Supply Chain Vulnerabilities of the Energy Transition

A Focus on Carbon Capture, Transportation, and Storage

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Solutions for Today | Options for Tomorrow

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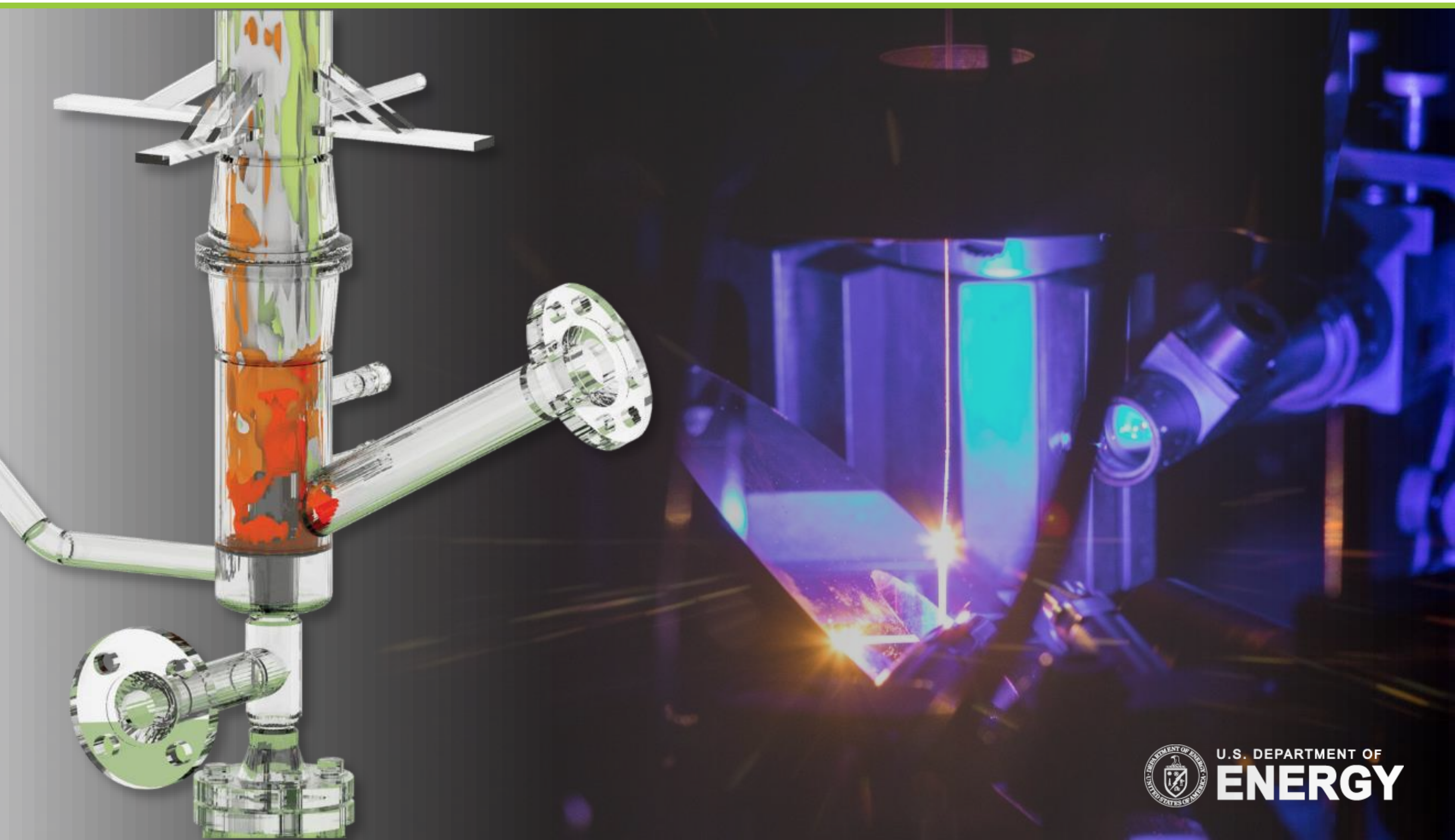
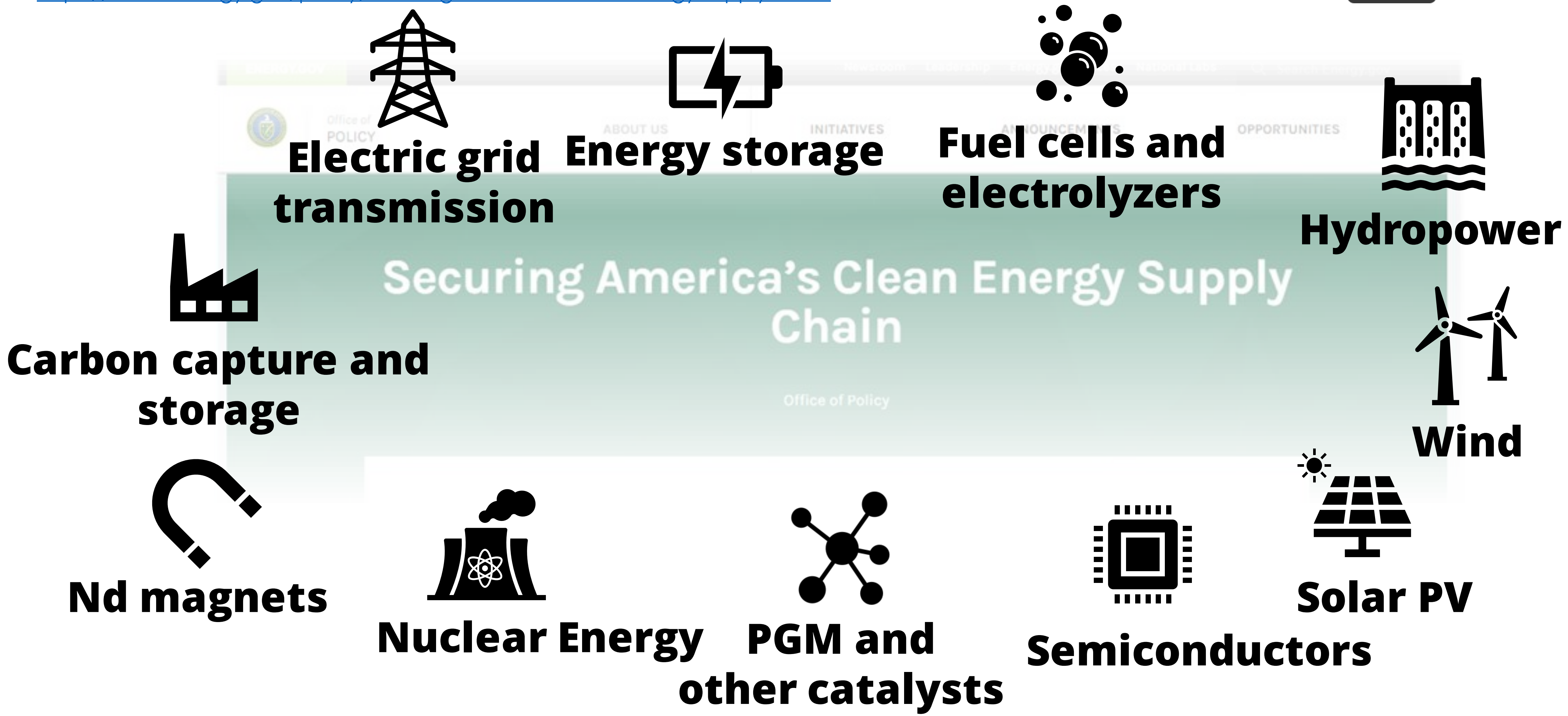
NETL Carbon Management Review Meeting
Aug. 18, 2022



Can We Manufacture the Energy Transition?

https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain



Five Risks Were Assessed Across Studies

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Risk of failing to meet 2035 and 2050 decarbonization targets based on bottlenecks.

The **first step** in the value chain. **Extracting** and **processing** raw materials. Lack of domestic or ally capacity can create risk.

Poor or **lack of policy** can impede clean energy deployment.

Investments in clean energy tech can require **high capital** and incur **high risk**.

- Raw Materials
- Value Add Manufacturing
- Policy
- Workforce
- Finance

The **second step** in the value chain. **Manufacturing** raw materials into usable parts, components, and assemblies. Lack of domestic or ally capacity can impede deployment.

Lack of workforce availability can impede clean energy deployment.

Materials and Manufacturing Face Greatest Risks

Reading 800 pages so you don't have to!

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Raw Materials

Value Add Manufacturing

Policy

Workforce

Finance

Low Risk — Moderate Risk — High Risk

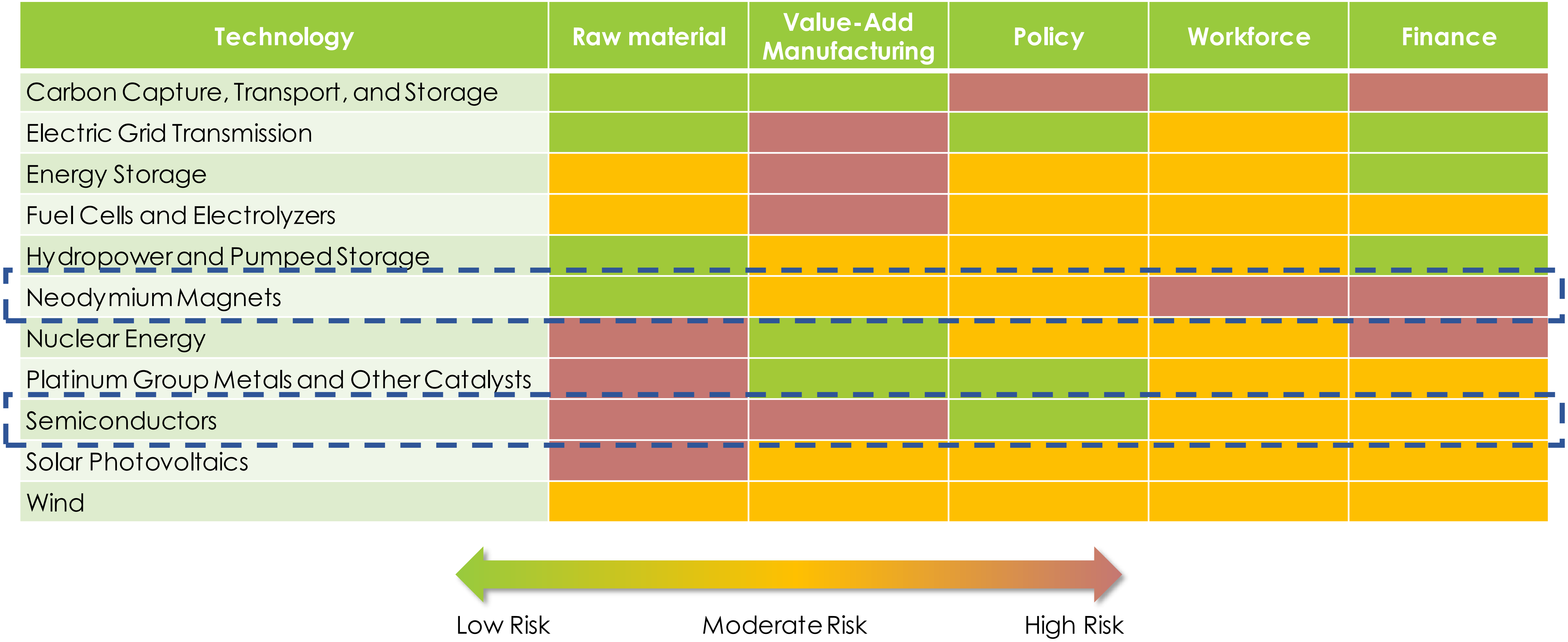
Headwinds

- Concerns of new externalities.
- Lack of domestic industrial capacity.

Tailwinds

- Consumer demand for low-carbon energy.
- Need for infrastructure upgrades.

Risk Profiles Are Not Uniform Across Technologies



Mineral Dependence Is Tech-specific as Well

High (■), medium (■), low (■), or no (■) usage of our "Great 8" critical minerals.

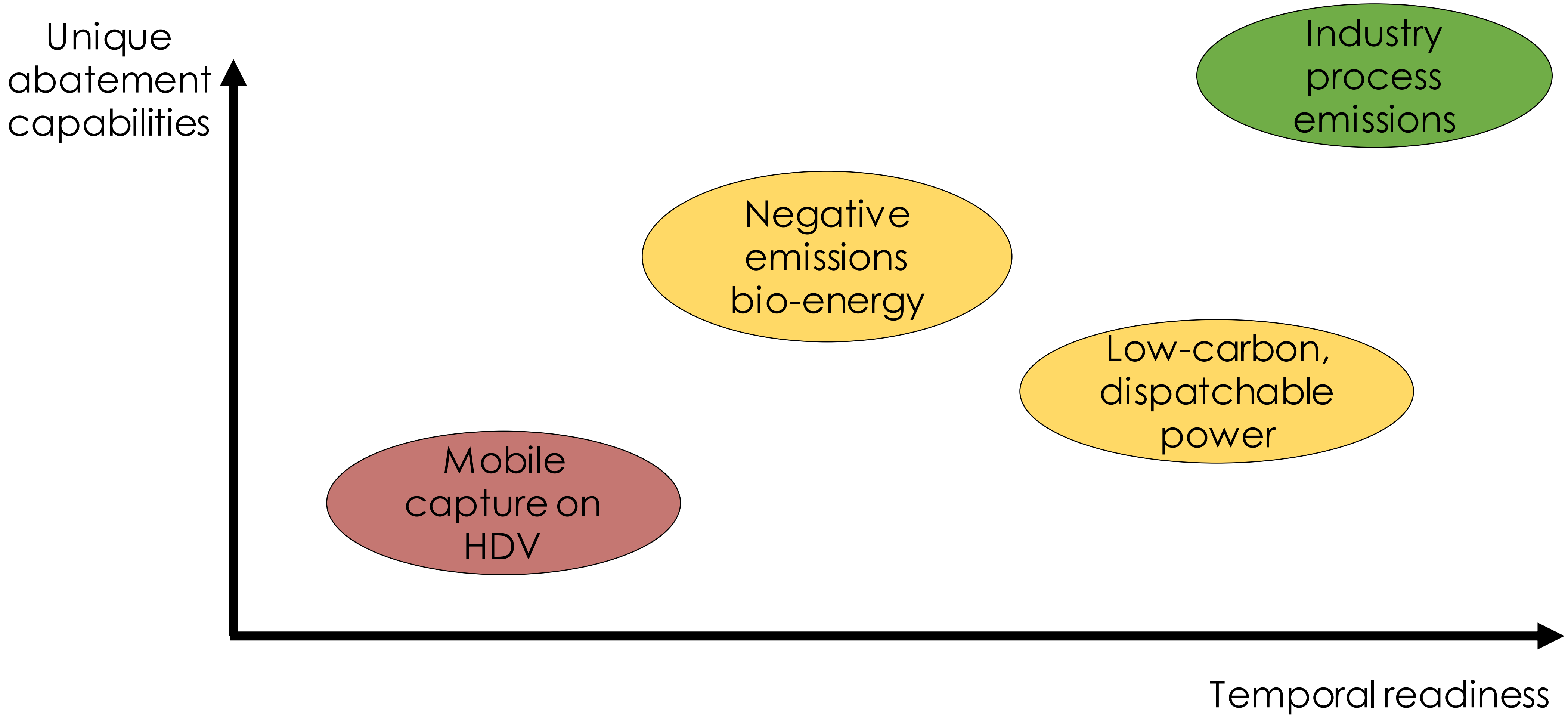
Technology	Al	Cr	Co	Graphite	Li	Mn	REE	Ti	Other
Carbon Capture and Storage (CCS)	Medium	Medium	None	None	None	Medium	None	Medium	Crude oil for solvents; steel pipe
Electric Transmission	High	Medium	None	None	None	Medium	Low	Medium	Steel, oil, copper, pressboard, paper, wood, aluminum, plastics, and silica gel
Energy Storage	High	Low	High	High	High	High	Low	Low	Nickel, iron, lead, sulfur
Fuel Cells, Electrolyzers	Medium	Medium	Medium	High	None	Medium	High	High	Iridium, platinum, strontium, oil, zirconium, lanthanum, nickel, iron, Nafion membranes
Hydropower and PSH	None	Low	None	None	None	Low	Low	Low	Steel, copper, cement, oil, electronic control systems
Neodymium Magnets	Low	Low	Low	Medium	Low	Low	High	Low	Iron, boron
Nuclear Energy	Medium	Medium	Medium	Low	High	High	High	High	Uranium for fuel; hafnium, indium, niobium, nickel for reactor vessel and piping
PGMs, Catalysts	None	None	Low	None	None	None	High	Low	-
Semiconductors	Low	None	None	High	None	None	None	None	Silicon; Gallium used for GaN substrate on silicon wafers
Solar Photovoltaics	Medium	None	None	None	None	Medium	None	None	Silicon, cadmium, and tellurium for modules
Wind	High	Medium	None	None	None	Medium	High	None	Balsa wood for turbine blades

What Might the Future of CCS Be?

And what are the barriers to reaching it?

What Are the "Killer Apps" for Capture?

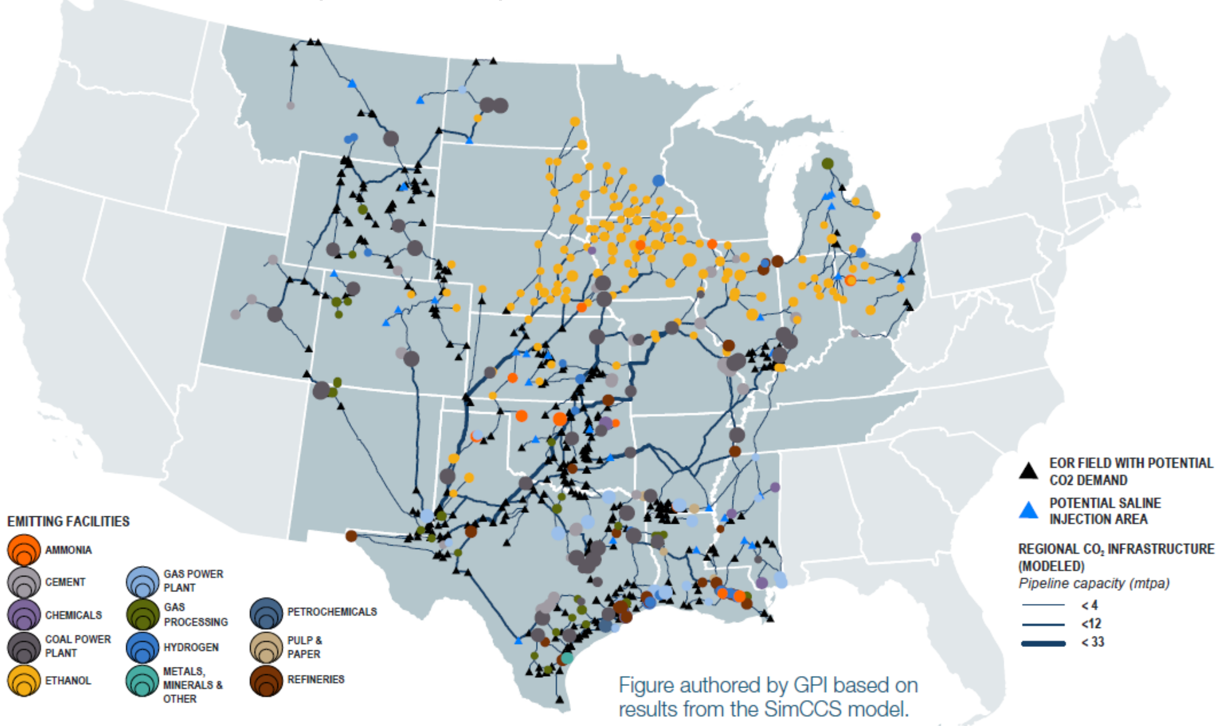
Illustrative, non-exhaustive examples



What Might a U.S. CCS Network Look Like?

Use of low-carbon dispatchable power…

GPI – 0.3 Gtpa >400 point sources



Or a bio-energy intensive network

NZAP – 1.6 Gtpa >1000 point sources

To stress a hypothetical supply chain, this study assumed a 2050 **deployment target of 2.0 Gtpa of CCS.**

How Would 2 Gtpa Be Captured?

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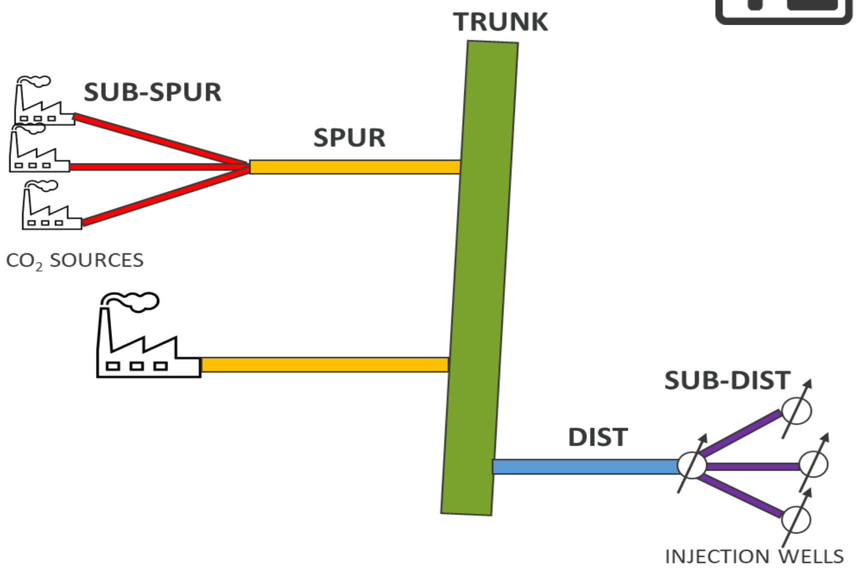
SEGMENTS + (% of U.S. CO_2 emissions, 2019)[1]	Electricity Generation (25%)		Industry (23%)		Dispersed Emitters (53%)		
Example Emitters	Natural Gas	Coal	Heat Production	Chemical Use (e.g., cement)	Agriculture	Transport	Comm. and Residential

	Solvents	Membranes	Sorbents	Cryogenic Systems
SOLUTIONS NOW (2021)[2]	Physical solvents	Polymeric	Zeolites	Ryan-Holmes process
	Chemical solvents		Activated carbon	Liquefaction
			Alumina	Distillation
SOLUTIONS EMERGING (2030-2050)[2]	Improved solvents	Ion transport	Carbonates	Improved distillation
	Biomimetic solvents (e.g., Hemoglobin derivatives)	Ceramic facilitated transport	Carbon-based sorbent	Hybrid processes
	Novel contacting equipment	Contactors	Perovskites	
			Oxygen chemical looping	
			O_2/N_2 separation	
			Hydrotalcites	
			Silicates	

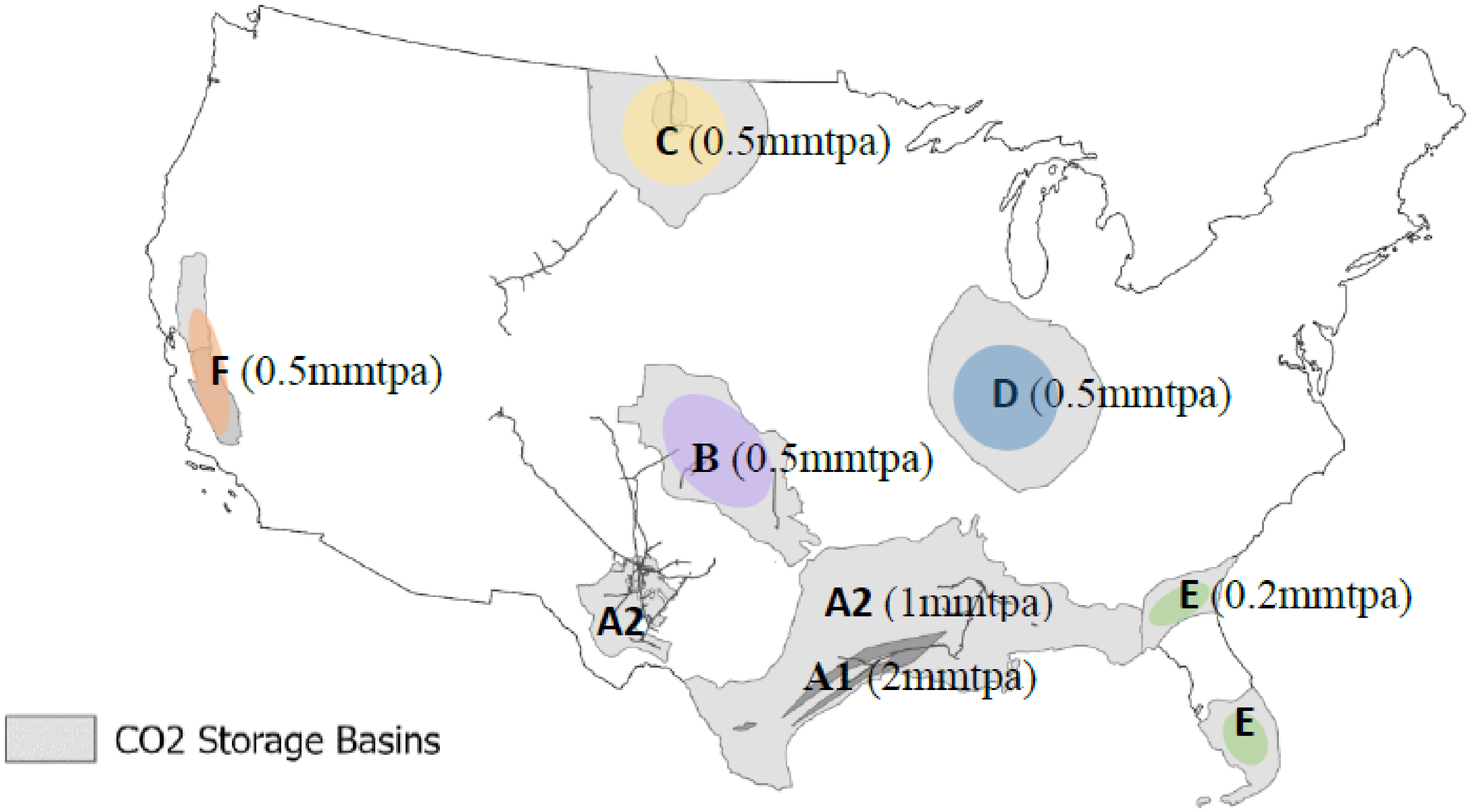
1. EPA
2 IPCC

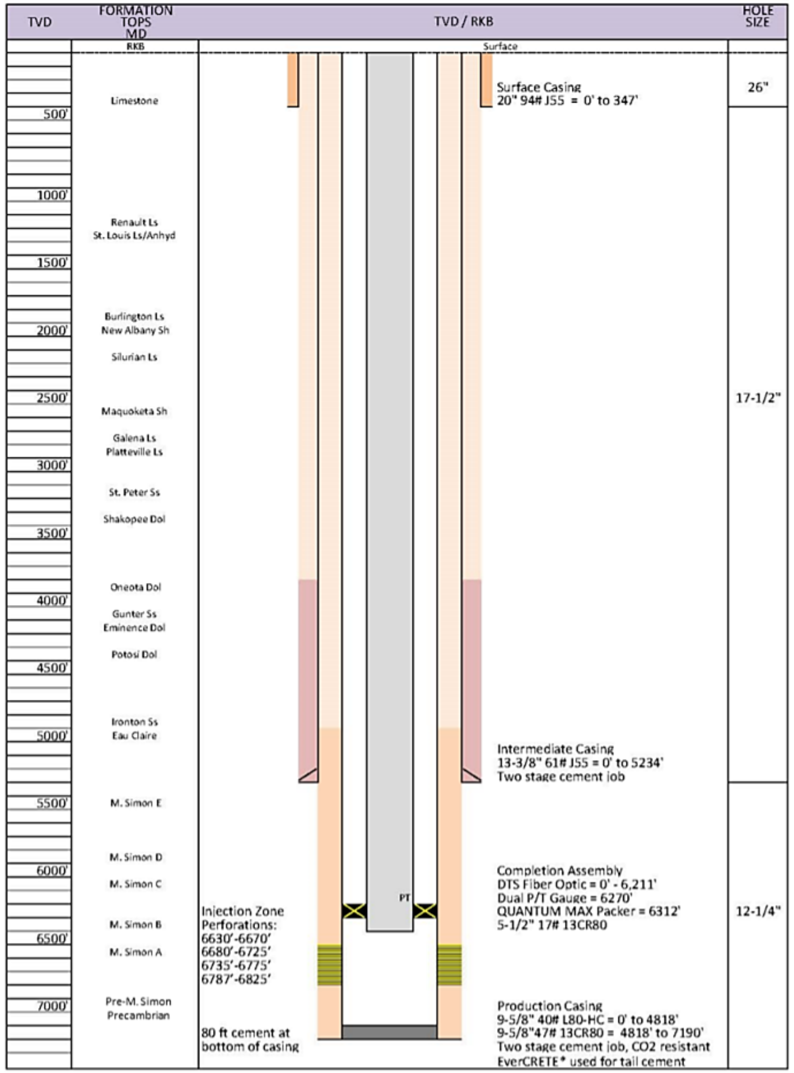
How Would 2 Gtpa Be Transported?

Princeton NZA model used as basis to scale infrastructure requirements from 1.7 to 2.0 Gtpa.

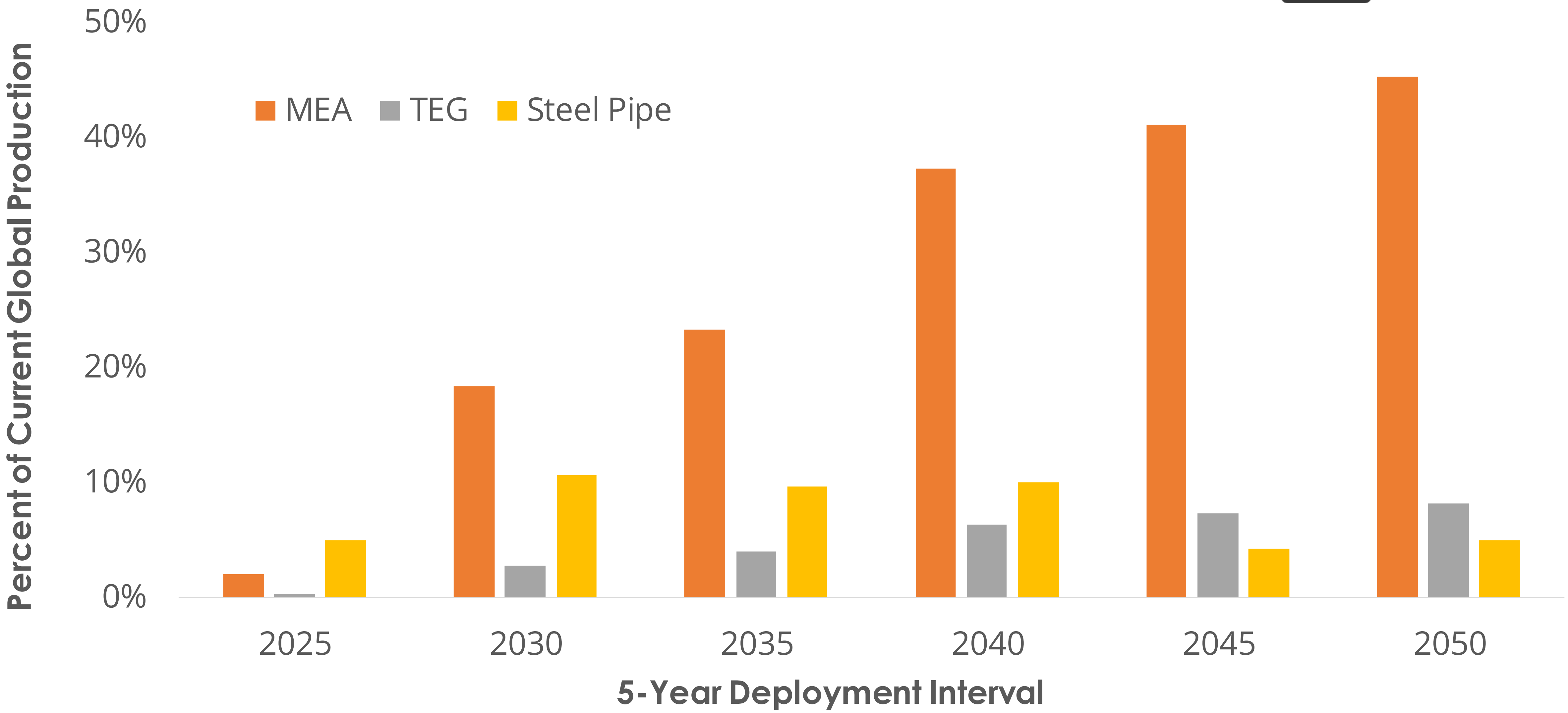


Where Would 2 Gtpa Be Stored?





Material Requirements Unlikely to Strain Markets



Innovation Likely Reduces Capture Chemical Risk

Key objective: maintain scale through material choices while improving performance.

Decreasing supply chain risk through diversification

First Gen: "MEA"

- Cansolv Capture System (Shell)
- Econamine Family (Fluor)
- KM-CDR Process (Mitsubishi Heavy Industries)

Second Gen: Advanced Solvents

Limit process redesign from Gen 1 *and* Leverage established chemicals supply chains *and* Industry collaboration to expedite availability

Third Gen: New Tech

Maintain optionality on CO_2 source *and* Engage whole of value chain in demonstrations *and* Improve DAC efficiencies

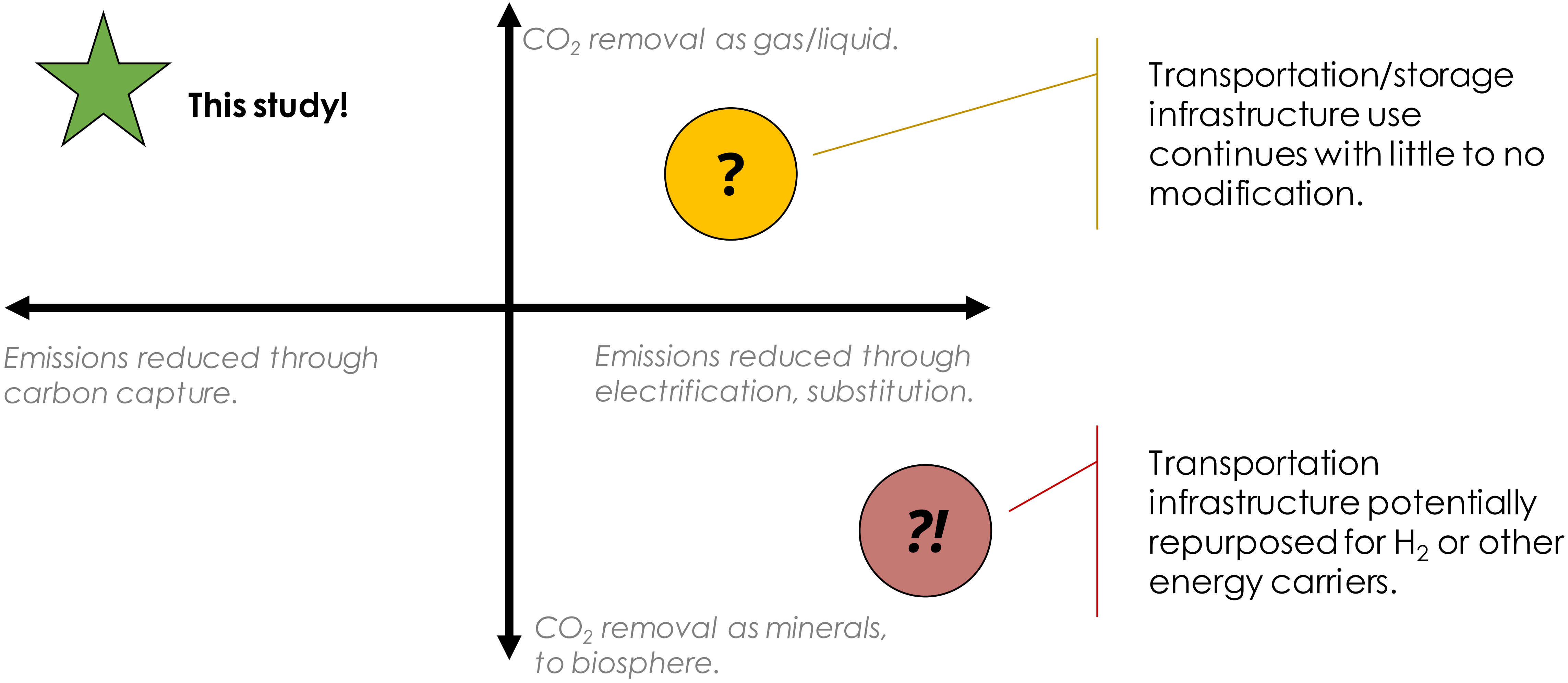
Material Requirements Unlikely to Strain Markets

CCS Value Chain Segment	Reliance on specialty materials	Geographic concentration of supply chain	Requirement of offshore sourcing	Policy barriers
Capture	**Low:** Bulk/commodity chemicals, materials.	**Low:** Diversified suppliers, low-cost options outside of China.	**Medium:** Chemical suppliers are mostly global, but 10% growth rates will be needed at scale.	**Medium:** Current incentive structures available, but insufficient for scale.
Transport	**Low:** Bulk/commodity steels.	**Low:** Diversified suppliers, overlap with NG pipeline supply chains.	**Medium:** U.S. has limited production capacity for commodity steels.	**Medium:** Cross-border, right of way issues for high number of private lands.
Storage	**Low:** Bulk/commodity steels, cements.	**Low:** Abundant saline aquifer storage.	**Low:** Geographically dispersed in U.S.	**Medium:** Interstate pore space rights vary.

Risks to deployment qualitatively assessed as High, Medium, or Low.

Adapting to Decarbonization Macro Shifts

The decarbonization landscape is rapidly evolving, but multiple futures for continued utilization of CCS infrastructure exist (especially transportation).



1. We need **more mining**, **refining**, **and manufacturing capacity** to meet our decarbonization objectives.
2. CCS is **relatively low risk** from a supply chain perspective.
3. Impediments to growth are primarily policy related and owing to the **vast**, **3-D scale of a CCS economy**.

Disclaimer

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