WHEN TRUST MATTERS

DNV

Carbon Capture and Storage

Finansanalytikeres Forening

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Erik A. Hektor

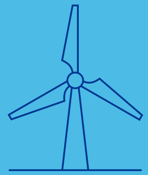
- More than 18 years of experience in the energy industry, with a focus on CCUS Technologies.
- Working experience:
  - 2003-2008 at Chalmers University of Technology as PhD student
  - 2008-today at DNV as Principal Researcher / Consultant working on emissions abatement including CCUS
- Educational background:
  - MSc Chemical Engineering – Chalmers University of Technology (Sweden)
  - PhD Energy and Environment – Chalmers University of Technology (Sweden)
    - Thesis: Post-Combustion CO_2 Capture in Kraft Pulp and Paper Mills

An independent assurance and risk management company

157	~12,000	100,000	100+	5% R&D
years	employees	customers	countries	of annual revenue

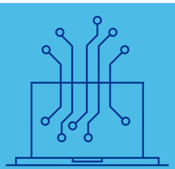
Ship and offshore classification and advisory

Energy advisory, certification, verification, inspection and monitoring



Management system certification, supply chain and product assurance

Software, platforms and digital solutions



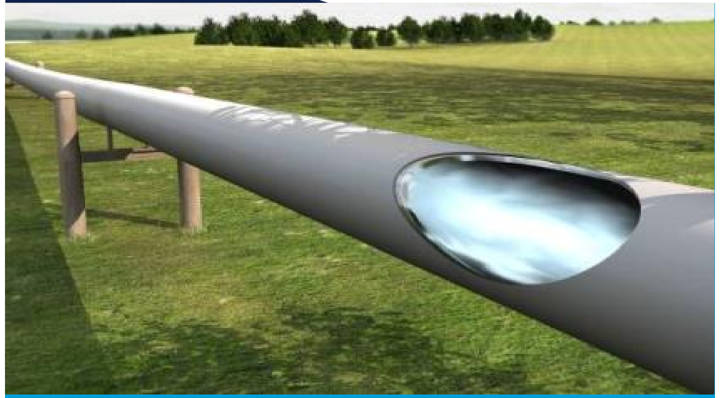
Helping scale CCS – 200+ projects in past 10 years

CAPTURE

- Fossil power plants
- Natural gas CO_2 reduction
- Other industrial processes

- Cost estimations
- Introduction of new technologies
- Technology review and benchmarking
- Up-scaling risk assessment
- HSE risk assessment
- Accidental release and dispersion
- Value of avoided CO_2

TRANSPORT



- Pipelines
- Ships

- Corrosion
- Material selection and structural design
- Flow assurance and operational issues
- Accidental release and dispersion
- Concept design for CO_2 ships
- Requalification of infrastructure

STORAGE

- Depleted oil or gas reservoirs
- Saline aquifers
- Enhanced oil recovery (EOR)

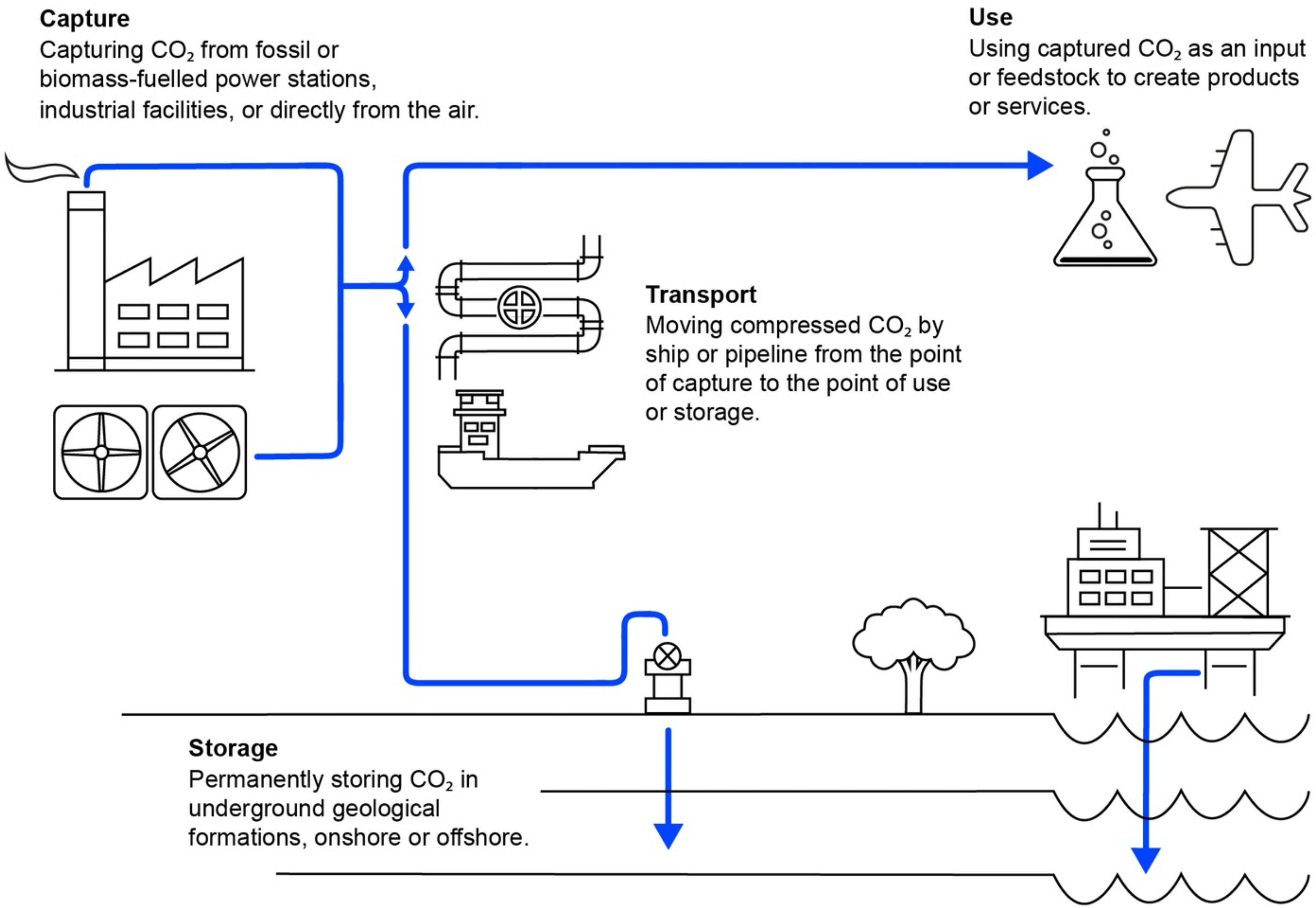
- Verification of storage sites
- Permanence of storage
- Risk management
- Monitoring and verification
- Public concern
- Transfer of responsibility

Content

1. **Introduction to CCUS**
    - Overview of current status and trends
2. **CO_2 capture technologies**
    - Basics of CO_2 capture
    - State of art technologies & Innovations
3. **CO_2 Transport – methods and infrastructure**
4. **CO_2 Storage – potential worldwide and storage types**
    - Storage capacity and distribution globally
5. **Cost of a CCS value chain**

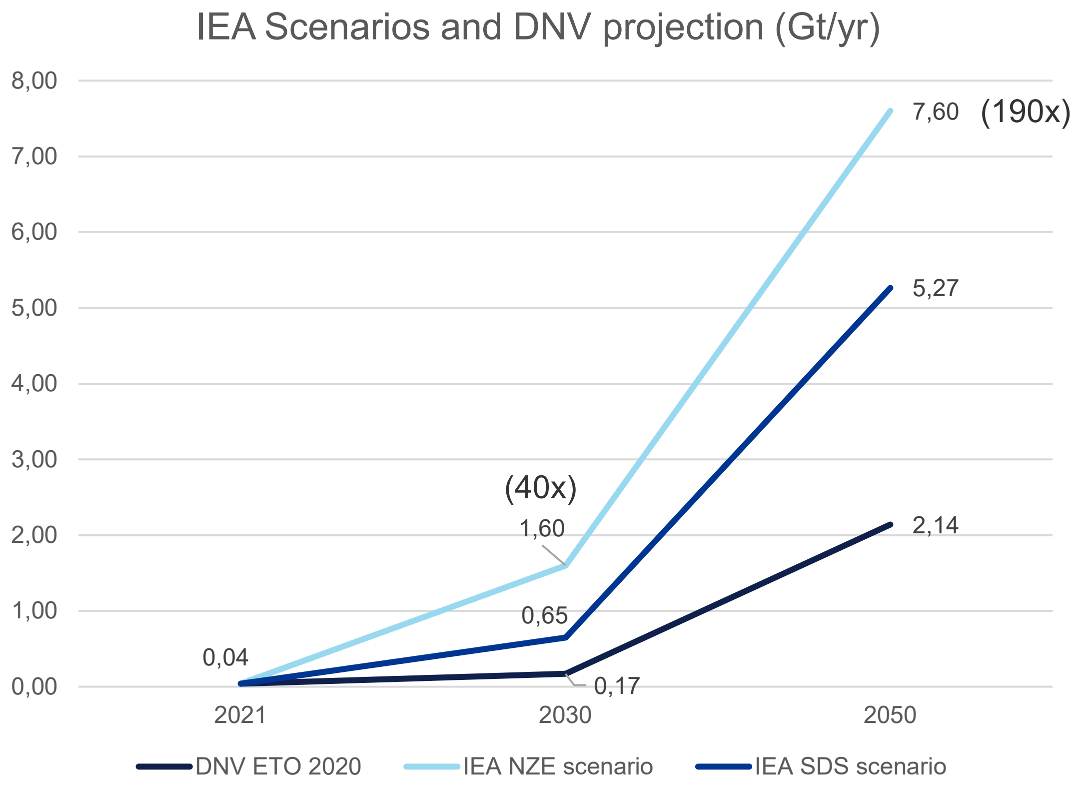
1. General Introduction

Carbon Capture Utilization and Storage



Current CCUS volume and future projections

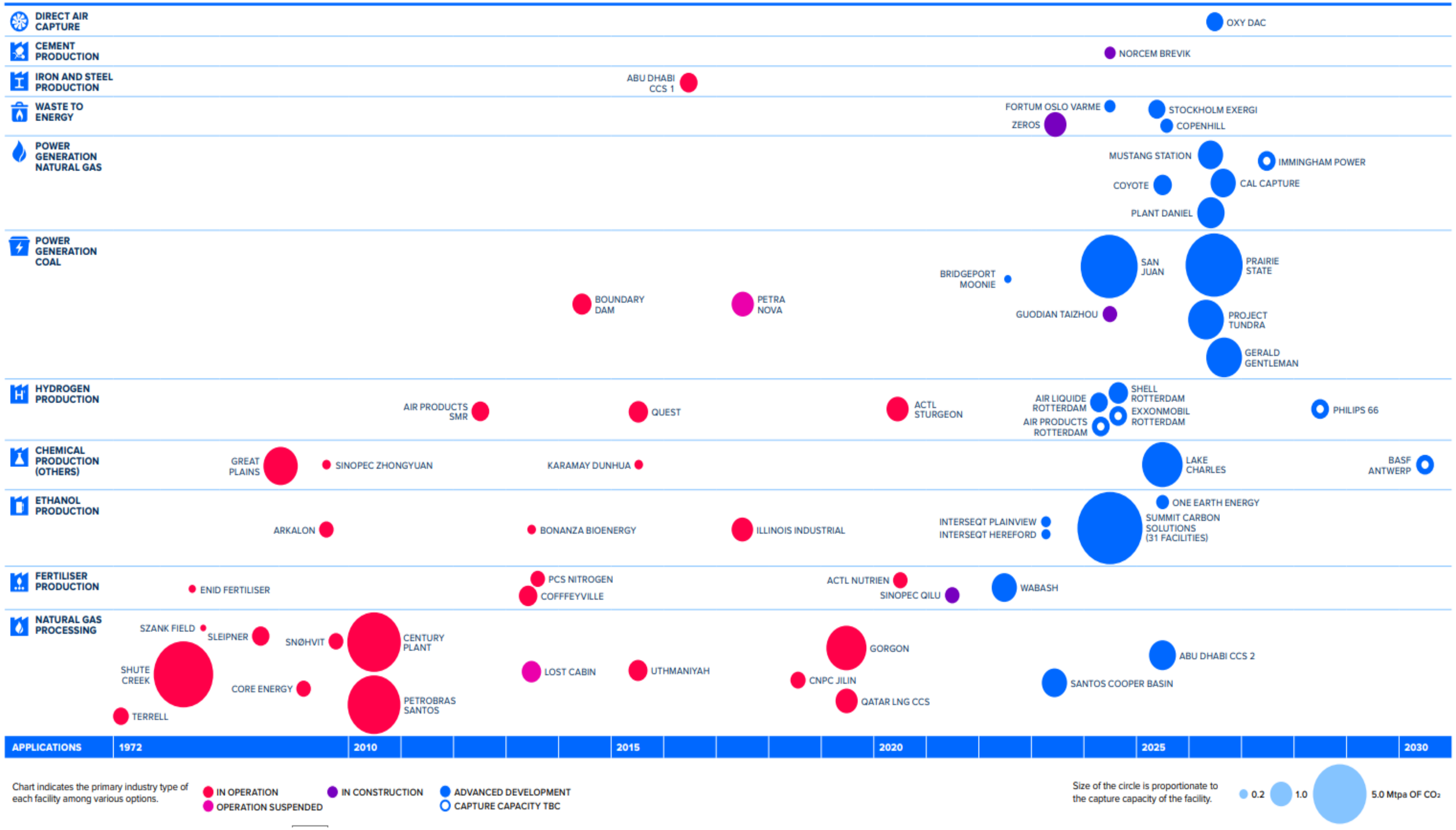
- CCS facilities currently in operation can capture and permanently store around 40 Mt of CO_2 every year.
- In the latest IEA Net Zero Emission scenario CCUS will total up to 7,6 Gt/yr which is a scale up of 190 times compared to today volume
- DNV projections, based on current trends, policies and technology progress, show that by 2050 CCS will account for about 2,1 Gt/yr (ETO 2020).



ETO = Energy Transition Outlook
NZE = Net Zero Emission
SDS = Sustainable Development

CCUS project map

Industrial applications



Today, there are 135 (+71 in 2021) commercial CCS facilities:

- 27 are operating
- 4 are in construction
- 58 are reaching advanced development
- 44 are in early development
- 2 are suspended

Source: Global CCS Institute 2021

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2. CO_2 Capture

Definition of CO_2 capture

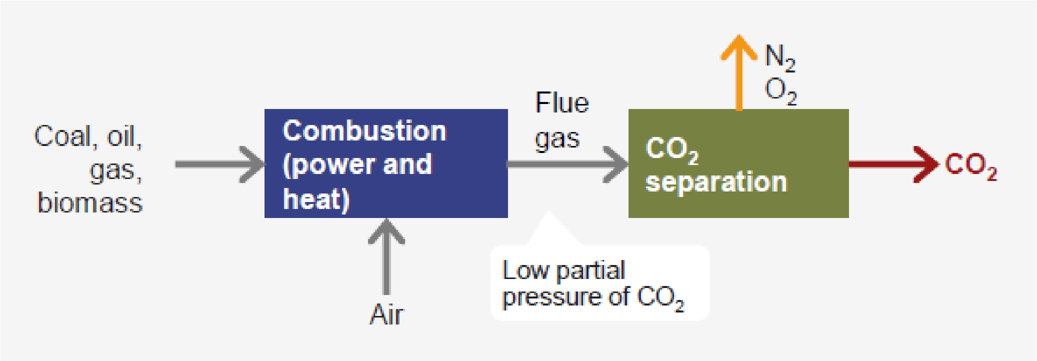
Separation of the CO_2 from a gas stream produced in a power station or an industrial process to obtain pure CO_2 for geological sequestration or further use.

Typically it includes the following steps:

- Separation of the CO_2 with a variety of technologies
- Purification of the separated CO_2 to meet transport and storage requirements
- Compression and liquefaction depending on transport method

Post, pre, and oxy-combustion

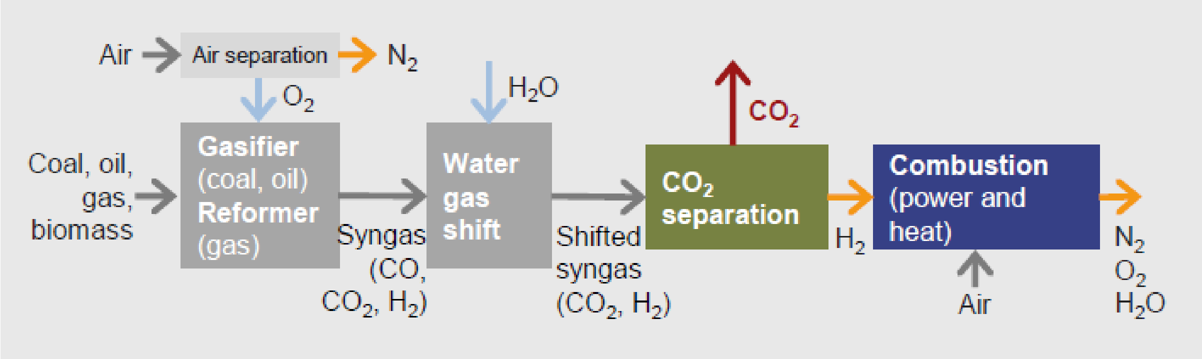
Post-combustion



Where:

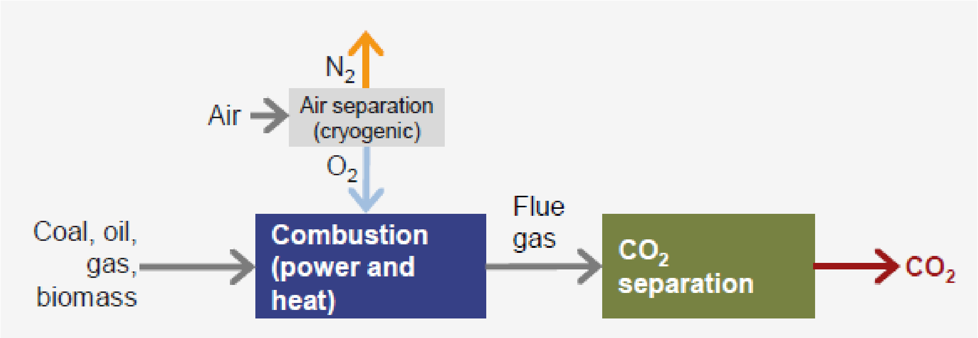
- Coal, biomass power plants,
- Gas turbines
- Industrial facilities
- Waste-to-energy plants

Pre-combustion



- Integrated Gasifier Combined Cycles (IGCC)
- Hydrogen production - Steam Methane Reforming

Oxy-combustion



- Coal and biomass fired power plants,
- Gas turbines (Allam Cycle)
- Industrial facilities (glass, cement)

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Several separation technologies are available

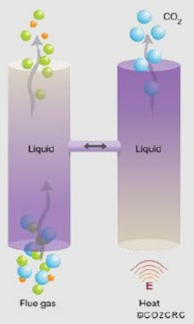
Carbon separation technologies

Absorption (solvents based)	Adsorption (sorbents based)	Membranes	Liquid or supercritical CO_2
Chemical: Ethanolamine (MEA), caustic, ammonia solution, etc. **Physical:** Selexol[TM], Rectisol, Fluorinated solvents, N-Methyl-2-Pyrrolidone (Purisol®)etc.	**Physical:** alumina, zeolite, activated carbon, CaO, MgO, Li_2ZrO_3, Li_4SiO_4	**Polymer based:** Polyphenylene oxide, Polyethylene oxide Poly ionic liquid **Inorganic membrane:** ceramic based, zeolite based	Dry ice formation at low temperature; separation affected by a series of compression, cooling, and expansion steps

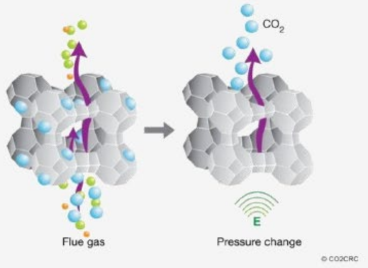
Require to be regenerated: pressure swing, temperature swing, moisture swing, or a combination thereof

Source: Kearney Energy Transition institute analysis

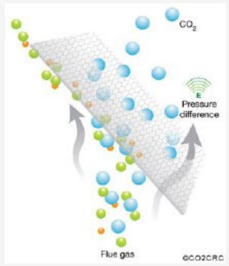
Amine-based absorption technology



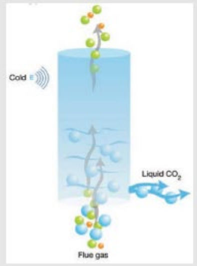
Pressure swing absorption technology



Membrane separation technology



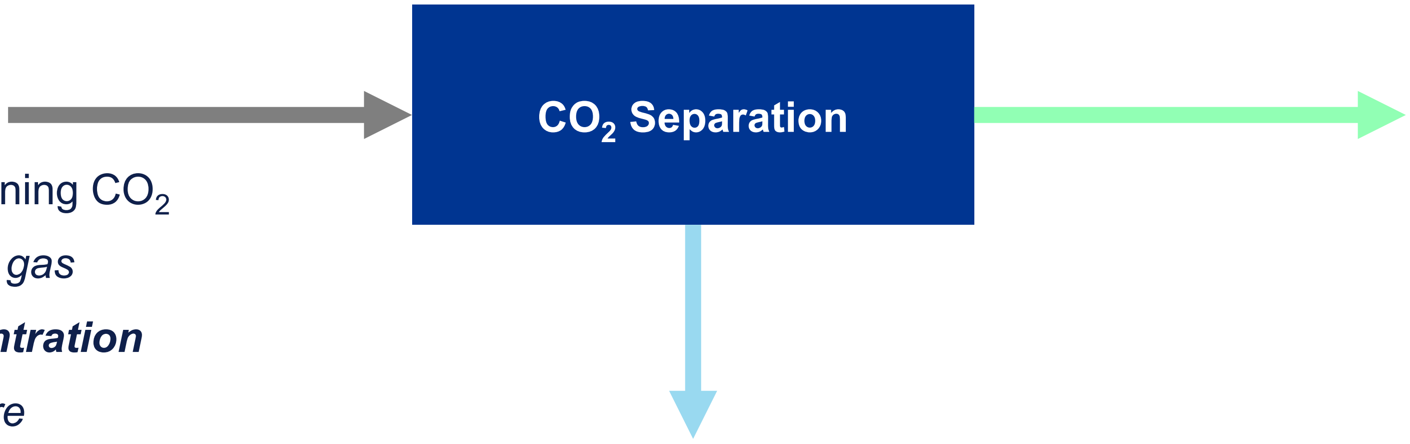
Liquid or supercritical CO_2 (cryogenic) distillation



Sources: CO2CRC; Kearney Energy Transition Institute analysis

Which separation technology?

Depends on the application



Gas containing CO_2

- *Type of gas*
- ***Concentration***
- *Pressure*
- *Pollutants*

Other gases (e.g. N_2, H_2, CH_4)

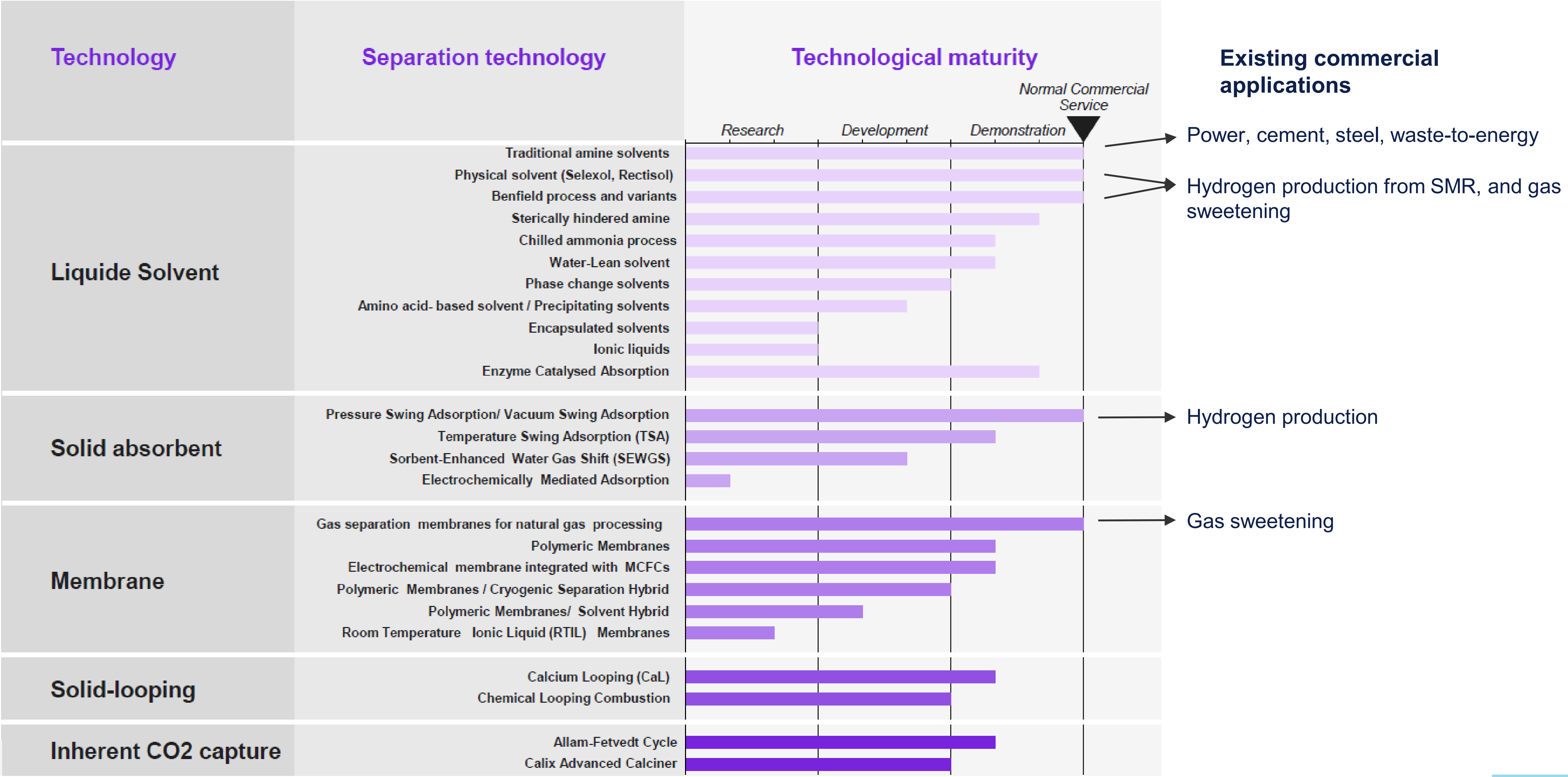
CO_2

- *Purity*

Some examples:

- Flue gas from coal power plant: low pressure, low/medium concentration, high pollutants (SOx, NOx, dust)
- Syngas from SMR: high pressure, medium/high concentration
- Cement plant: low pressure, medium/high concentration, many pollutants

Maturity of CO_2 capture technologies



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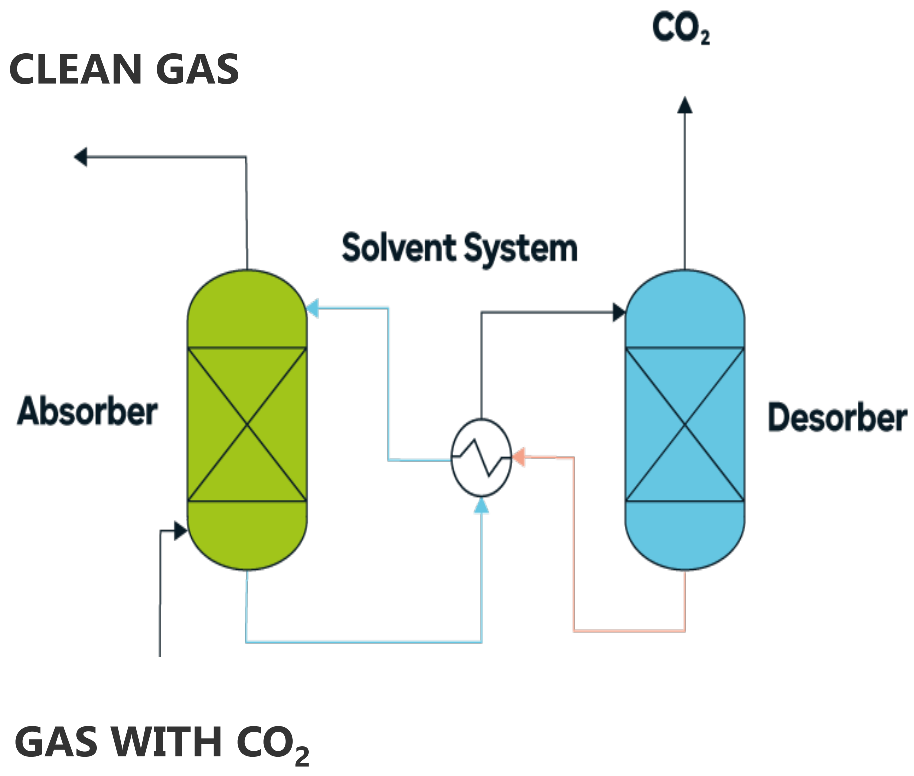
Separation using liquid solvents

Absorption-desorption cycles using either chemical or physical solvents

Demonstrated at large scale:

- **Coal/Gas/Waste**
- **Gas processing**
- **Petro-Chemical** (Blue Hydrogen, Ammonia)
- **Steel**
- **Bio-ethanol**



Demonstration underway:

- **Biomass power**
- **Cement**

Integration of amine-based separation processes

Requirements:

- Thermal energy for solvent regeneration – typically medium pressure steam
- Utilities: Cooling Water / Electricity / Demi-water / Steam
- Periodic reclaiming and make-up of solvent because it degrades (causes: high temp., O_2, NO_x, SO_x)
- Degraded solvent need to be disposed as waste

Advantages:

- Easy to retrofit (end of pipe solution)
- Mature and available form several vendors on the market
- Easy to operate

Downsides:

- High energy demand (2,5-4 MJ/kg of CO_2 captured) -> high OPEX
- Emission of cleaned flue-gas needs to be controlled
- Adds permitting and HSE requirements of a chemical plant

Carbon Capture technologies – innovations

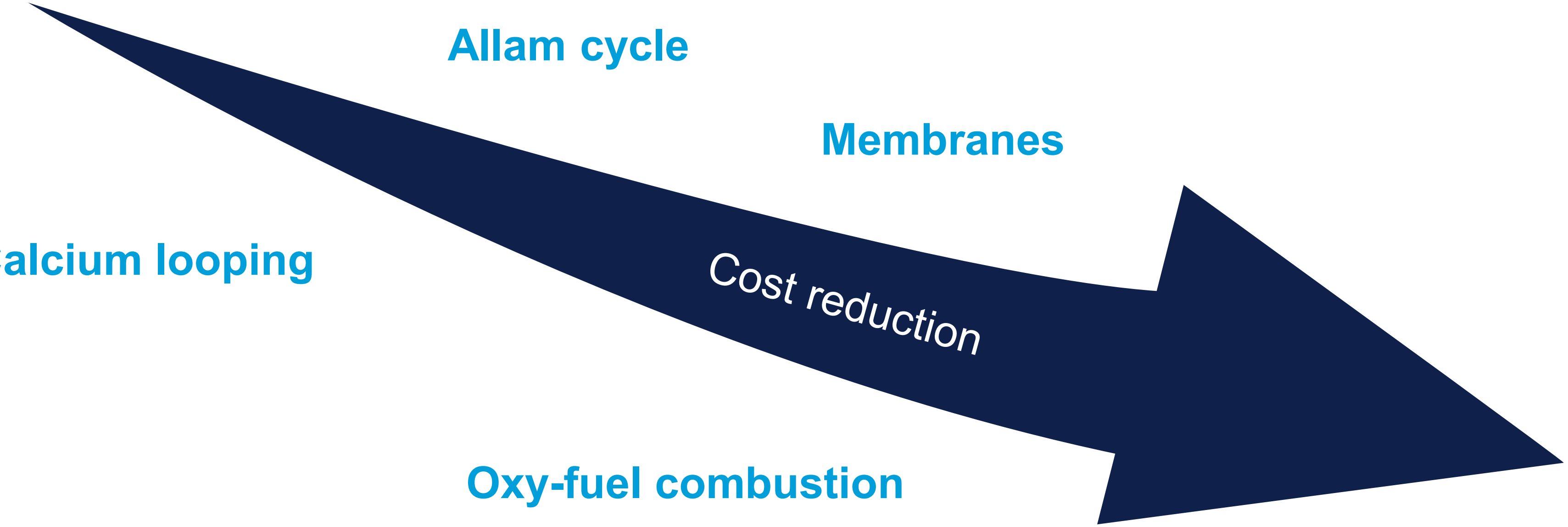
Several new concepts are being developed

New solvents

Allam cycle

Membranes

Calcium looping



Oxy-fuel combustion

- Lower energy use
- Cheaper materials
- More compact
- Less water use
- More Env. friendly
- Easily scalable

3. CO_2 Transport

CO_2 Transport

Pipeline

Volumes: cost effective for large volumes, high CAPEX, low OPEX

Distances: long distances

Transformation for transport: Compression under the form of supercritical fluid

Ship

Volumes: technically feasible to transport large volumes, low CAPEX, high OPEX

Distance: long distances

Transformation for transport: liquefaction[1]

Railcars

Volumes: cost-effective for small and medium volumes, low capex, high opex

Distances: over long distances

Transformation for transport: Liquefaction[1]

Trucks

Volumes: cost effective for very small volumes, low capex, high opex

Distances: traveling short distances

Transformation for transport: liquefaction[1]

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4. CO_2 Storage

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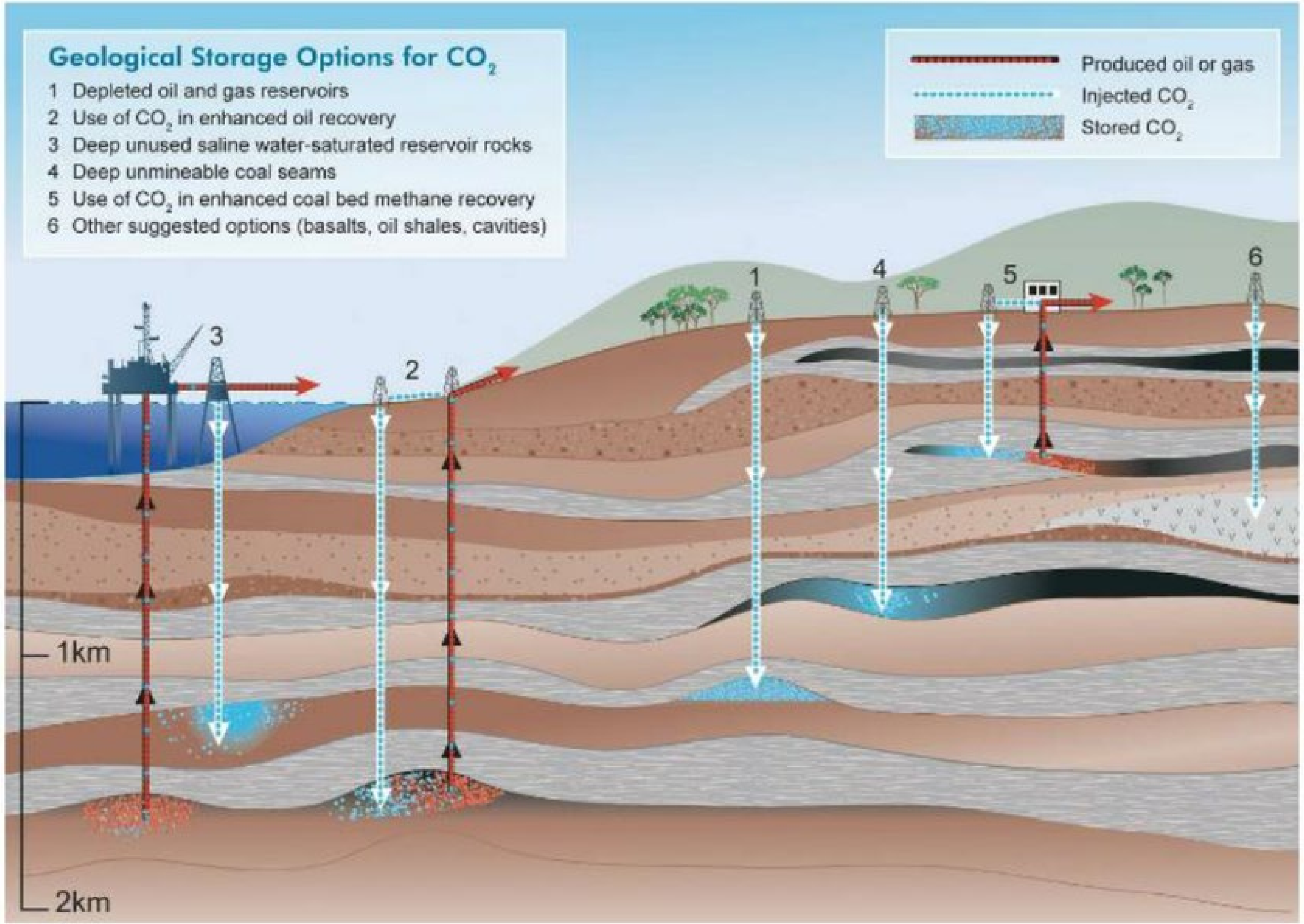
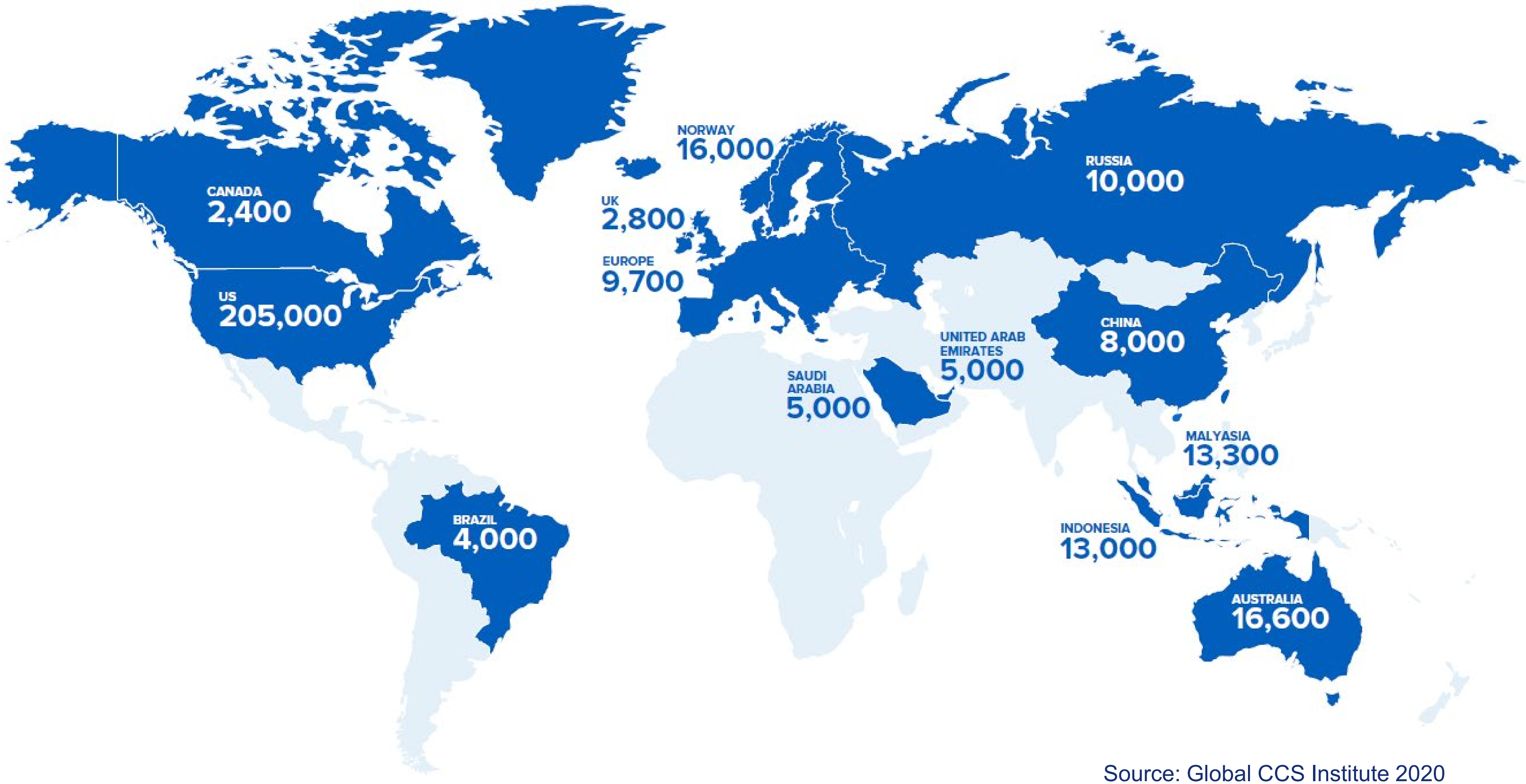
CO_2 Storage
Different options for CO_2 storage



CO_2 Storage

CO_2 Storage resources (millions of tonnes) of major oil and gas fields



Source: Global CCS Institute 2020

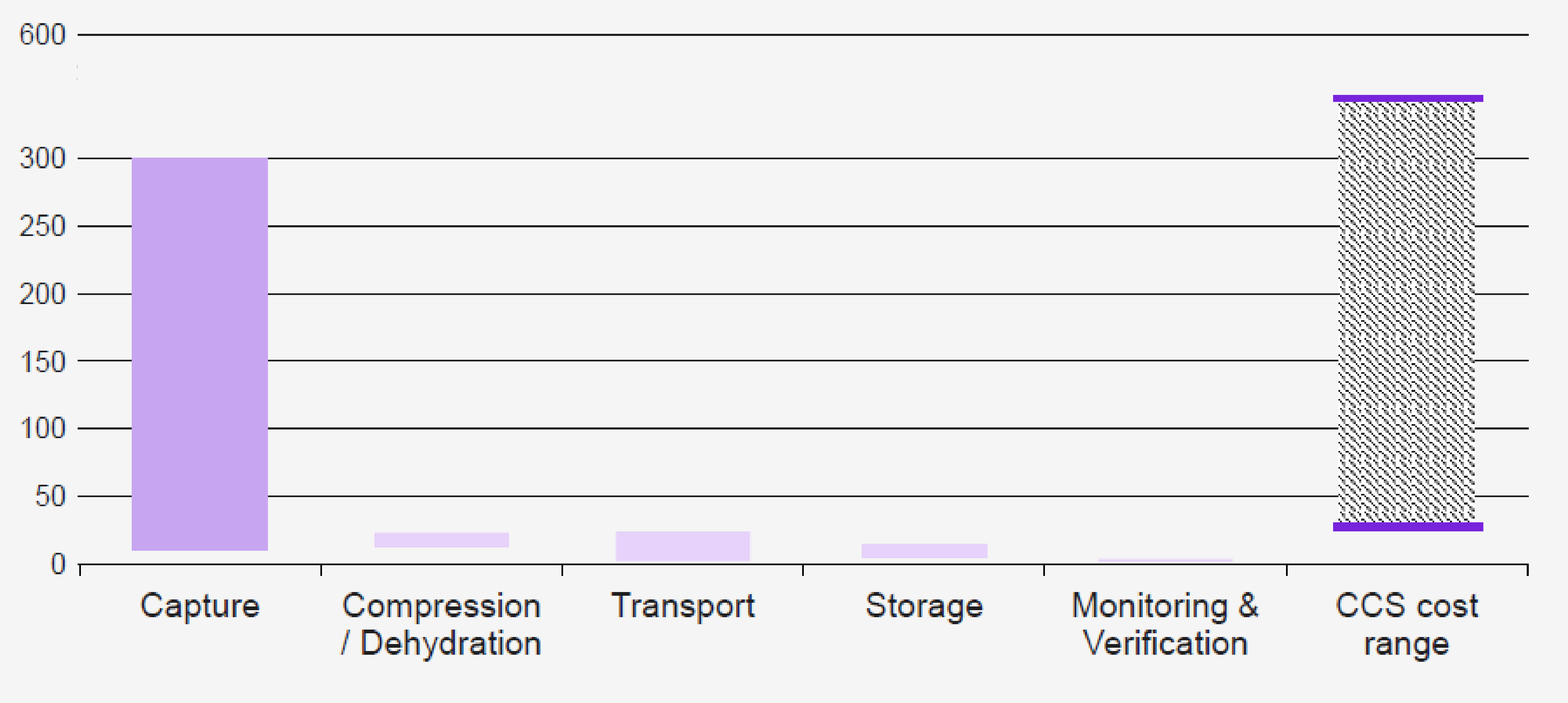
Geological storage resources for CO_2 in saline formations is hundreds of times larger than the resources of oil or gas fields shown in this figure.

STORAGE CAPACITY GLOBALLY IS NOT A CONSTRAINT

5. Cost of CCS

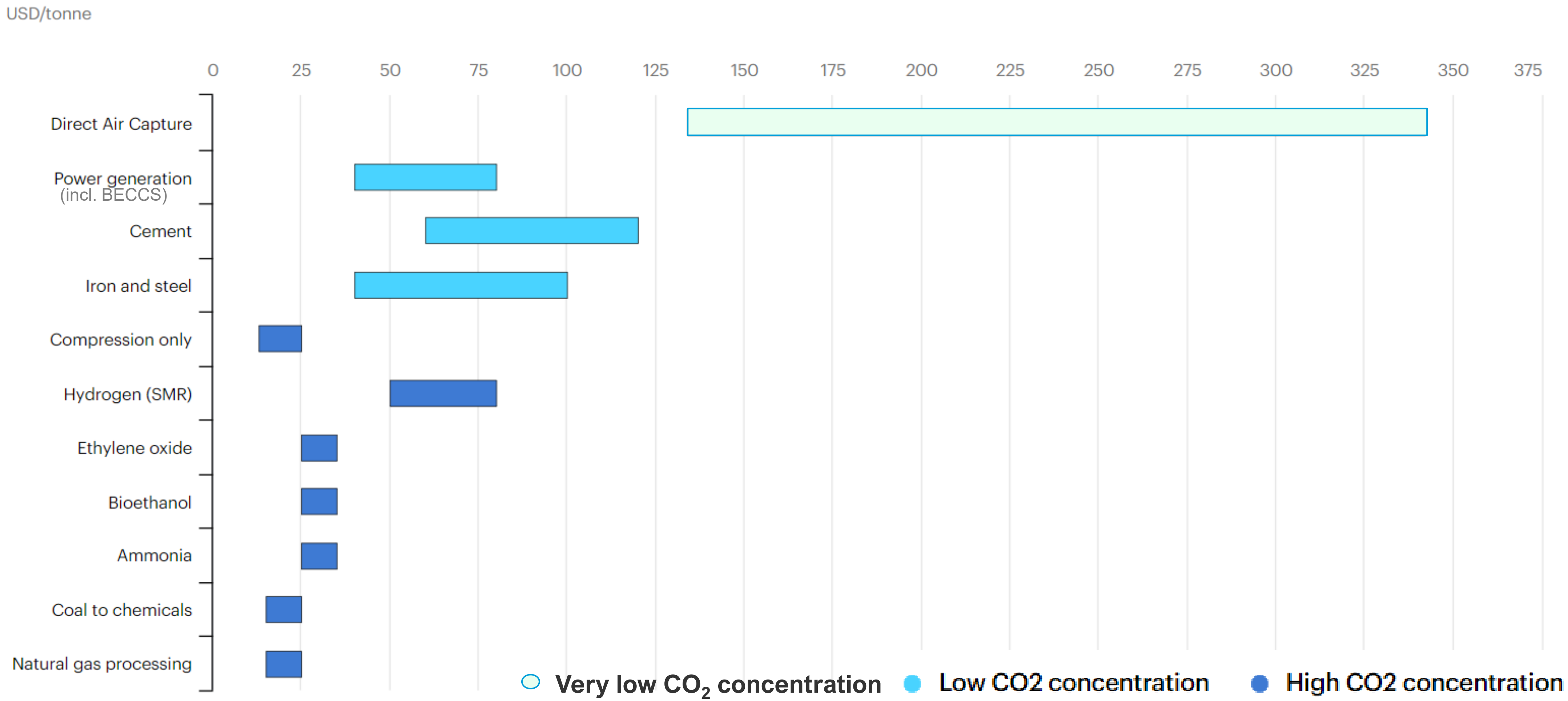
Cost of a CCS project

Cost range for capture, compression & dehydration, transport, storage and monitoring & verification (USD/t_{CO2})



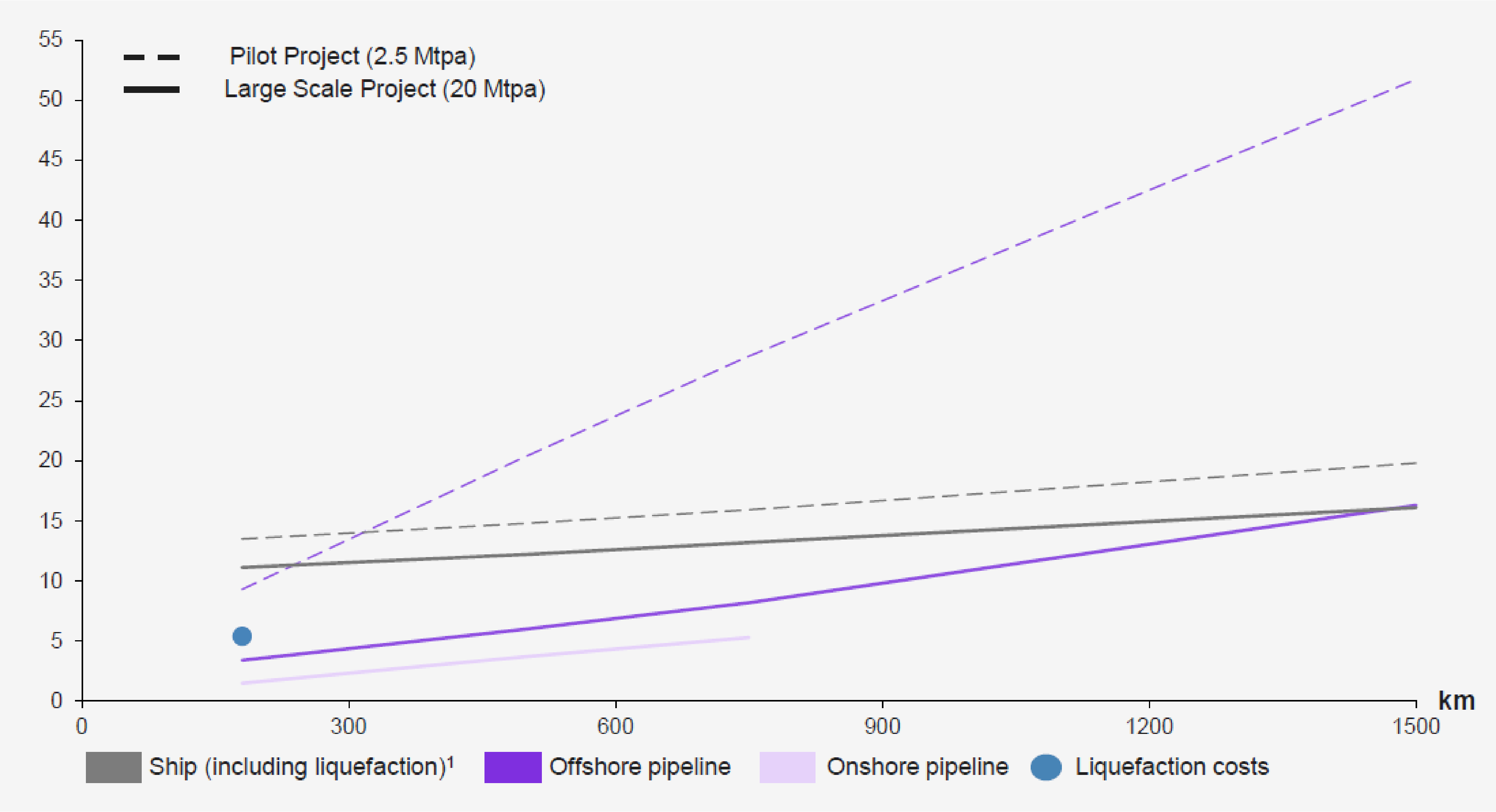
Cost of CO_2 capture (not including transport & storage)

by sector and initial CO_2 concentration (IEA 2019)

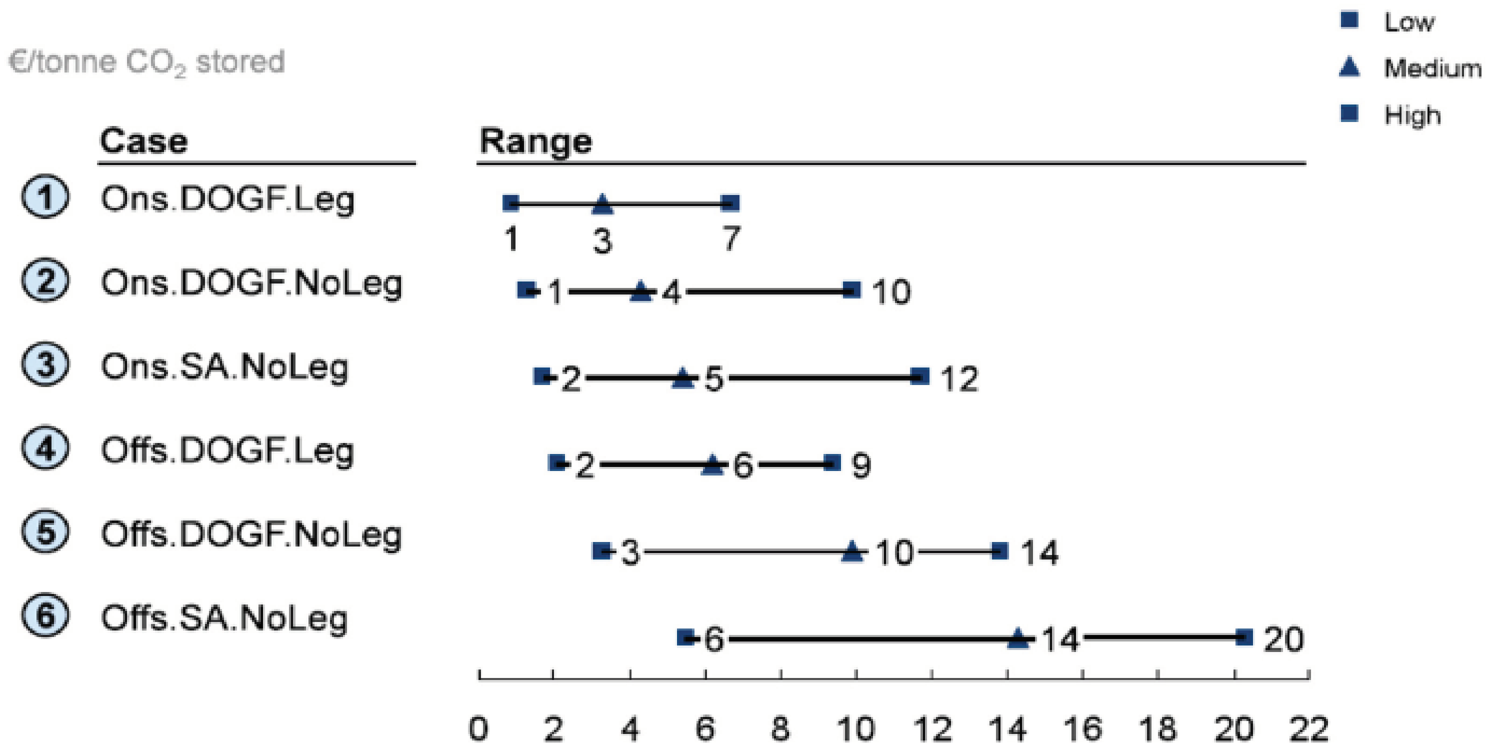


Source: https://www.iea.org/commentaries/is-carbon-capture-too-expensive

Cost of CO_2 transport
Pipeline vs Shipping



Cost of CO_2 Storage



Ons = On Shore
Offs = Off Shore
DOGF = Depleted Oil / Gas Fields
SA = Saline Aquifers
Leg = With Legacies*
NoLeg = No Legacy

* "With Legacies" means existing wells that are re-usable for the storage process

Thank you for your kind attention

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