of generation sources

estimated generation and firm capacity provided by fifty 100-MW CPG plants



power-sector CO_2 emissions from the combustion of fossil fuels

annual and cumulative CO_2 sequestered by the CPG plants

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Bielicki et al., (2023)

Major Gaps in Knowledge for Sedimentary Basin CO_2-Geothermal and CO_2-Bulk Energy Storage

1. What are the impacts on (multi-phase) fluid and energy flow due to geological heterogeneity at scales ranging from hydrostratigraphic layering to the pore scale and how do these impacts affect sedimentary basin CO_2-geothermal and CO_2-BES? Can the reservoir variability be leveraged to benefit the technologies?
2. What reservoir management strategies should be pursued to optimize the benefits of multi-decadal heat extraction?
3. What are the best deployment and operational strategies in light of decreasing sources of CO_2 and increasing penetrations of variable renewable energy on the grid?
4. ~~How can life cycle assessment techniques be used to estimate the levels of decarbonization more accurately and determine the parameters that most greatly influence those outcomes?~~

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Perspective

The promise of coupling geologic CO_2 storage with sedimentary basin geothermal power generation

Jeffrey M. Bielicki,[1,2] Martina Leveni,[1] Jeremiah X. Johnson,[3,*] and Brian R. Ellis[4]

SUMMARY

Achieving ambitious greenhouse gas mitigation targets will require technological advances and cost reductions in dispatchable carbon-free power generation sources that can provide load following flexibility to integrate high penetrations of variable wind and solar power. Several other sectors may be difficult to decarbonize and a net-zero or net-negative carbon economy may require the deployment of geologic carbon dioxide (CO_2) storage. Utilizing CO_2 as a working fluid for geothermal energy production and energy storage can achieve both goals: isolating CO_2 from the atmosphere and providing valuable power system services to enable high penetrations of variable carbon-free electricity production. The use of CO_2 as a working fluid facilitates access to low-grade heat in sedimentary basins, which are widely available and could allow for strategic citing near CO_2 sources or where power system flexibility is needed. In this perspective piece, we summarize the state of knowledge for sedimentary basin CO_2-geothermal, sometimes referred to as CO_2 plume geothermal, and explore how it could support decarbonization of the energy sector. We also present the potential for using geologically stored CO_2 for bulk energy storage which could provide valuable time-shifting and other services to the power grid. We explore the promise and challenges of these technologies, identify key research gaps, and offer a critical appraisal of the role that policy for a technology at the intersection of renewable energy, energy storage, and geologic CO_2 storage may play in achieving broad deployment.

THERE IS A NEED FOR DISPATCHABLE CARBON-FREE POWER AND GEOLOGIC CO_2 STORAGE TO ACHIEVE DEEP DECARBONIZATION

Anthropogenic emissions of greenhouse gases—most notably CO_2—are accelerating global climate change (IPCC et al., 2021). The negative environmental, economic, and social effects of climate change have motivated substantial efforts to decarbonize economies. Many pathways to achieve deep reductions in greenhouse gas emissions require the power sector to drastically reduce CO_2 emissions while simultaneously electrifying other sectors, such as transportation and heating (Krey et al., 2014; Williams et al., 2012; National Academies of Science, Engineering and Medicine, 2021; Jenkins et al., 2018). Decarbonization of the power sector can occur through a transition to less carbon-intensive fuels (e.g., from coal to natural gas), the displacement of fossil fuels (e.g., from coal to nuclear), the rapid increase in deployment and utilization of renewable energy (e.g., more use of wind, solar, and geothermal), and broad implementation of geologic CO_2 storage (GCS).

Although wind and solar power have become increasingly cost effective, (U.S. DOE EIA, 2021) high penetrations of variable wind and solar energy capacity can pose grid integration challenges and result in the curtailment of these carbon-free generation sources and diminishing reductions in net CO_2 emissions (Denholm et al., 2015; Arbabzadeh et al., 2019; Das et al., 2020). Figure 1 illustrates these challenges, with multi-day periods of high wind generation followed by periods of low wind output (Southwest Power Pool), and diurnal patterns of solar generation balanced by increasing imports and natural gas generation during the off-peak hours (California Independent System Operator). In both regions, there are time intervals where carbon-free generation exceeds 75% of total generation, and other periods where this share drops to 20%. The challenges posed by integrating variable wind and solar can be addressed with the

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Bielicki et al., (2023)

Major Gaps in Knowledge for Sedimentary Basin CO_2-Geothermal and CO_2-Bulk Energy Storage

5. What levels of incentives are necessary to encourage the growth of this industry and what conditions on these incentives would ensure the greatest levels of decarbonization?
6. What influences public support or opposition to the use of CO_2 for producing geothermal energy and how might this affect the technology deployment?
7. What are the technical and legal issues surrounding large-scale implementation of these technologies such as pressure or groundwater level changes extending over multiple pore-space owners across the whole basin?

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Perspective

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Major Takeaways From These Remarks

Location matters

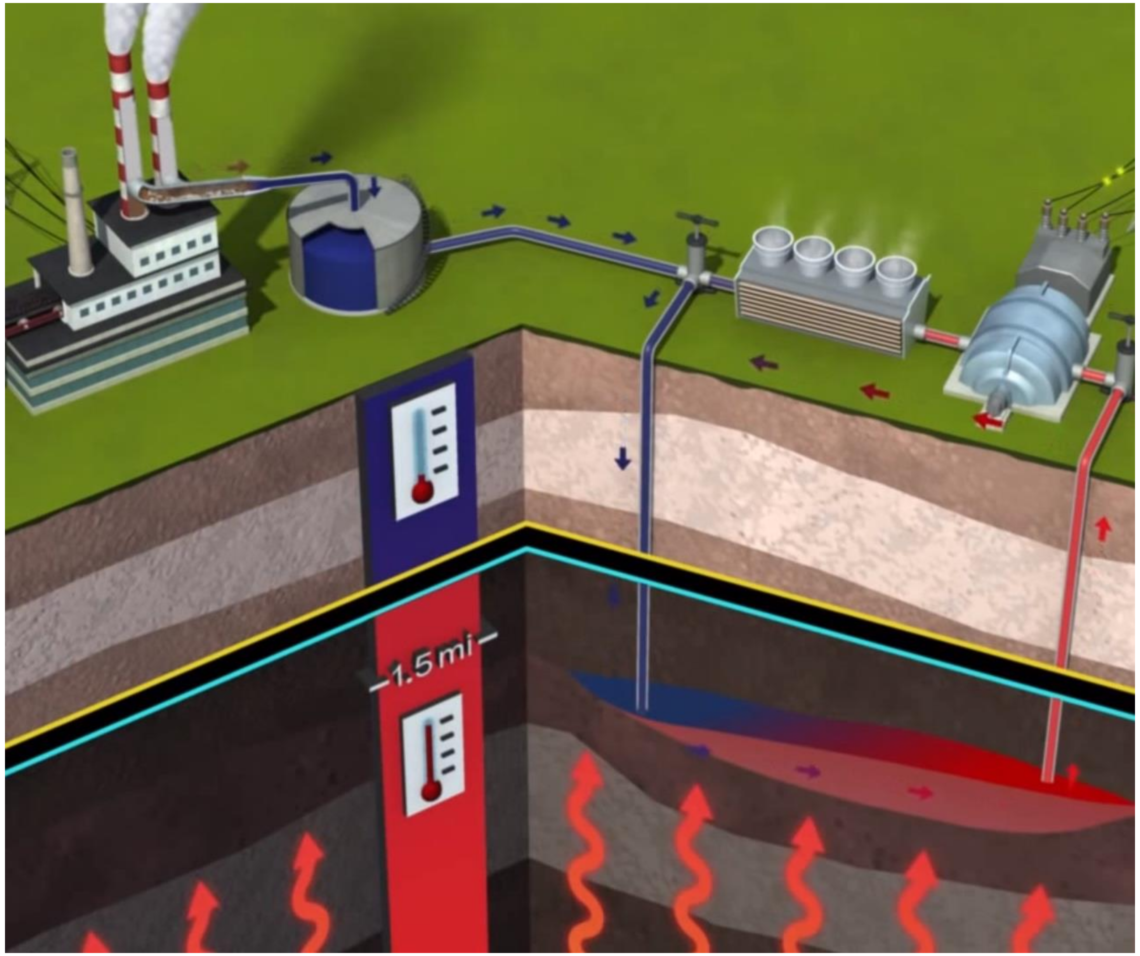
Reservoir characteristics matter

Sources of CO_2 matter

Non-technical issues matter

The technology has promise, but also obstacles: **we still have a lot to learn**.

New and different understanding arises from the **research, development, demonstration, deployment, and diffusion**



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Other relevant journal and conference papers available at: https://u.osu.edu/bielicki.2

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