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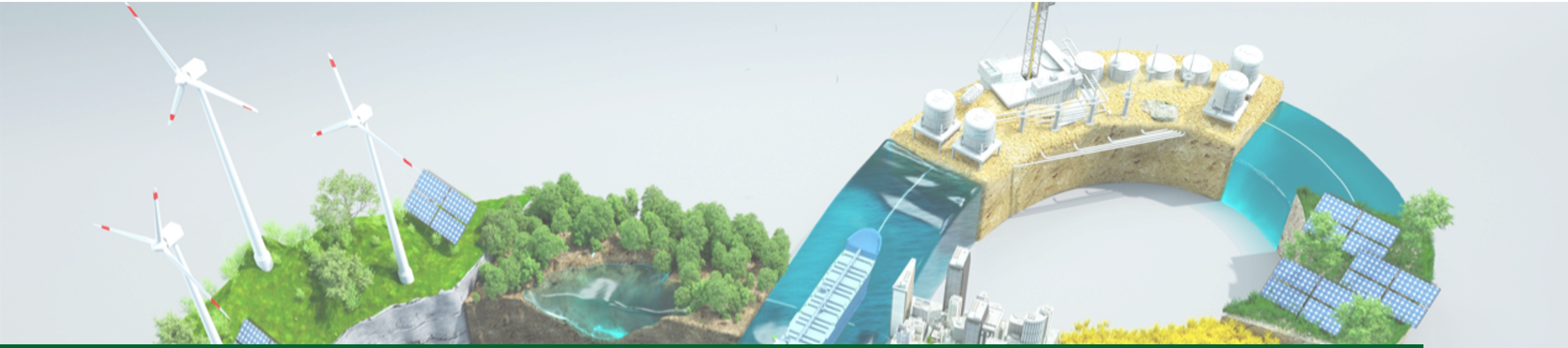

# Pathways to Commercial Liftoff

**Carbon Management** | June 2023

# Carbon management covers a wide range of activities

NOT EXHAUSTIVE - INCLUDES FOCUS APPLICATIONS EXPLORED IN THIS REPORT

Focus of this report

## 1 $CO_2$ sources

**Emissions from point-sources** (e.g., industrial emissions)

**$CO_2$ in the atmosphere**


## 2 $CO_2$ capture

**Point-source capture:** point $CO_2$ sources, with the green highlighted areas the focus of this report:

- Ethanol
- Natural gas processing
- Coal power
- Natural gas power
- Ammonia
- Steel
- Cement
- Hydrogen
- Pulp and paper
- Refining and chemicals

**Atmospheric and other capture:**
A variety of capture technologies, with the highlighted areas the focus of this report:

- Direct Air Capture (DAC)
- BiCRS (Incl. BECCS and biochar/bio-oil)
- Mineralization
- Nature based solutions
- Ocean capture

## 3 $CO_2$ compression & transport

Mode of transporting $CO_2$ from point of capture to point of use / storage, with the green highlighted areas the focus of this report:

- Pipeline
- Rail
- Truck
- Barge/ship

## 4 $CO_2$ use/storage

Ways by which $CO_2$ can be stored or used

Ability to use $CO_2$ will depend on the characteristics and volume of captured $CO_2$

Focus for this report includes the following green highlighted applications:

- Storage in saline aquifers and depleted oil and gas reservoirs
- EOR storage
- Use in synfuel
- Use in building materials
- Use in plastics
- Mineralization

# Modeling suggests U.S. need for hundreds of millions of tons/year of carbon management

**Estimated U.S. CCUS, CDR required to reach Net Zero by 2050**


**Source: Graph represents low and high case scenarios for carbon management deployment from the** 2021 White House Pathways to Net-Zero GHG Emissions by 2050 and 2021 Princeton Net Zero America; More detailed summaries of modeling efforts available in full Report on liftoff.energy.gov

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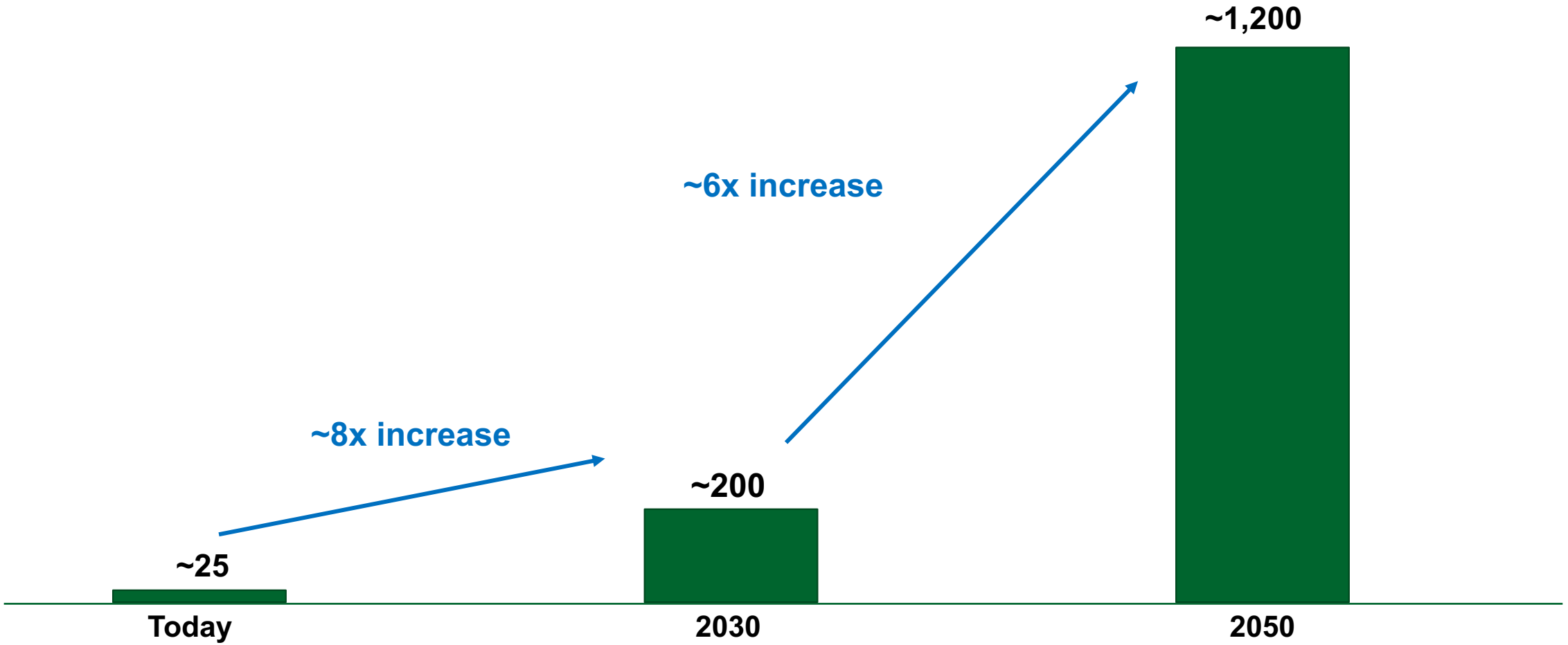
# That means massive scale-up from current capacity

**U.S. Carbon management scale-up needed,** tonnes per year




Source: Based on midpoint of ranges in Net-Zero America study

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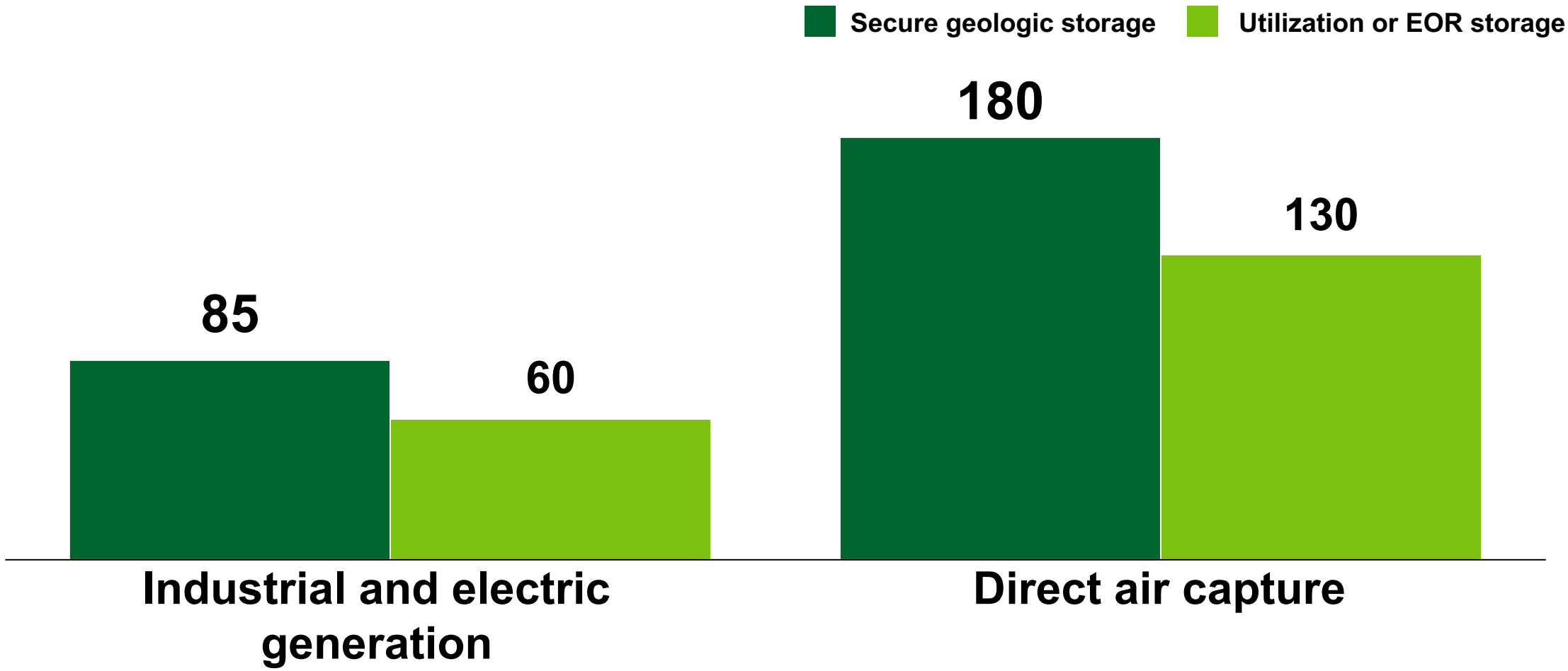
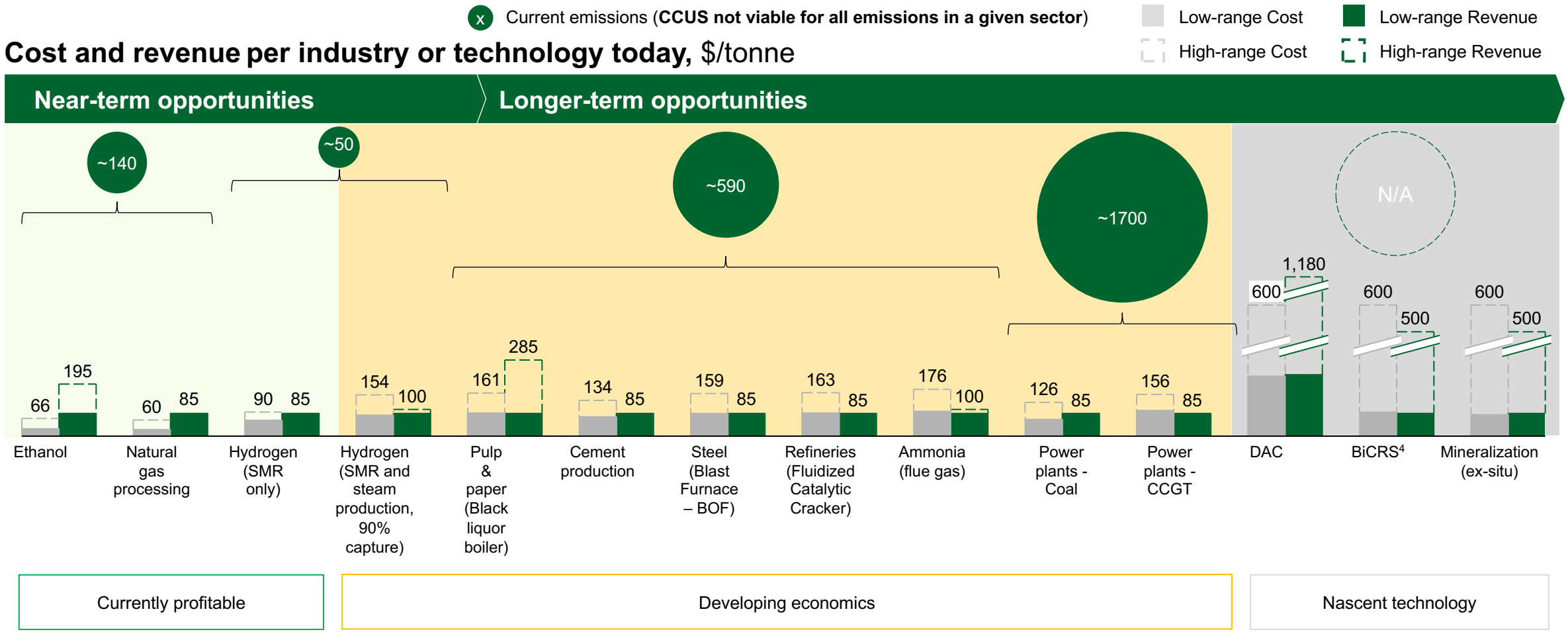
# The 45Q tax credit provides a steady, reliable incentive for many carbon management projects

## 45Q credit value by source and disposal method, $/tonne



# Carbon management is profitable in some industries, but for widespread deployment revenue/cost improvements or policy support are needed



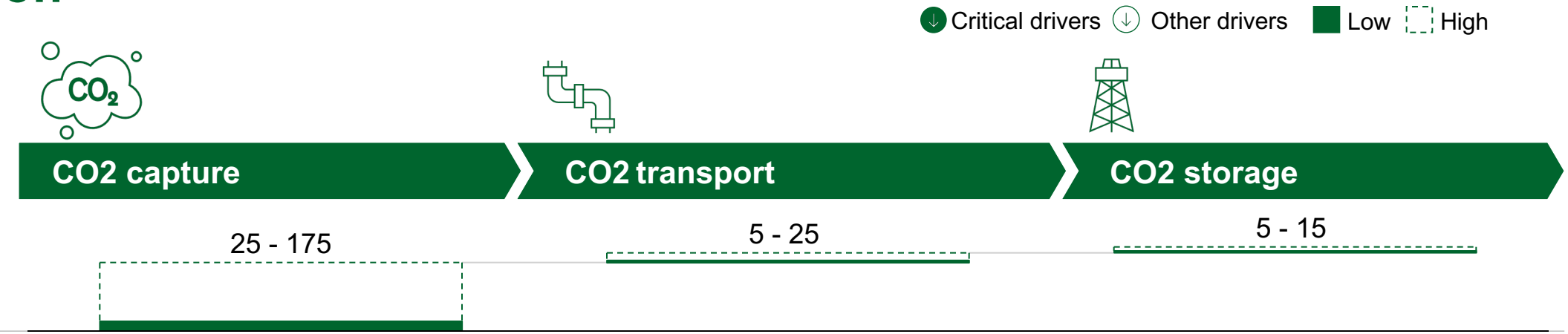

**Project specific economics dependent on $CO_2$ capture capacity, utilization, distance to storage and existing equipment**

Sources and references can be found in DOE's "Pathways to Commercial Liftoff: Carbon Management" report at liftoff.energy.gov

# Challenges to widespread deployment are significant but can be overcome

| Challenges | Solutions |
|---|---|
| 1 Cost uncertainty for "next generation" CCUS applications and early deployments of certain CDR types | Support for early project development in high-cost sectors and DAC can enable faster cost reductions |
| 2 Revenue uncertainty driven by absence of compliance markets, and immature markets for removals | Development of bankable revenue streams for carbon removals and low-carbon products can spur development |
| 3 Lack of commercial standardization (e.g., sequestration agreements / liability provisions) | Creation of archetypal, field-tested business models and terms will enable the development and execution of partnerships |
| 4 Lead-times in permitting storage (e.g., for Class VI injection wells) | Building EPA and State technical and regulatory capacity will increase the efficiency and effectiveness of the Class VI permitting program |
| 5 Lack of transport and storage infrastructure | Initial build-out from large integrated projects and regional aggregations of profitable projects can spur build-out |
| 6 Local opposition to project development in some instances | Capacity building and early, frequent, and transparent engagement between developers and communities can strengthen trust and improve project outcomes |

# 1 Capture drives the majority of unit costs and offers the most potential for reduction




| | CO2 capture | CO2 transport | CO2 storage |
|---|---|---|---|
| **Cost reductions possible?[2]** | Large reductions | Moderate reductions | Small reductions |
| **Current cost reduction levers** | ↓ Economies of scale, targeting largest capture sources<br>↓ Technology innovations for novel capture technologies<br>↓ Learning by doing<br>↓ Modularization and standardization | ↓ Siting close to reservoirs to minimize distance<br>↓ Economies of scale (e.g., increasing diameter and added compression) , aggregating various CO2 sources in a hub<br>↓ Utilization of existing right-of-ways | ↓ Siting on well characterized site with existing infrastructure and good monitorability<br>↓ Economies of scale, leveraging large reservoir capacities<br>↓ Reduction of MMV costs by R&D and learning by doing |

Sources and references can be found in DOE's "Pathways to Commercial Liftoff: Carbon Management" report at liftoff.energy.gov

# 2 Potential non-45Q revenue streams for carbon management are not "bankable" today

## There is demonstrated demand for low-embodied carbon materials and CDR…

US Government Moves Toward Low-Carbon Product Procurement

ENR Engineering News-Record

CNBC **JPMorgan agrees to purchase $200 million worth of carbon removal**

Fastmarkets

'Green steel' premiums to become commonplace within the next decade

**$500-2,000**

Observed sale prices of CDR removals

REUTERS Occidental signs four-year deal with jet-maker Airbus for carbon credits

**Climeworks sign carbon removal contract with PwC Switzerland**

Sustainability.

## …But offtake contracts are not sufficient to unlock financing for large projects

> The biggest uncertainty is on the voluntary carbon markets side -- at what price point is what market depth available? If people ask us for a firm offtake stack, **the inconvenient truth is that it's not there right now**
> *-DAC developer*

> Right now, nobody will pay us any more for [low-carbon] cement and nobody cares if we produce it or not. **There is no market reward, so we can never justify those investments**.
> *-Cement executive*

> If you have a 10-year offtake contract then excellent--that's a bankable stream. But **right now it's not quite at the level we need.**
> *-DAC investor*

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# 4/5 Scale-up will require developing storage sites capable of holding billions of tonnes of $CO_2$

## Commercial storage capacity needs

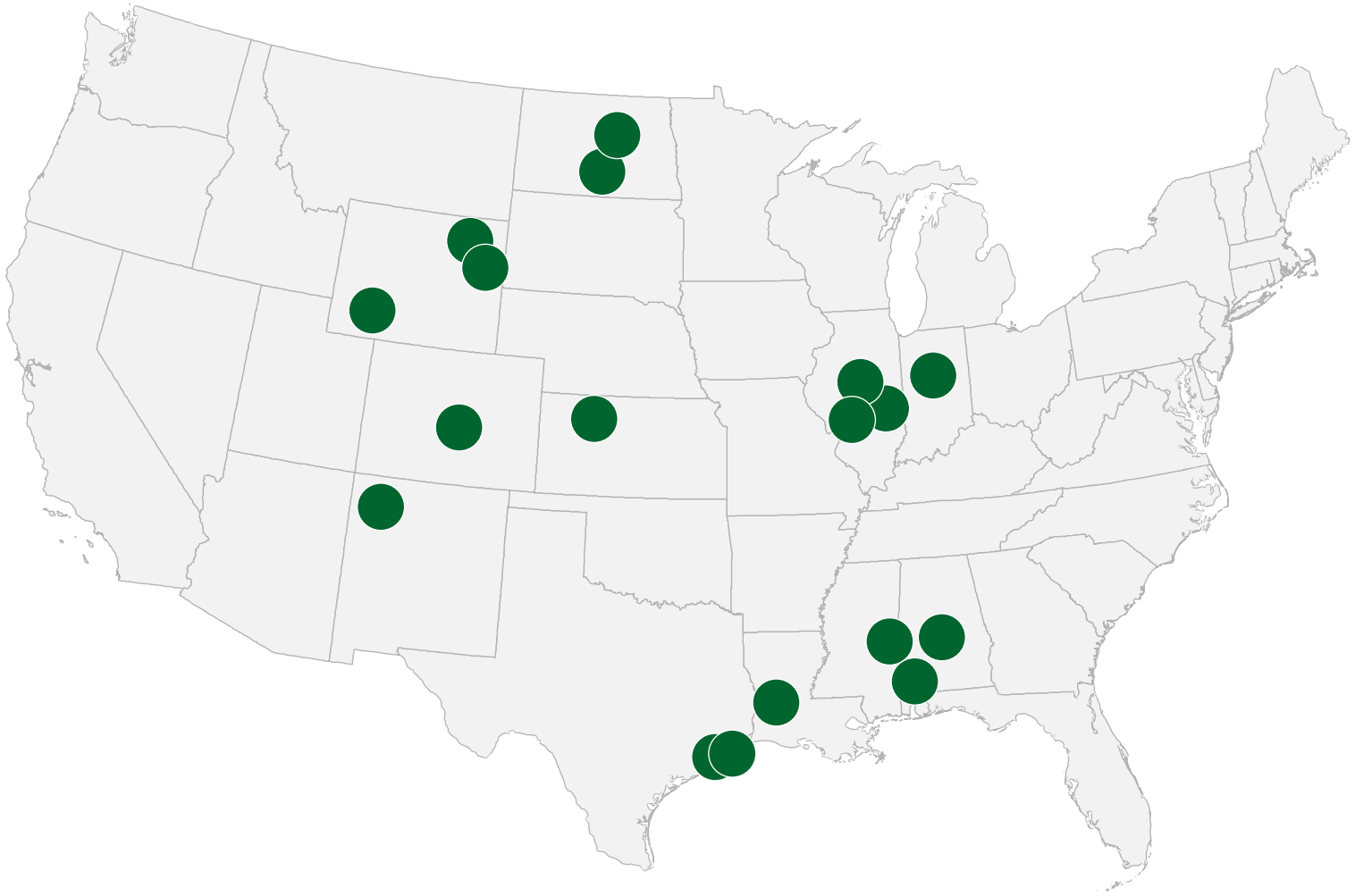
**2,000**

**Million tons of commercial storage capacity needed by 2030**

**13,500**

**Million tons of commercial storage capacity needed by 2040**

## Sites currently in development through DOE FECM CarbonSAFE program

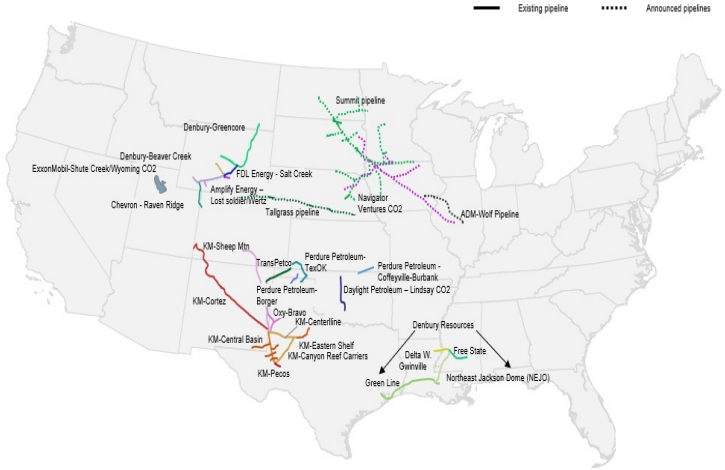
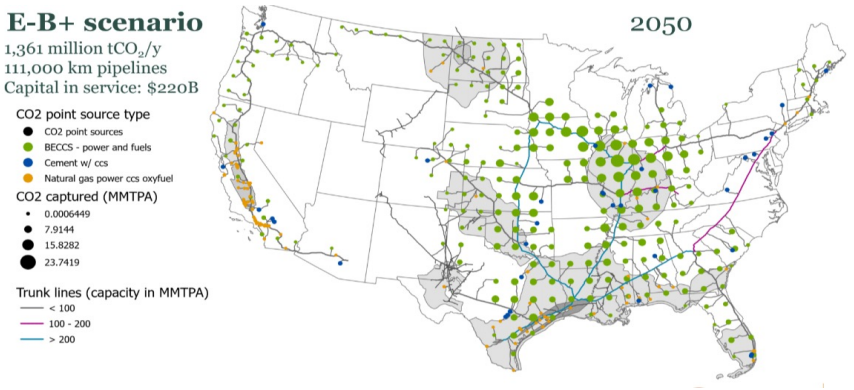
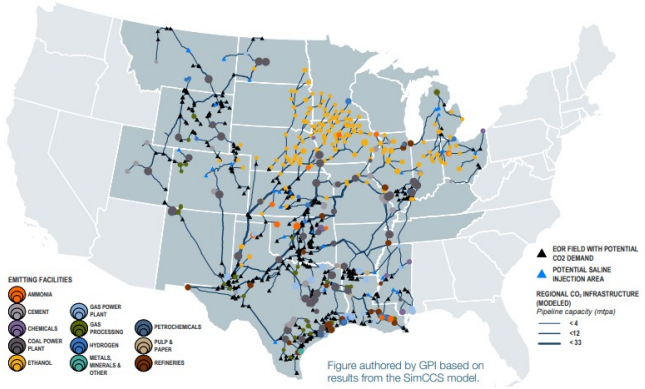


Source: FECM Strategic Vision (2022), NETL CarbonSafe Phase III and IV projects



Source: Extracted from NETL website - https://netl.doe.gov/carbon-management/carbon-storage/carbonsafe

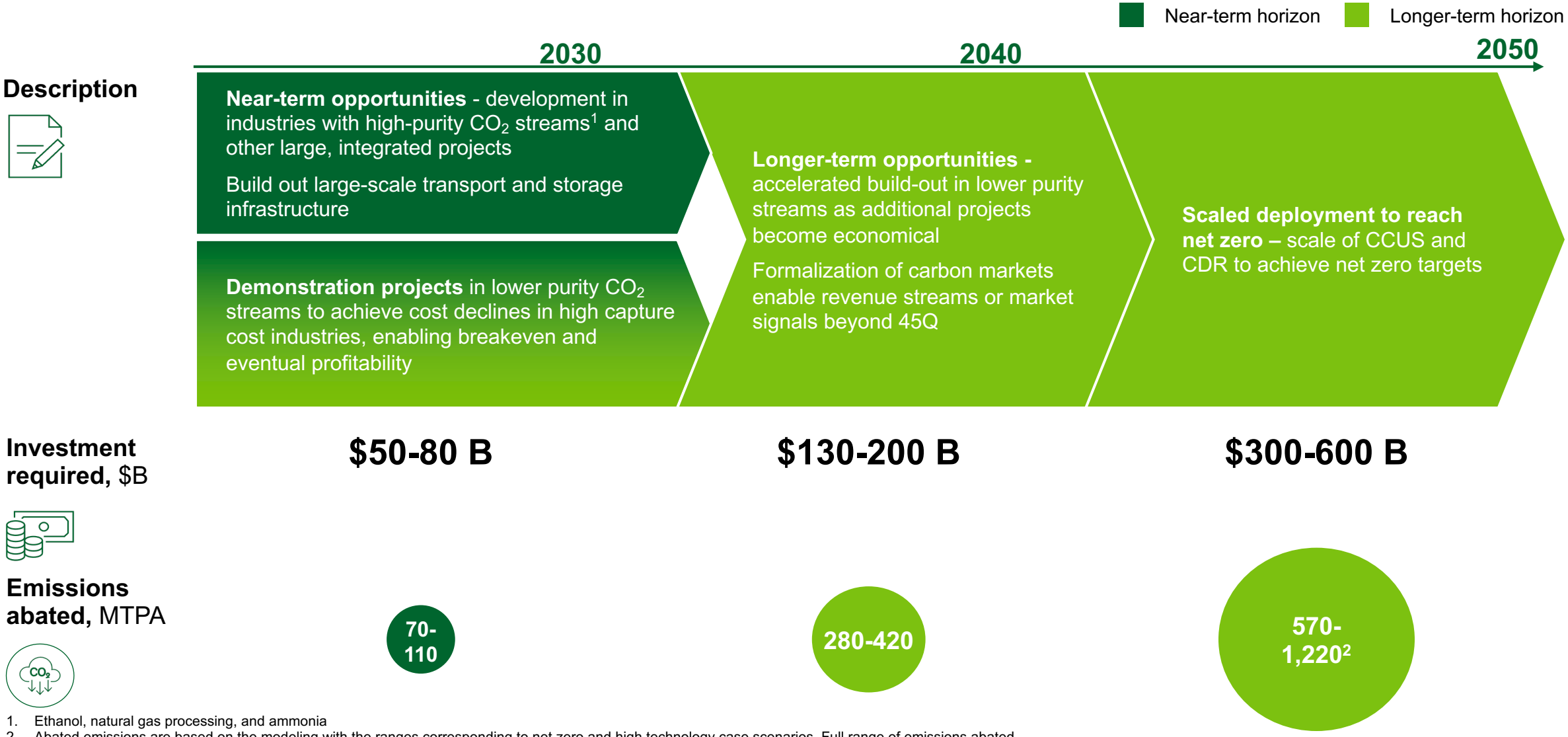
# 5 Carbon management at net-zero scale could require at least a 6x scale-up in $CO_2$ pipeline capacity

| Case | Pipeline scenario | Case | Pipeline scenario |
|---|---|---|---|
| **Current state** (~4,500 miles) |  | **Net Zero Americas** (~70,000 miles) |  |
| **Great Plains Institute** (~30,000 miles) |  | **DOE stress case from Net Zero America** (~96,000 miles) |  |



Source: NETL Review of CO2 Pipelines in the United States, Princeton net-zero Americas, Great Plains Institute

# The next decade will lay the groundwork for full commercial liftoff




1. Ethanol, natural gas processing, and ammonia
2. Abated emissions are based on the modeling with the ranges corresponding to net zero and high technology case scenarios. Full range of emissions abated given other reports range from 400-1800 MTPA