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SUSTAINABLE ENERGY CONSULTING

SPEE
SOCIETY OF PETROLEUM EVALUATION ENGINEERS

CARBON CAPTURE, UTILIZATION, & STORAGE (CCUS) VALUE CHAIN

SEPTEMBER 1, 2021

Risk Assessment Feasibility Studies Economic Due Diligence United Nations Classification Framework

Utilization and Sequestration Authenticate Greenhouse Gas Assertions Surface and Sub-Surface Integration

INTRODUCTION TO THE VALUE CHAIN

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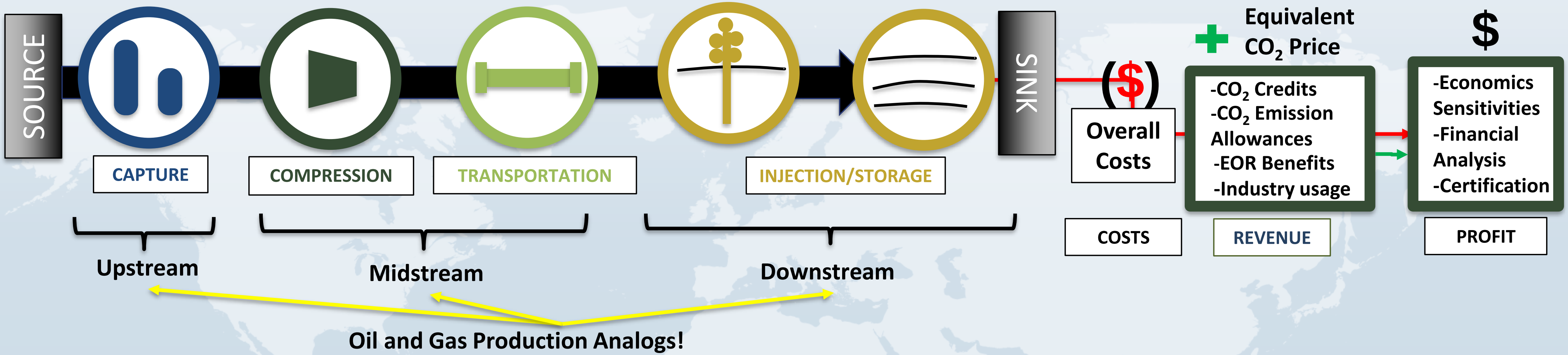
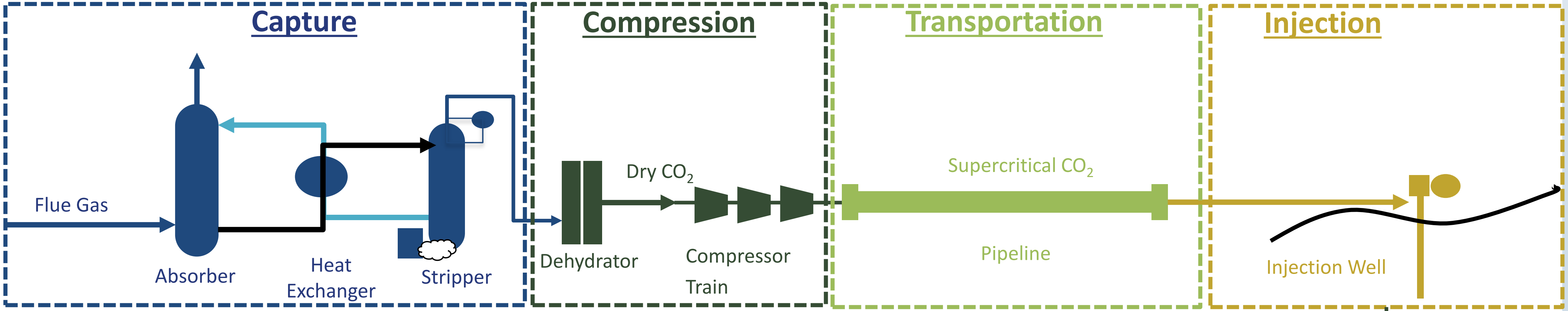


Surface	Sub-Surface	Commercial
Carbon production, capture, transportation, and injection facilities: - Capture Configuration and Technology - Compression & Transportation design - Injection well design for handling CO_2	• Capacity, containment, and injectivity for CO_2 storage reservoirs. • Integrated EOR modeling and studies generate optimized development plans.	• Carbon and climate policies and regulations from capture to point of sale or reservoir to determine the economic benefit • Certification of CO_2 reserves and EOR projects (SPE-SRMS)

*CCS & CCUS is interchangeably used wherein CCS is Carbon Capture and Storage/Sequestration and CCUS – Carbon Capture, Use/Utilization, and Storage/Sequestration

CASE STUDY 1: POWER PLANT CCUS PROJECT

Specifications: Post-combustion carbon capture from a coal power plant; Capturing 1.4 MTPA from 240 MW boiler; 82 mile pipeline, 12” diameter, CO_2 transported in supercritical state; Injection for EOR



- CO_2 injected for EOR – CO_2 will remain in the reservoir as a result
- Economics driven by:
  - Oil price: At what price does incremental oil recovery generated by miscible CO_2 injection justify cost to build/operate facility?
  - 45Q Tax Credit: Generates tax offset varying depending on end-use of CO_2

ANALYZING RAPID MARKET GROWTH

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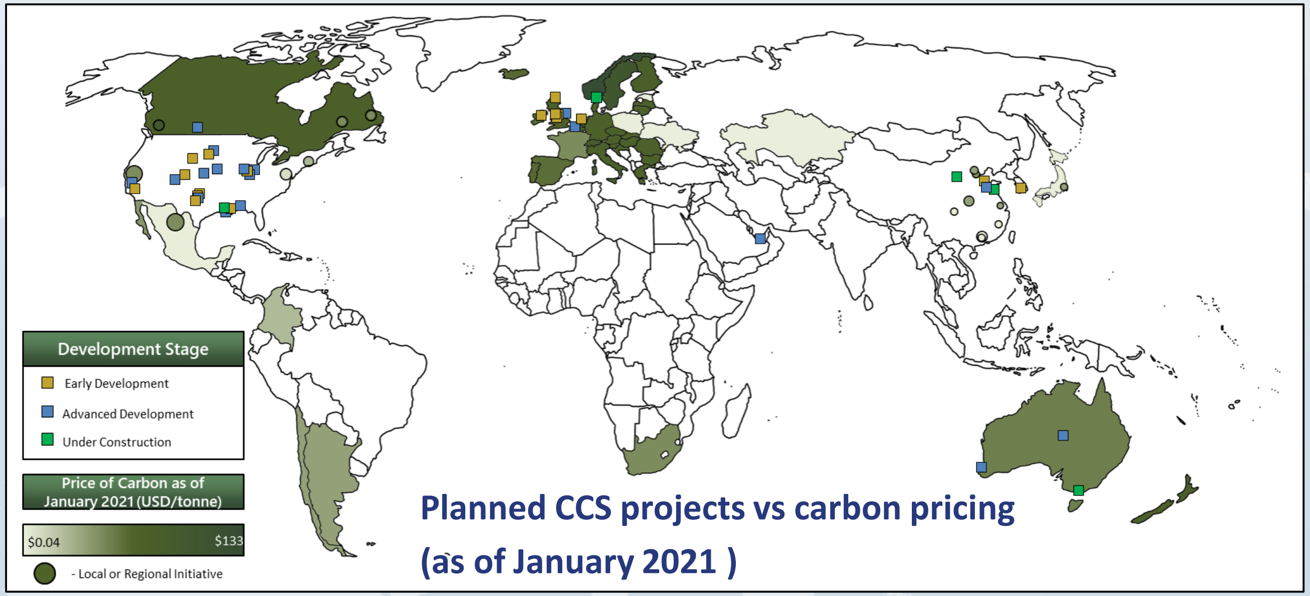
Intergovernmental Panel on Climate Change (IPCC) set a goal of limiting global temperature increase to 1.5 °C in 2015

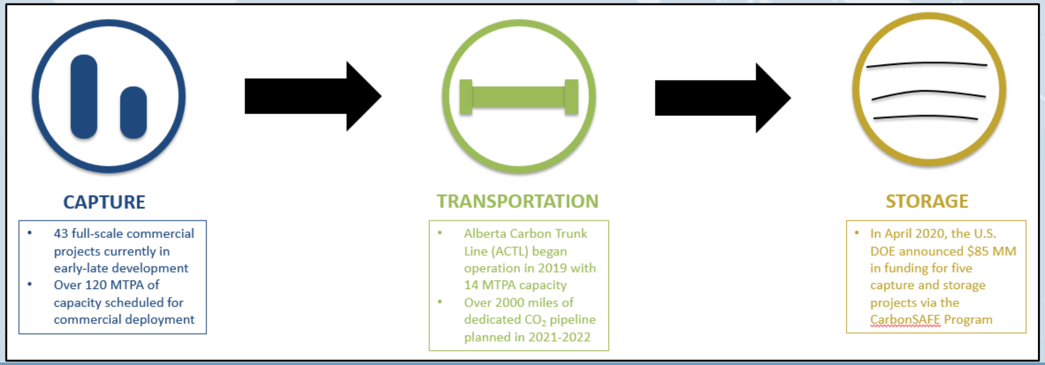
5,635 MTPA Carbon Capture required by 2050 estimated by Global CCS Institute versus 39 MTPA deployed today

- Majority in U.S., Northern Europe, and China
- Carbon pricing is generally uncertain across projects and is tied to geography
- US Projects in advanced development due to carbon incentive (45Q) speculation
- Projects in Europe generally are in early development



Planned CCS projects vs carbon pricing (as of January 2021)

Project Growth Across the Value Chain



DE-MYSTIFYING CARBON CAPTURE

Capture **Configuration** location of CO_2 capture in the stream flow and general source of CO_2

Capture **Technology** process technology used to separate CO_2 from other components to generate a pure CO_2 stream

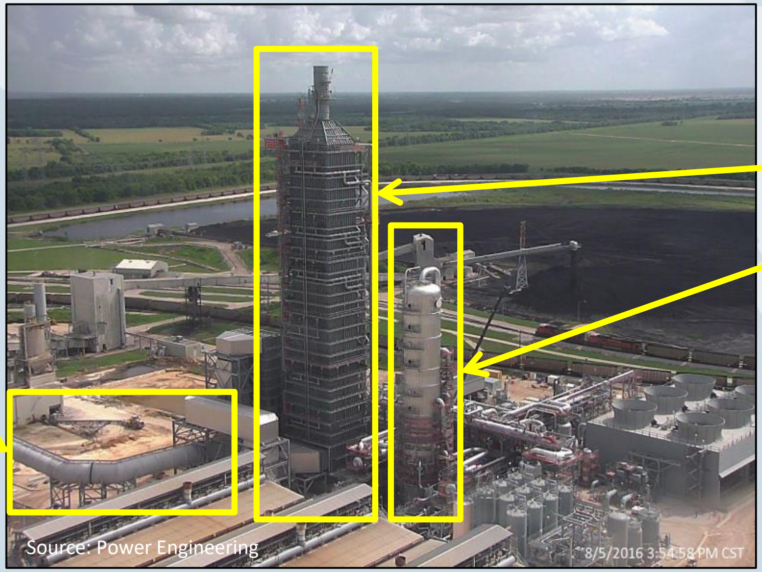
- Combustion (Post & Pre) configuration dominates while Absorption technology is less risky and most deployed
- Post-combustion capture is almost exclusively used with absorption technology, while pre-combustion capture typically uses adsorption, but can use absorption as well.

Example: Petra Nova CCUS - Thompsons, TX

Configuration:
Post-Combustion

CO_2 captured after combustion occurs from coal-fired power plant

Flue gas stream from power plant exhaust



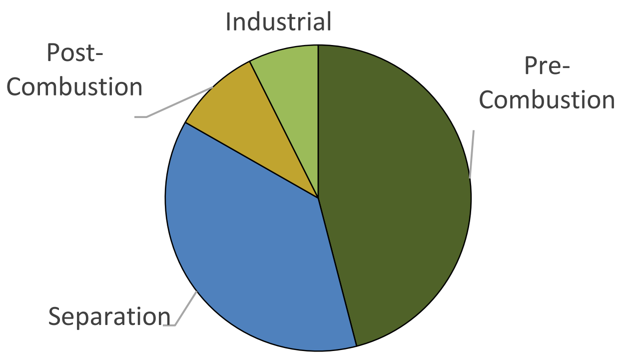
Technology:
Absorption

Absorber Column

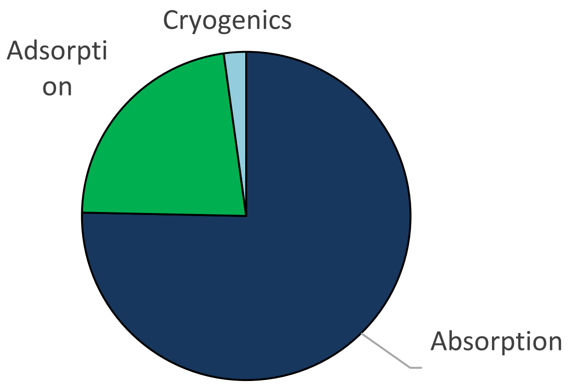
Stripper Column

Absorber and stripper used as component of absorption technology

Capture Configuration



Capture Technology



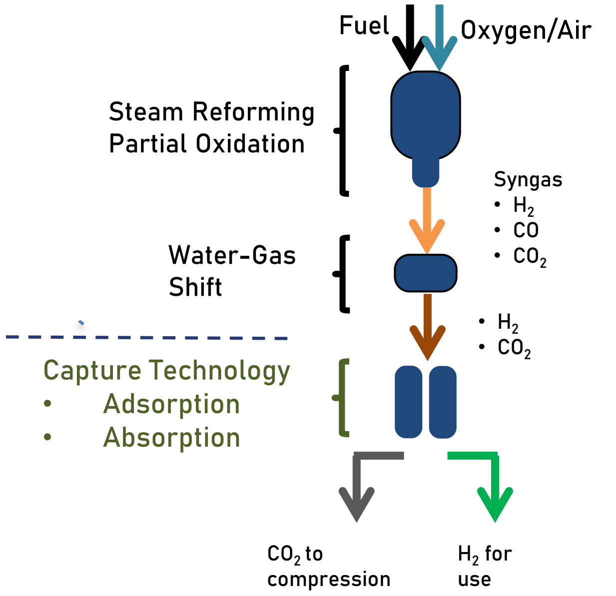
Currently Deployed CCS Projects

CAPTURE CONFIGURATIONS

Pre-Combustion Capture

Sources:

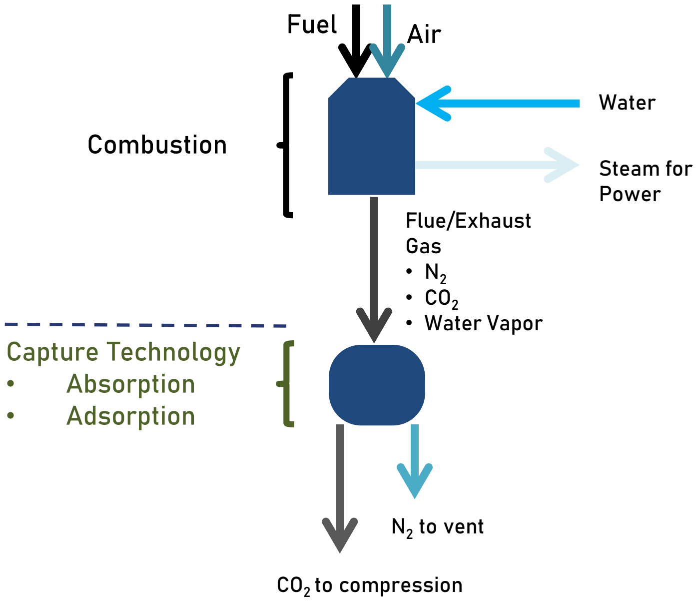
- Hydrogen Production
  - Refining
  - Ammonia Production
  - Fertilizers
  - Petrochemicals
- Power Generation



Post-Combustion Capture

Sources:

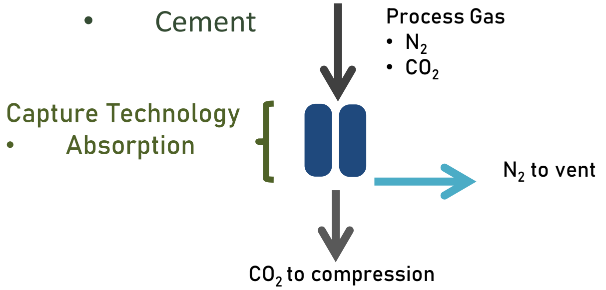
- Power Generation
- Gas Processing
- Iron/Steel Production
- Refineries
- Cement Production



Industrial Capture

Source:

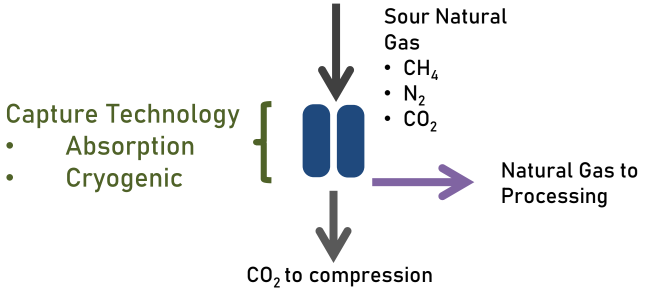
- Steel Production
- Cement



Separation

Sources:

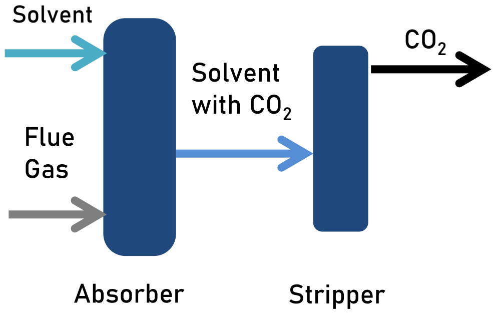
- Natural Gas Processing



CAPTURE TECHNOLOGIES

Absorption

Most deployed technology



Latest advancements have focused on:

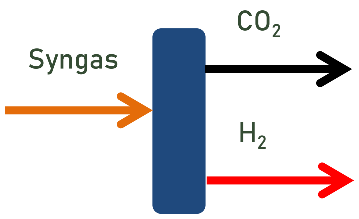
- Optimizing solvent or process
- Refrigerated Ammonia solvent
- CaO looping

Adsorption Example: Vacuum Swing Adsorption at Air Products' Port Arthur SMR

1. SMR reforms natural gas to produce syngas (carbon monoxide and hydrogen gas)
2. Water-gas shift reactor used CO and H_2O to produce more H_2 and CO_2
3. Vacuum Swing Adsorption separates CO_2 and H_2
4. CO_2 gas is dehydrated and compressed

Adsorption

Used in applications where hydrogen or syngas is needed



- Latest advancements have focused on improving the sorbent or catalyst
- Used in fertilizer plants, refineries

Membrane Separation

- Selective membrane only lets certain gas species across
- High pressures required
- Advancements focusing on improving membrane material

Cryogenic Separation

- Physical process reduces temperature to separate CO_2
- Not commercially mature – low temperatures require high amounts of energy

CO_2 FLUID CHARACTERISTICS

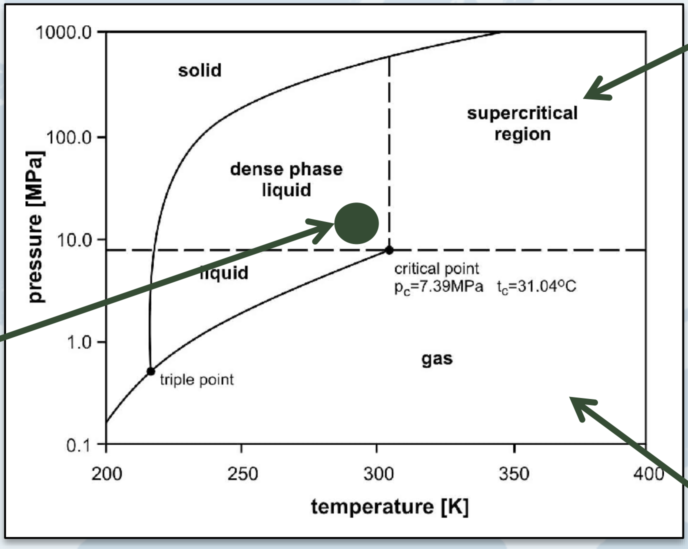
Depending on the technical and commercial requirements of project, CO_2 may be transported in different physical states.

Dense Phase

- The dense phase has a viscosity similar to gas but a density similar to liquids
- Typical CO_2 transportation is performed at 10 – 15 MPa and 15 – 30 °C to maintain dense phase

Example:

Abu Dhabi CCS Phase 1



CO_2 phase diagram

Supercritical Phase

- The supercritical phase is similar to dense phase, but is neither a liquid nor a gas
- Higher pressure drops over the same distance when compared to dense phase

Example:

Hilcorp West Ranch

EOR Pipeline

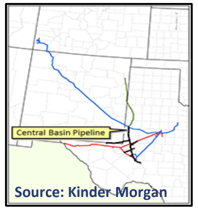
Gas Phase

The low density of gas phase means less capacity is available to transport but does not require high cost of compression to liquid phase

Example:

Kinder Morgan Central

Basin CO_2 Pipeline



CO_2 COMPRESSION CONSIDERATIONS

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Dehydration is required to minimize corrosion and can be accomplished using:

- Cryogenic dehydration
- TEG (Tri-ethylene glycol) dehydration

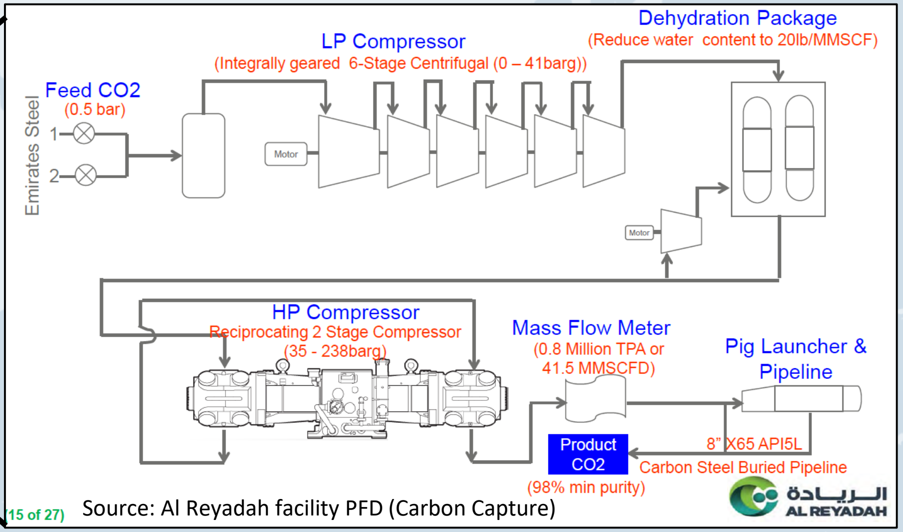
For liquid CO_2 transportation compression is required to shift CO_2 into dense phase

- Centrifugal good for high volume
- Reciprocating good for high pressures

Source: CSL Forum

ADNOC's Al Reyadah Carbon Capture Facility

Al Reyadah PFD showing dehydration and compression



Source: Al Reyadah facility PFD (Carbon Capture)

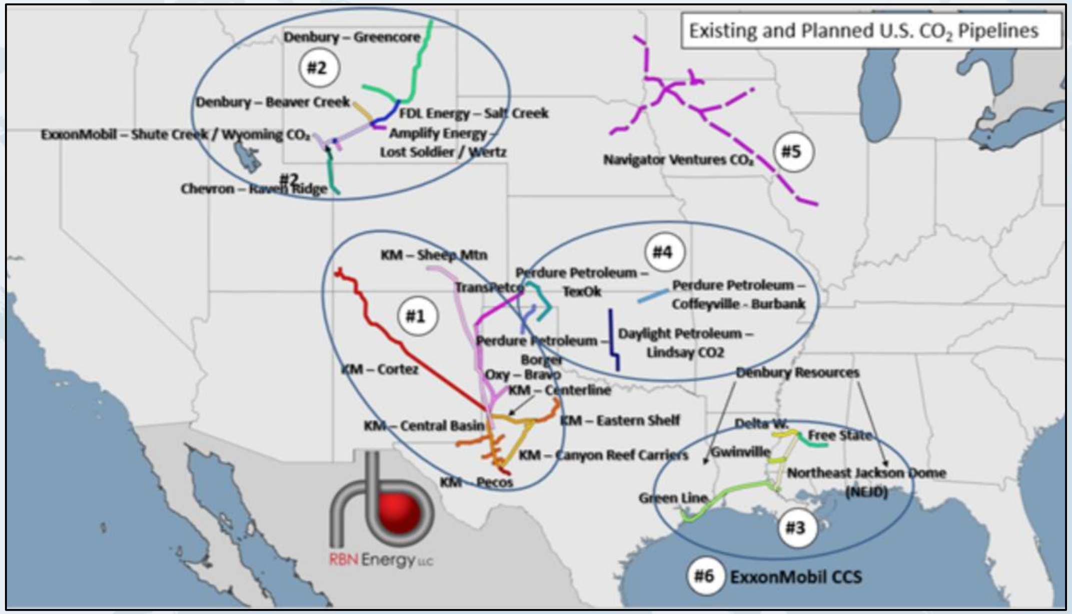
TRANSPORTATION VIA PIPELINES

CO_2 Pipelines differ in some critical considerations compared to oil & gas pipelines:

- Corrosion Protection: Because CO_2 forms carbonic acid in the presence of water, it is necessary to ensure high CO_2 purity through dehydration before entering the pipeline. Internal coating is often required to extend long pipeline operating life.
- Operating conditions: Maintaining operating conditions within certain pressure and temperature ranges is required to prevent CO_2 phase transition

Pipeline Growth in the Industry

- As of 2018, over 5000 miles CO_2 pipelines exist worldwide (Compared to 4000 mi in 2013, 1500 mi in 2007)



Map of Existing and Planned CO_2 Pipelines as of June 2021

CO_2 FOR EOR AND LONG-TERM STORAGE

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EOR and Injection Considerations

-CO_2 availability (natural or anthropogenic)
-Corrosion resistant equipment, 316 SS, Glass Reinforced Epoxy (GRE), Internally Plastic Coated (IPC) CS, CRAs
-Leak monitoring during injection and after abandonment
-Appropriate reservoir conditions

Criteria for Screening Reservoirs for CO_2 EOR Suitability

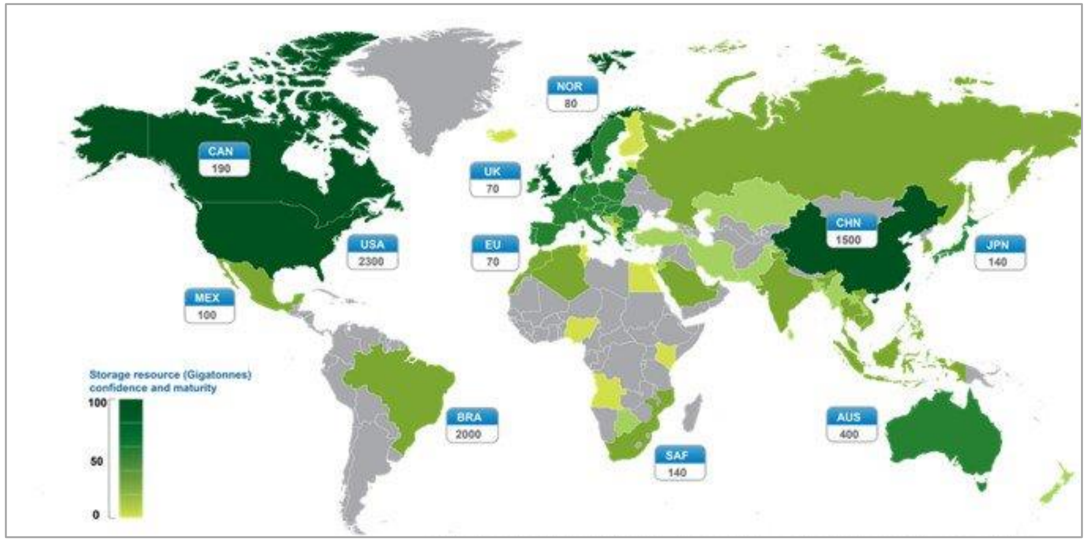
Depth, ft	< 9,800 and >2,000
Temperature, °F	<250, but not critical
Pressure, psia	>1,200 to 1,500
Permeability, md	>1 to 5
Oil gravity, °API	>27 to 30
Viscosity, cp	≤10 to 12
Residual oil saturation after waterflood, fraction of pore space	>0.25 to 0.30

CO_2 Sequestration Potential

Ample Storage Capacity

USA	Brazil	China	Australia	Canada	South Africa	Japan	Mexico	Norway	United Kingdom	European Union
2300	2000	1500	400	190	140	140	100	80	70	70

*All Values in Gigatonnes



Global CCS Institute (November 2017)

Storage Projects

Deep Saline Formations

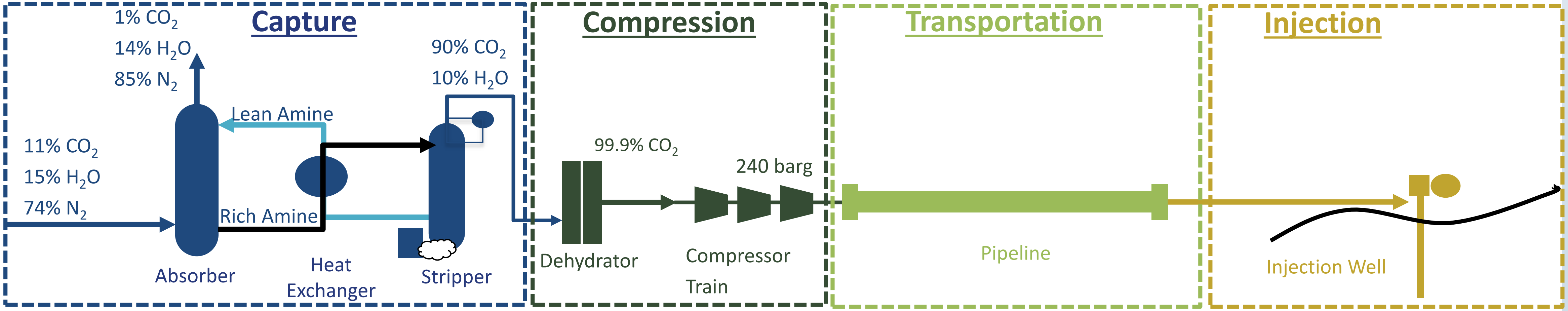
- Sleipner (Norway) 1996 – Current; Gas Processing Facility; 1 MTPA
- Gorgon (Australia) 2018 – Current; Gas Processing Facility; 4 MTPA

Depleted Oil and Gas Reservoirs

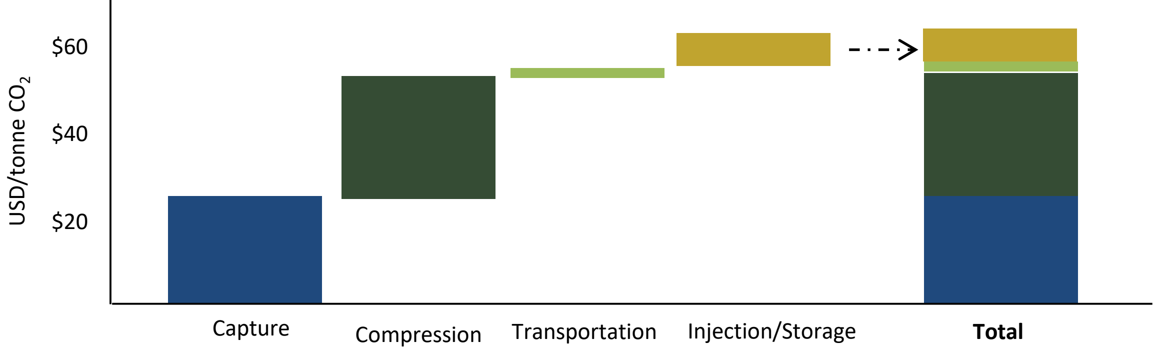
- In Salah (Algeria) 2004 – 2011; Gas Processing Facility; 1.2 MTPA

CASE STUDY 1: POWER PLANT CCUS REVISITED

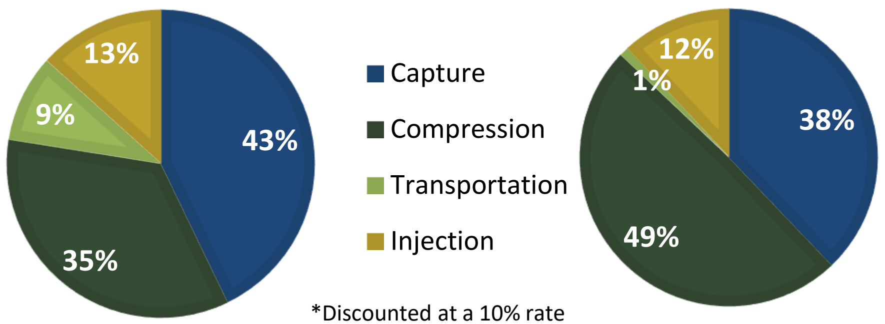
Specifications: Post-combustion carbon capture from a coal power plant; Capturing 1.4 MTPA from 240 MW boiler; 82 mile pipeline, 12" diameter, CO_2 transported in supercritical state; Injection for EOR



Breakeven Price (BEP) Analysis*



CAPEX – 52% of project cost	OPEX – 48% of project cost



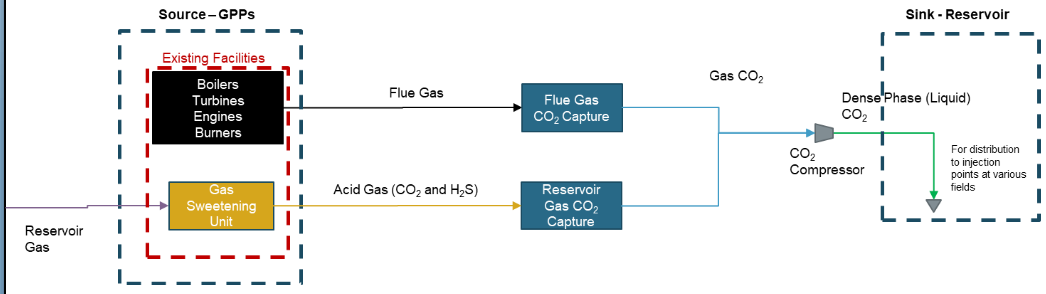
*Discounted at a 10% rate

CASE STUDY 2: NATURAL GAS PROCESSING CCS CONCEPT COMPARISON

Scope of Work

The client wanted an idea of potential capture concepts and costs for multiple natural gas processing plants located in the same region:

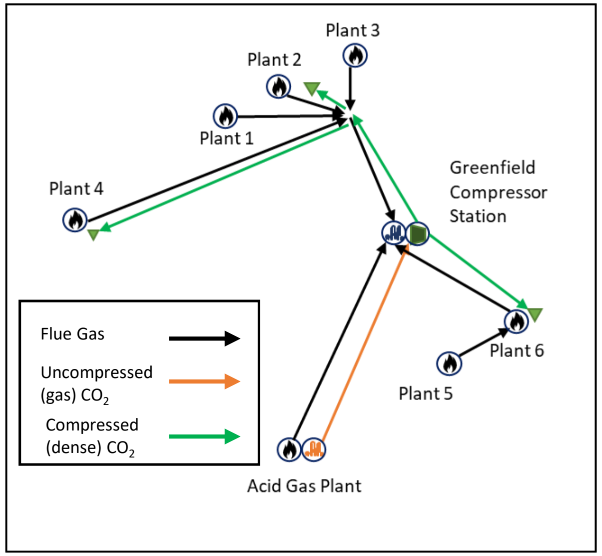
- Seven gas processing plants provided CO_2 from flue gas from on-site power generation – One plant additionally provided CO_2 from reservoir gas.
- We looked at nine different concepts – varying the capture and compression configuration of the plants and estimated CAPEX, OPEX, and \$/tonne CO_2 captured for all concepts



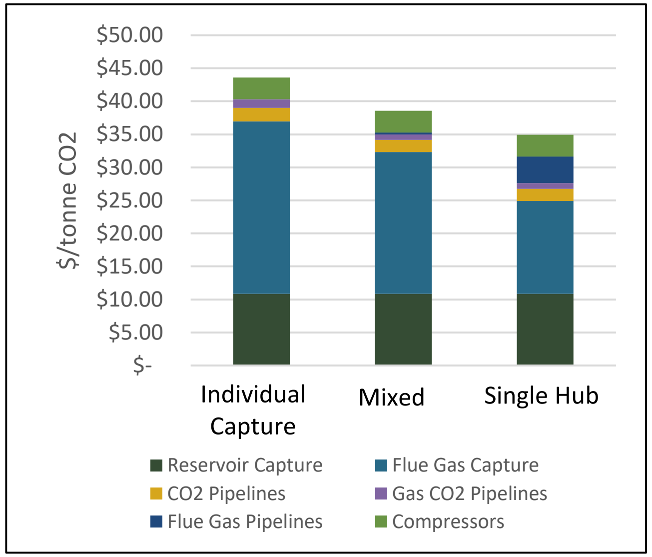
Technical Features

- 5.28 MTPA CO_2 captured
- Over 10 Bscfd of natural gas processed
- Post-combustion absorption considered as commercially mature capture technology
- Greenfield compressor station able to process 432 MMscfd pure CO_2 from 6 barg to 240 barg using 92,600 HP of compression
- Flue gas, gas CO_2, and dense-phase CO_2 pipeline lengths differed based on the concept evaluated

Example Facility and Pipeline Diagram



$/tonne CO_2



Conclusions

- Based on our analysis, we concluded that capturing CO_2 at a single location instead of individually at each plant would significantly reduce overall project costs

STRATEGIES TO REDUCING BREAKEVEN PRICE

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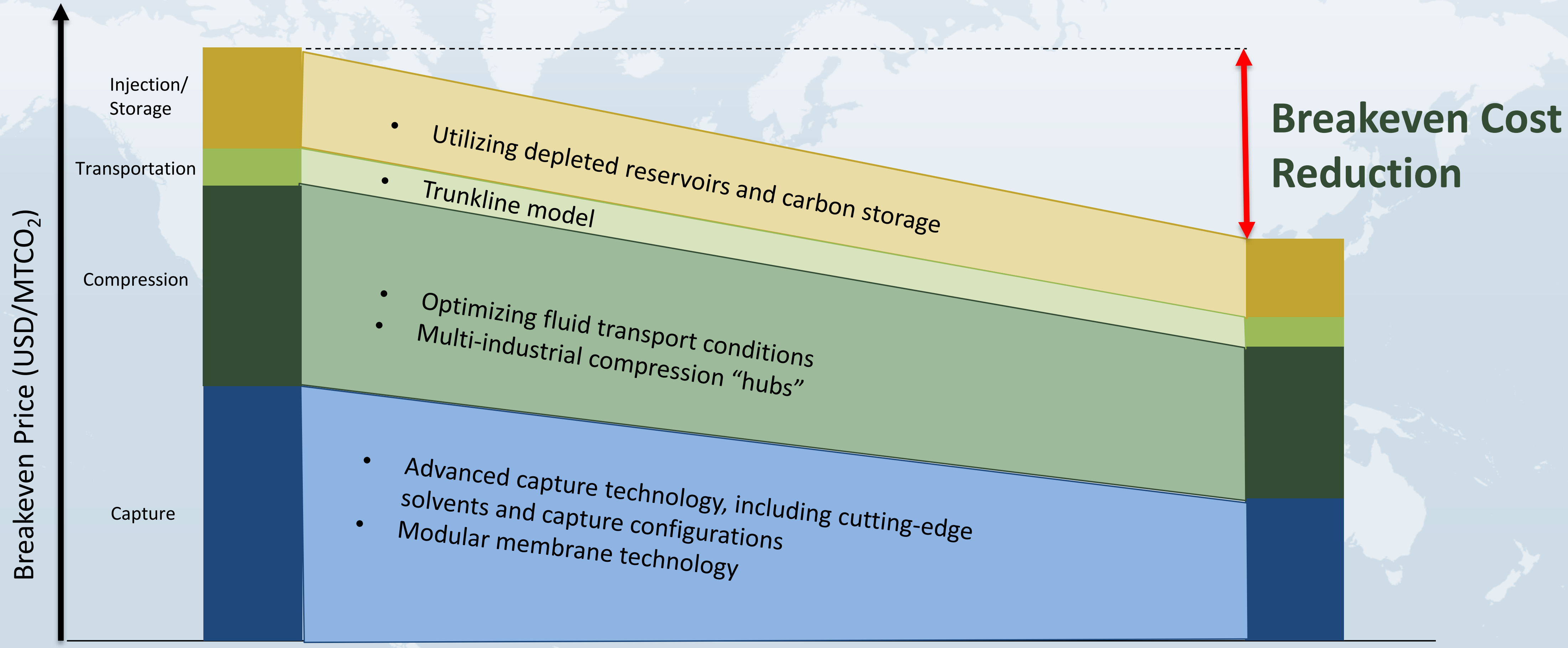
What are some examples of key potential drivers for reducing cost/tonne CO_2 captured?



REVIEWING POLICY CONSIDERATION

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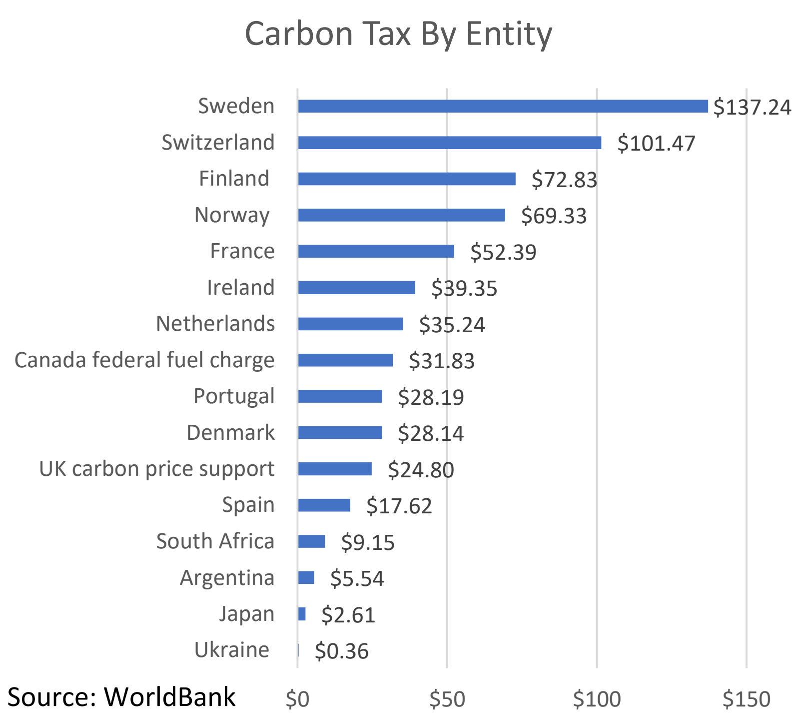
Approaches to price of carbon

Carbon Tax (CO_2/tonne)



Carbon Tax Pricing of Various Countries as of July 14, 2021

Emission Trading System (ETS)

- An emissions trading system generally works by the “cap and trade” system. The government establishes a maximum amount of emission allowances (the “cap”) and distributes them to different facilities either freely or by auction.
- Facilities are then free to trade excess emission allowances as needed. An under-emitting facility can profit by selling allowances to a facility which is projected to over-emit.

Tax Credit (45Q)

- U.S. Tax Credit expanded in 2018 to increase the value of utilizing CO_2 for EOR or long-term sequestration
- Facilities must be under construction by January 1, 2026

	2018	…	2026
Enhanced oil recovery (EOR)	$17	…	$35
Dedicated geological storage	$28	…	$50

Risk Assessment

United Nations Classification Framework

Sub-Surface Integration

Sequestration

Economic Due Diligence

Utilization

Authenticate Greenhouse Gas Assertions

Surface Integration

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THANK YOU!

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