



# Carbon capture for use or sequestration

Renewable Thermal Technology



# Carbon capture is applicable for a range of large stationary combustion and process emitters

## Industrial: Concentrated CO<sub>2</sub>



### Petrochemicals

Byproduct from production of methanol, carbon black, etc.



### Ammonia

Byproduct from use of fossil fuels to produce hydrogen for ammonia



### Ethanol

Byproduct of fermentation of glucose for ethanol production



Nearly all applications also produce combustion emissions for **industrial heating**

## Industrial: Dilute CO<sub>2</sub>



### Refining

Mostly fuel combustion for boilers & furnaces to refine raw materials



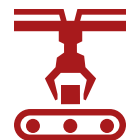
### Cement

Byproduct of calcination of limestone to produce clinker



### Iron & Steel

Several sources of CO<sub>2</sub> including coking coal, blast furnaces



### Aluminium

Reduction process creates CO<sub>2</sub> from alumina electrolysis

## Power sector (not focus of this fact base)



### Coal-to-Power

Combustion of coal for electric power produces dilute CO<sub>2</sub> offgas



### Gas-to-Power

Combustion of gas for electric power produces dilute CO<sub>2</sub> offgas



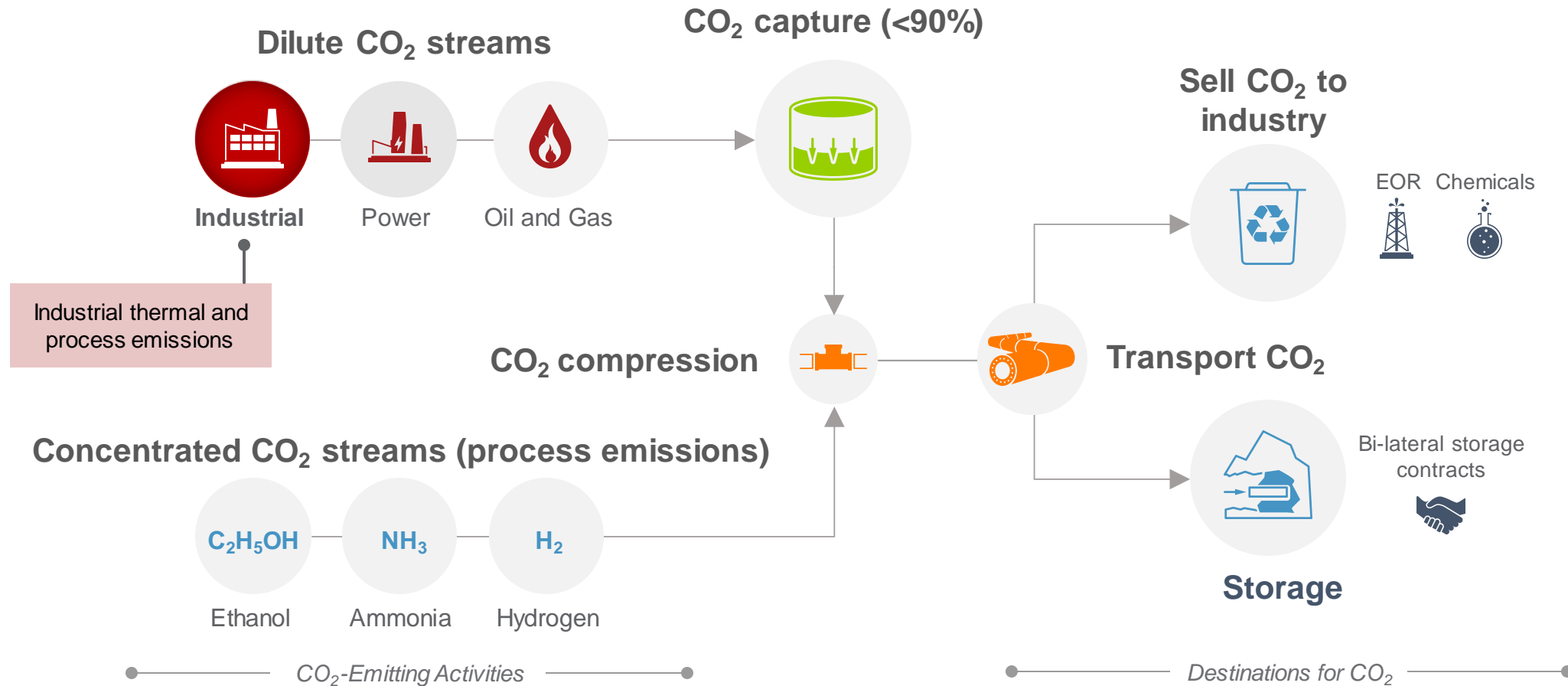
### Biofuels-to-Power

Combustion of biomass for electric power produces dilute CO<sub>2</sub> offgas

**List not exhaustive, many smaller emitting industrial sectors also appropriate for CCUS**



# CCUS captures up to 90% of CO<sub>2</sub> from stationary emitters and transports it for storage or utilisation



# Four main drivers determine the technical and economic viability of CCUS for thermal combustion applications



## Concentration

- Cost of carbon capture inversely correlated with level (i.e., partial pressure) of CO<sub>2</sub> in capture stream



## Location

- CO<sub>2</sub> source location important for:
  - aggregating emission streams
  - transport of captured CO<sub>2</sub>
  - storage or use of CO<sub>2</sub>



## Source of Heat

- Regeneration of carbon capture solvent typically requires low-cost heat at ~120°C



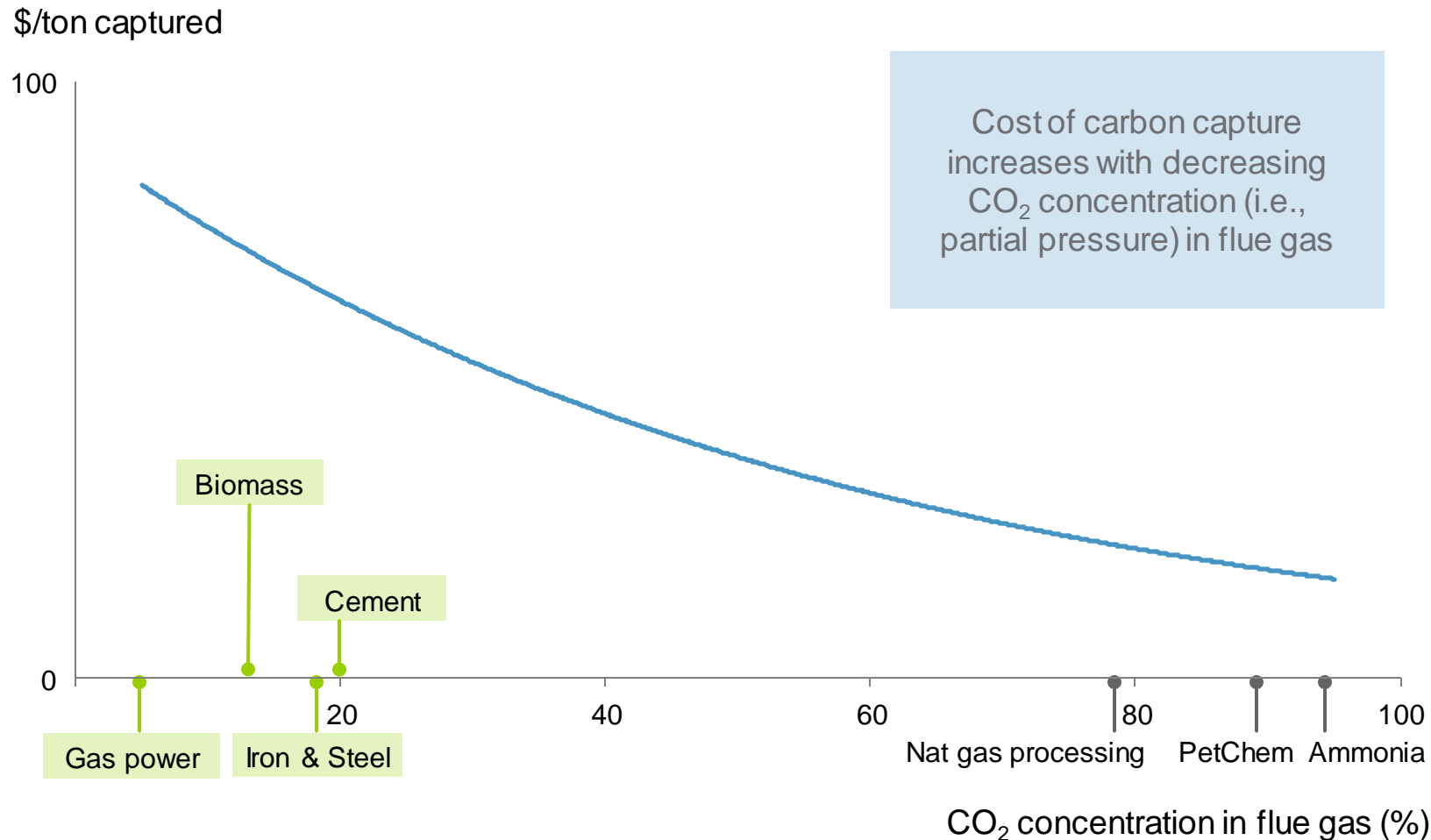
## Process Emissions

- Opportunity to simultaneously capture non-combustion process emissions



## Concentration

# Level of CO<sub>2</sub> in flue gas is a key cost driver



- Flue gas from industrial thermal combustion typically contains <10% CO<sub>2</sub>, resulting in higher carbon capture costs relative to process emissions
- *Note: Cost of CO<sub>2</sub> capture (\$/ton) is independent of emissions intensity (kg CO<sub>2</sub> per MMBtu) and fuel costs*

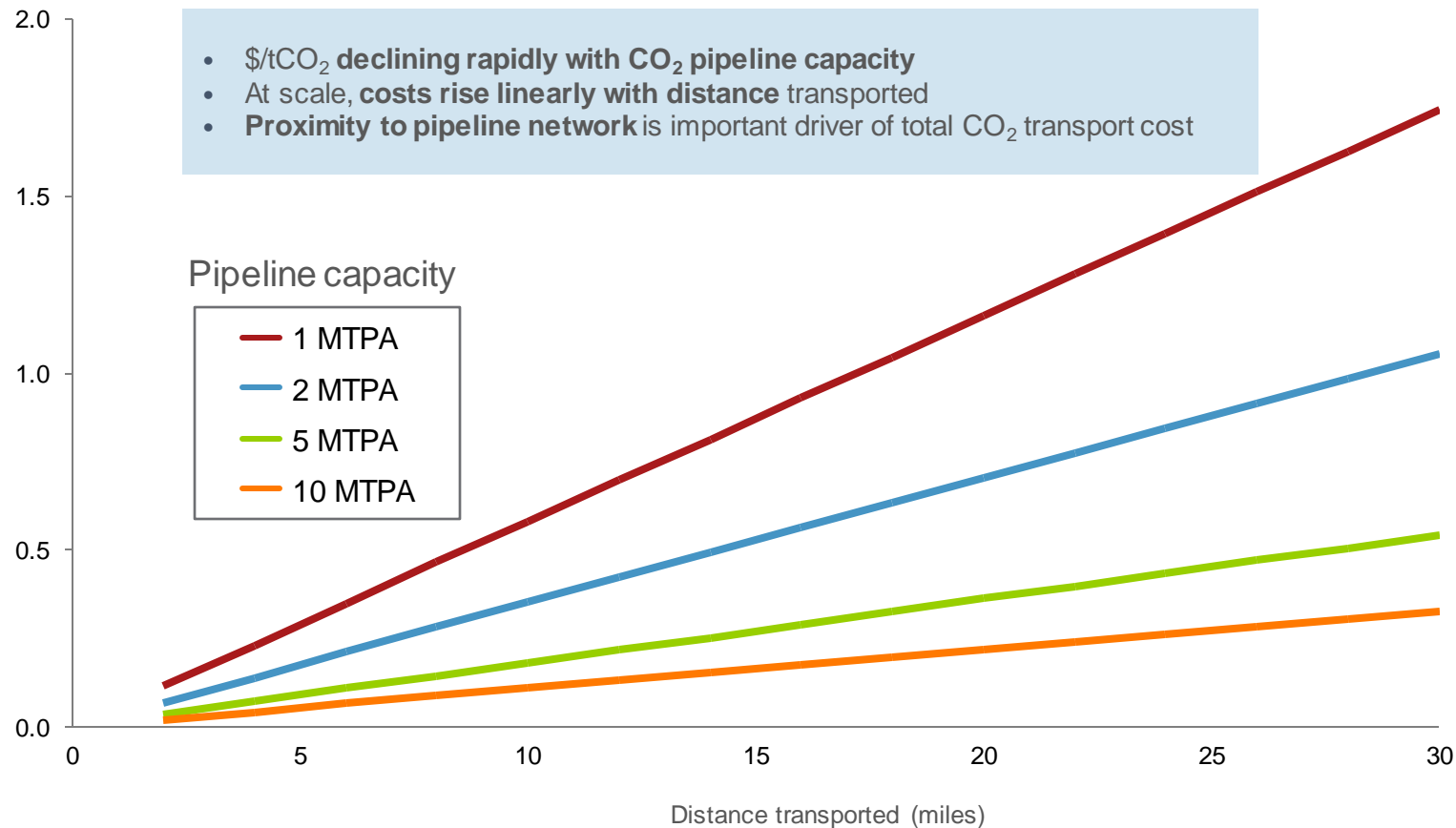
Note: Assuming 8% WACC, 85% utilization rate, 20-year lifetime  
Source: Industry Sources, NPC, IEAGHG, BCG Analysis



## Location

# Carbon capture costs increases proportionally with CO<sub>2</sub> transportation distance, but decline with increasing pipeline capacity

Trunk pipeline total cost (\$/tCO<sub>2</sub>)

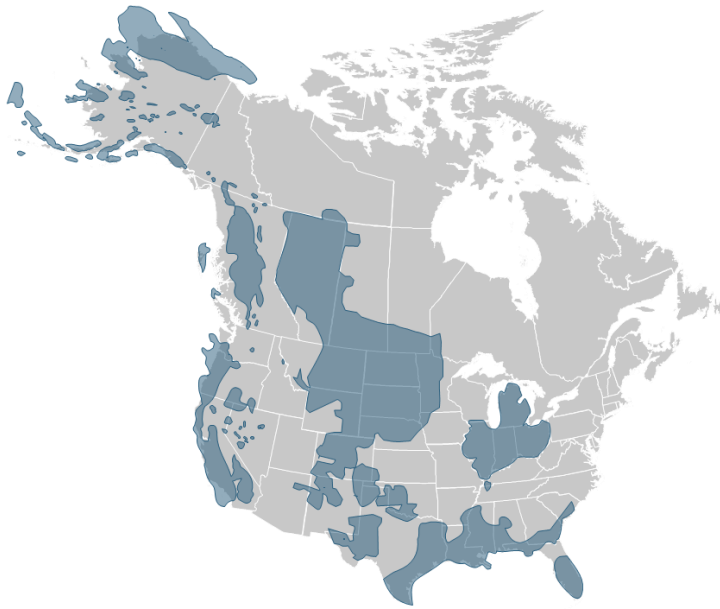


- Pipeline network development is likely necessary to unlock CCS potential for a wider set of industrial players.
- Joint or national development of CO<sub>2</sub> pipeline will accelerate CCS for industrials, who may be currently geographically challenged to deploy CCS

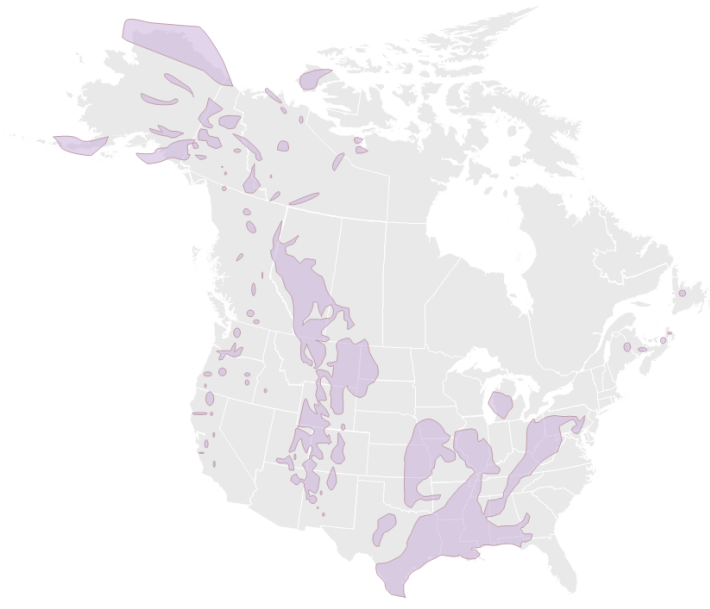


## Location

# Viable geologies for CO2 sequestration available in large portions of North America, providing potential sites for carbon capture and storage



Saline aquifers



Coal/O&G



Basalt deposits<sup>1</sup>

Proven technology, likely solution for short to medium term

Uncertain storage durability

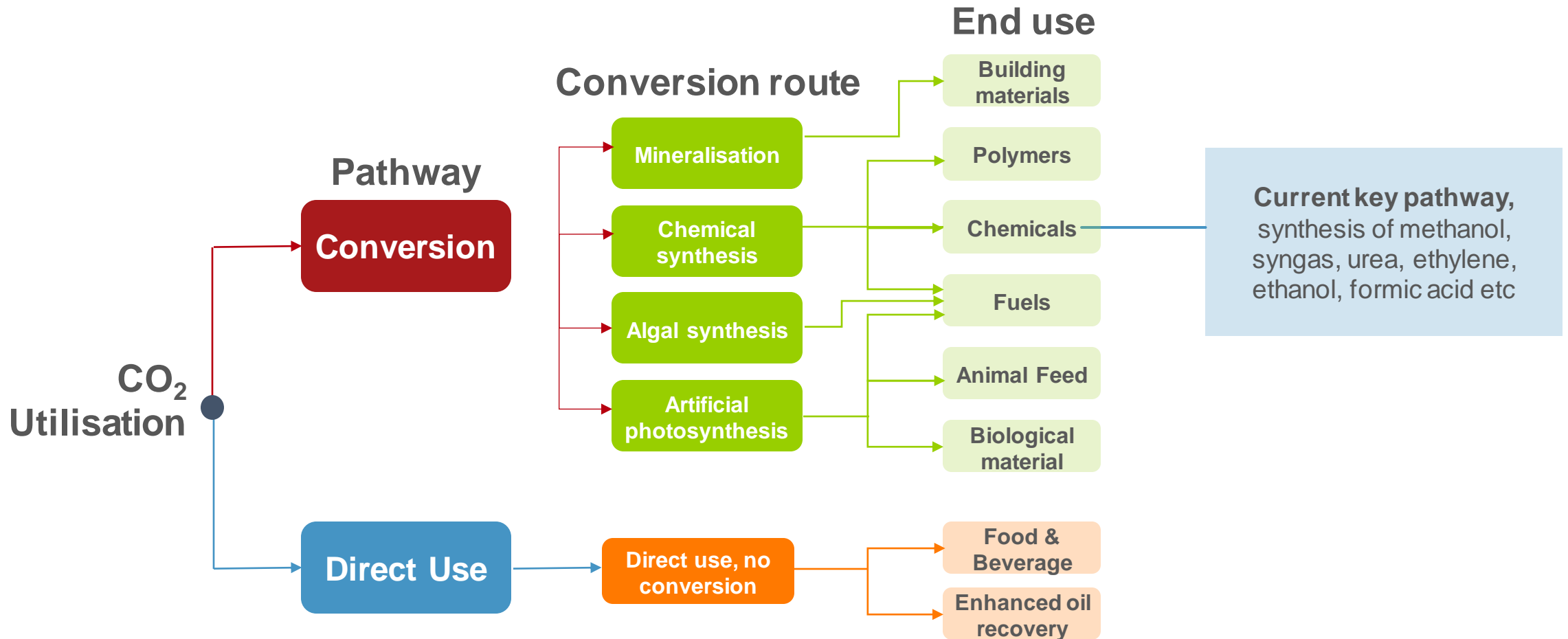
Emerging technology

1. Not yet fully proven but with high expectation as a form of permanent CO2 sequestration given the chemical reactions within basalt to form solid carbonates  
Source: USGS, NETL NATCAB



Location

# Similar to storage, utilization of captured CO<sub>2</sub> also depends on proximity between source of emissions and end use location

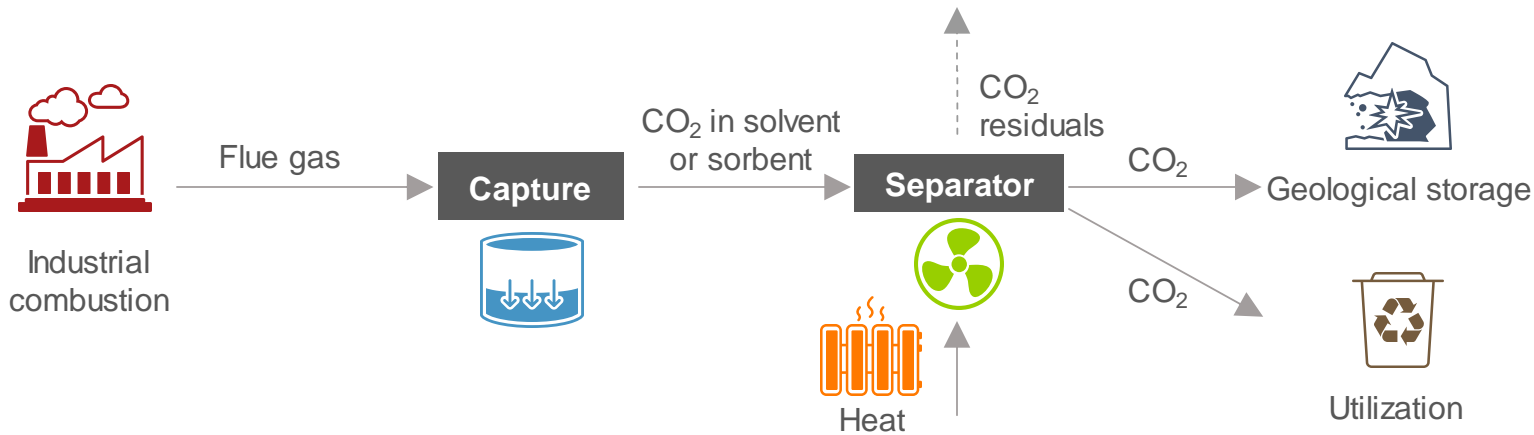






## Source of Heat

# Thermal energy used to drive carbon capture is a major component of CCUS cost



- Existing CCUS systems typically use a solvent (e.g., MEA) to capture CO<sub>2</sub>, while novel CCUS systems are being developed using pressure-swing or electrification processes
- Heat at approximately 120°C is applied to the solvent to release CO<sub>2</sub>
- Depending on flue gas CO<sub>2</sub> concentrations, source of heat, and other factors, cost of solvent regeneration heat can constitute 20-50% of total carbon capture costs per ton of CO<sub>2</sub>
- Waste heat streams is the most effective way to provide heat to drive the carbon capture process

## Forms of regeneration heat (in order of descending cost)

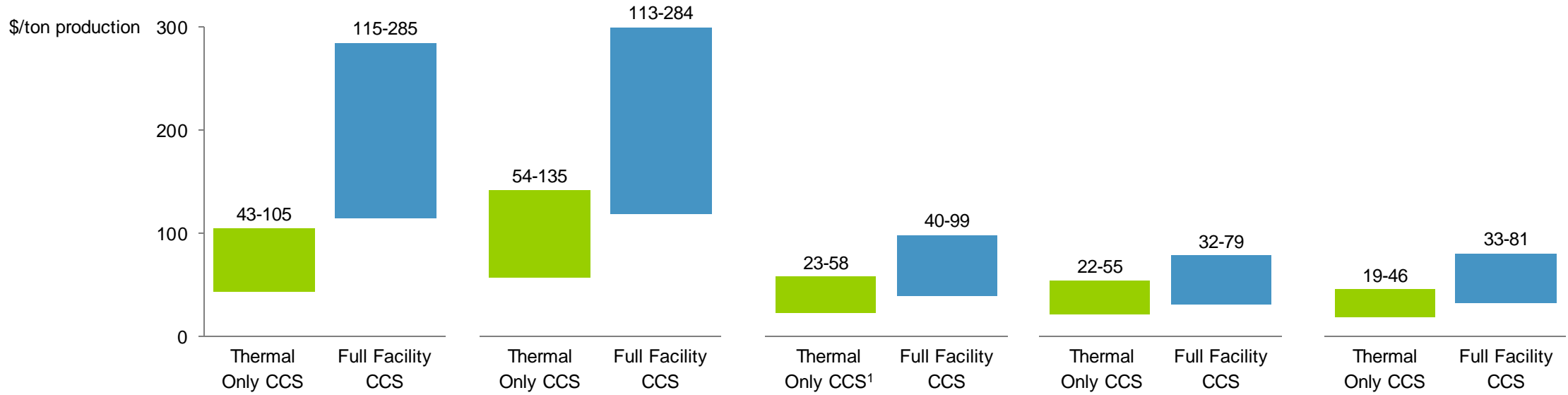
- Electric resistance
- Low temperature steam
- Hot water
- Waste heat streams



## Process Emissions

# Beyond thermal-related CO2 capture, CCS is likely required to decarbonize process emissions in various hard to abate sectors

Range of cost increase per ton of material produced, with coal or natural gas as original heat source



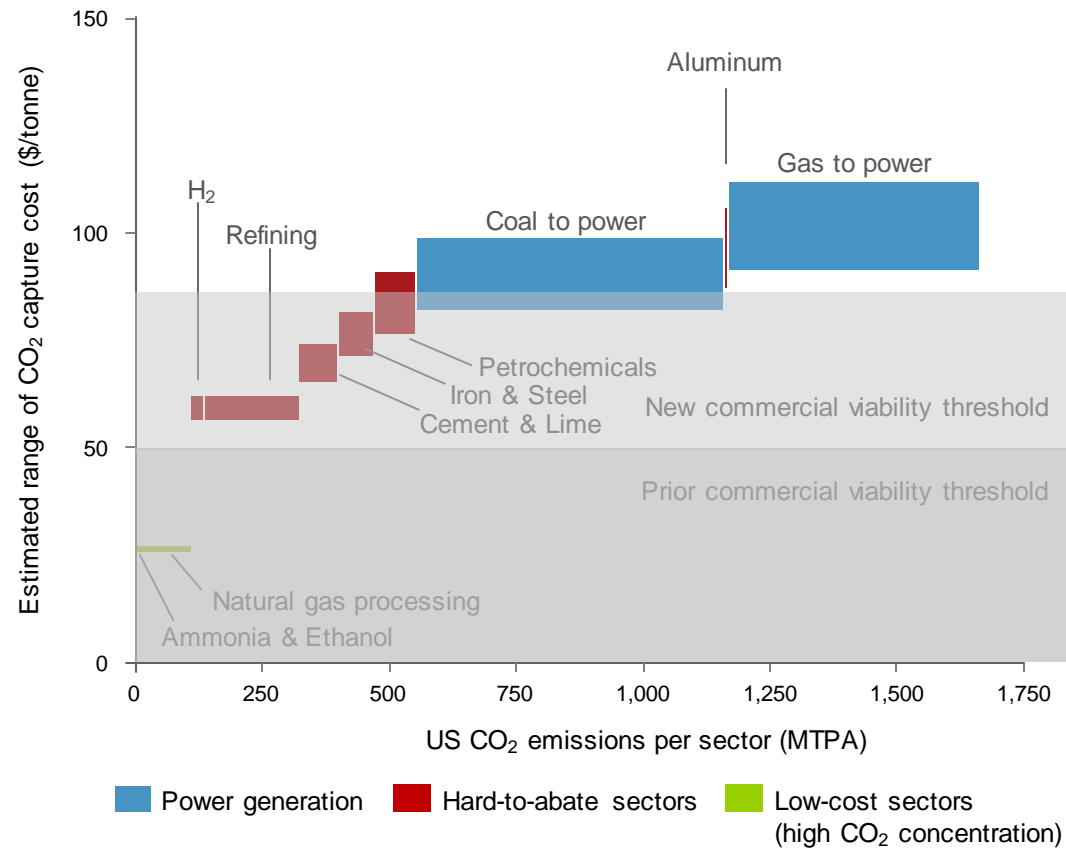
	Ammonia	Steel	Cement clinker	Glass	Methanol
<b>Baseline commodity cost (\$/ton)</b>	500	400	100	300	430
<b>Original heat source</b>	Natural gas	Coal	Coal	Natural gas	Natural gas
<b>CCUS as part of sector decarbonization</b>	Required in short term	Required in short to medium term	Required	Low requirement	Low requirement

1. Cement clinker production likely not able to separate thermal vs full facility emissions in kiln | Source: Columbia University

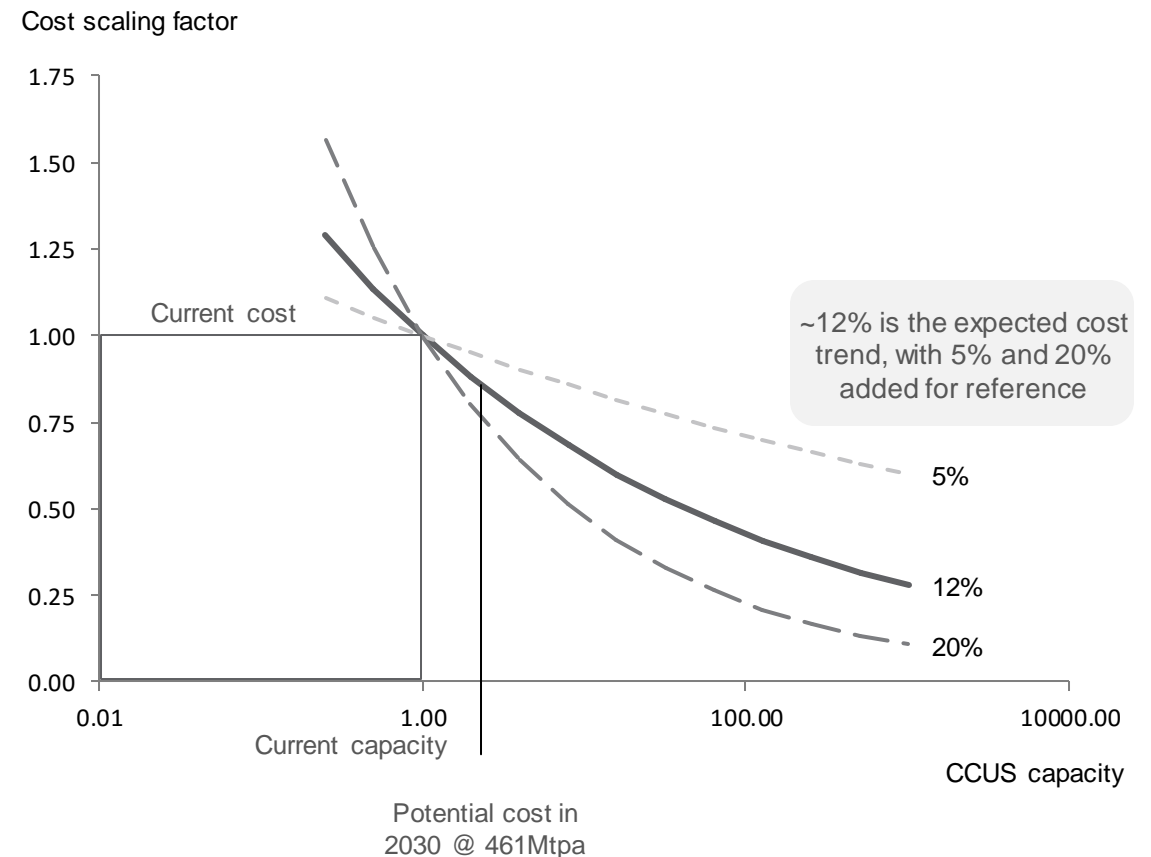


# Inflation Reduction Act increases 45Q tax credits to \$85/t making CCUS potentially viable for refining, hydrogen, cement, & steel sectors

\$85/ton incentives significantly expand CCUS commercial viability

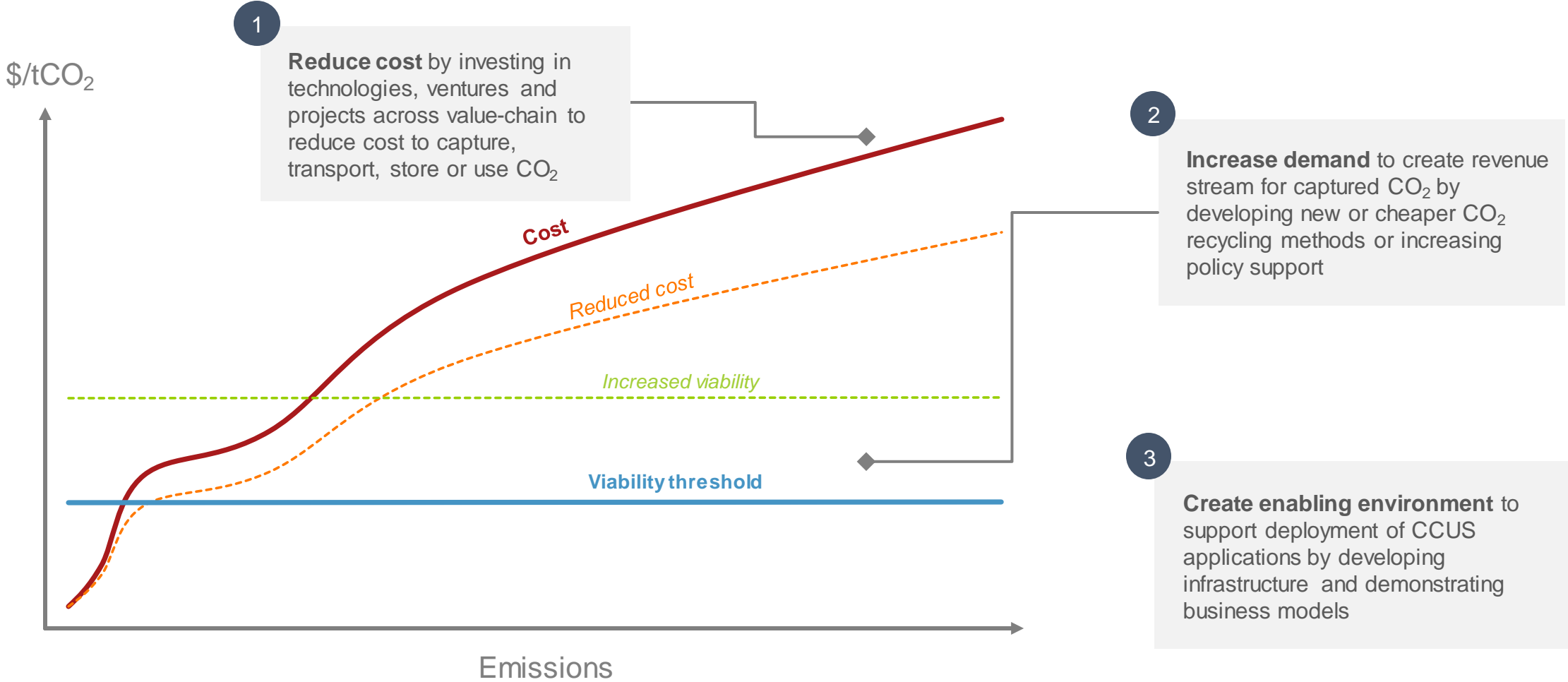


...and further cost reductions of ~12% are expected as deployment doubles, making coal+CCUS potentially viable



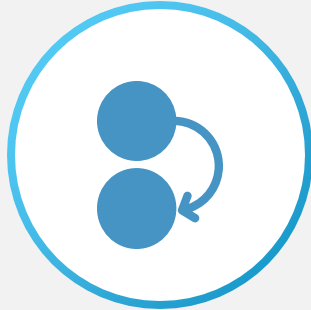


# Three broad strategies can increase the viability of CCUS for industrial heating decarbonization

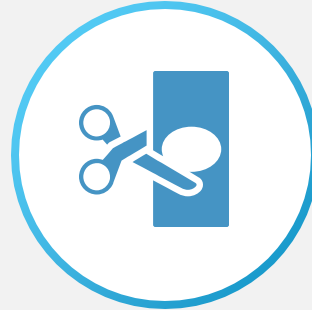


# CCUS for industrial heating decarbonization has many advantages and unique features, but faces several key barriers to adoption

## Advantages



No major modification required to the industrial process



May be more cost effective than alternative renewable heating options



Technical capacity to store CO2 underground is functionality unlimited



Can simultaneously capture CO2 from process emissions

## Barriers



Cost can be high and does not add value unless there is a price on carbon



Extensive supplemental infrastructure required



Non-renewable and not a long-term solution



Does not capture 100% of CO2 emissions

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