CARBON CAPTURE UTILIZATION & SEQUESTRATION IN BC

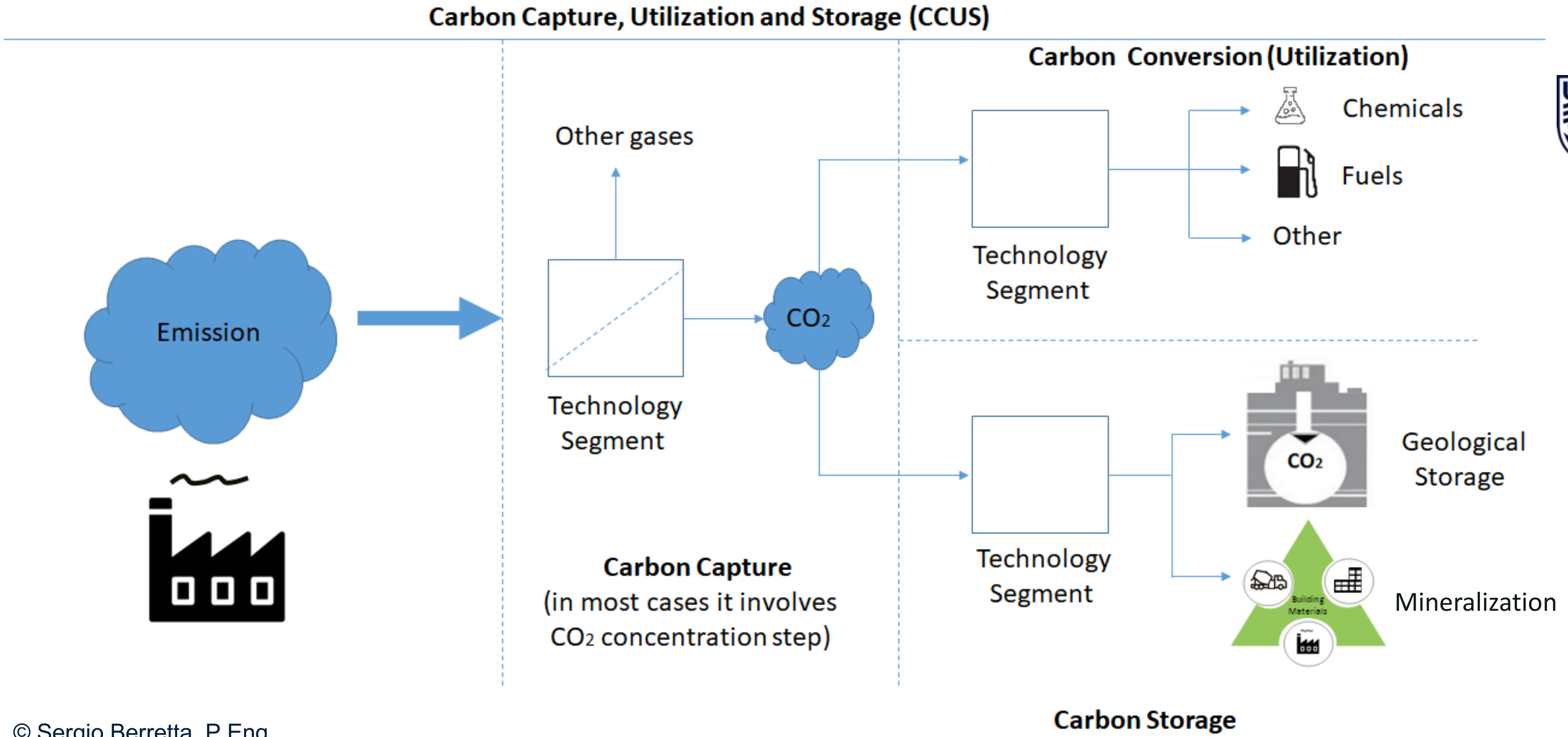
ECOSYSTEM READINESS

DR. NAOKO ELLIS

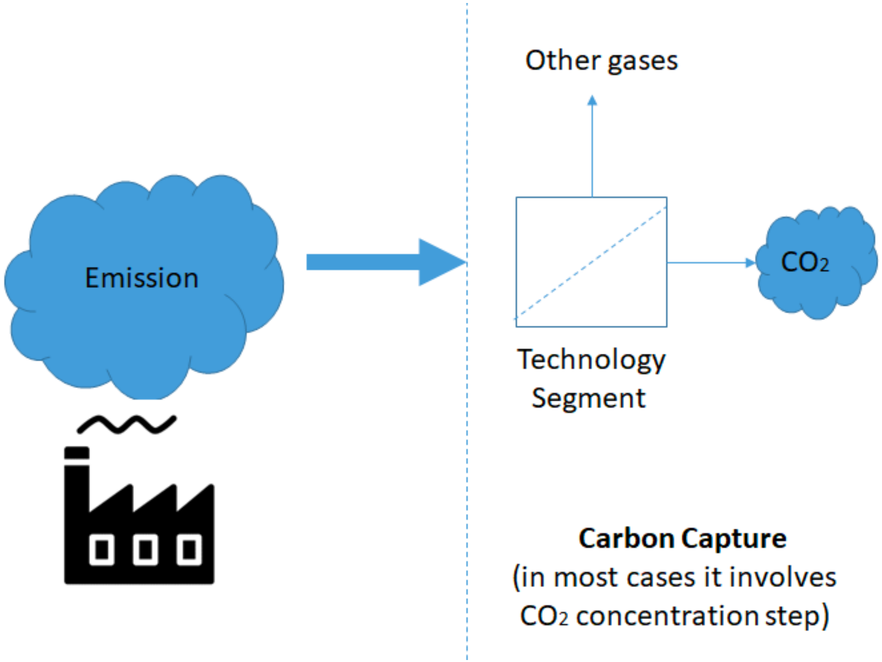
Professor, Chemical & Biological Engineering
University of British Columbia

CARBON CAPTURE TECHNOLOGY READINESS

CCUS PROCESS PATHWAY



CARBON CAPTURE - CURRENT STATE

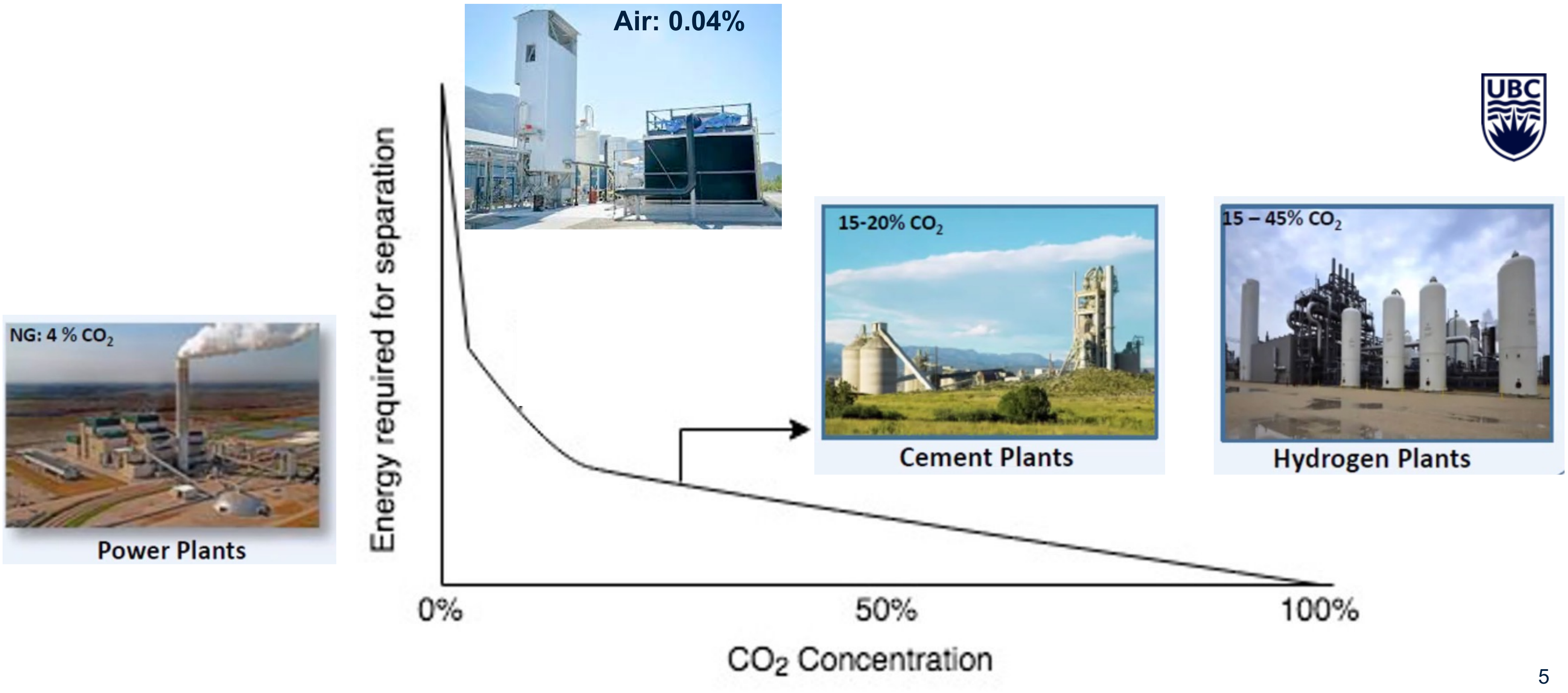


As of 2020:

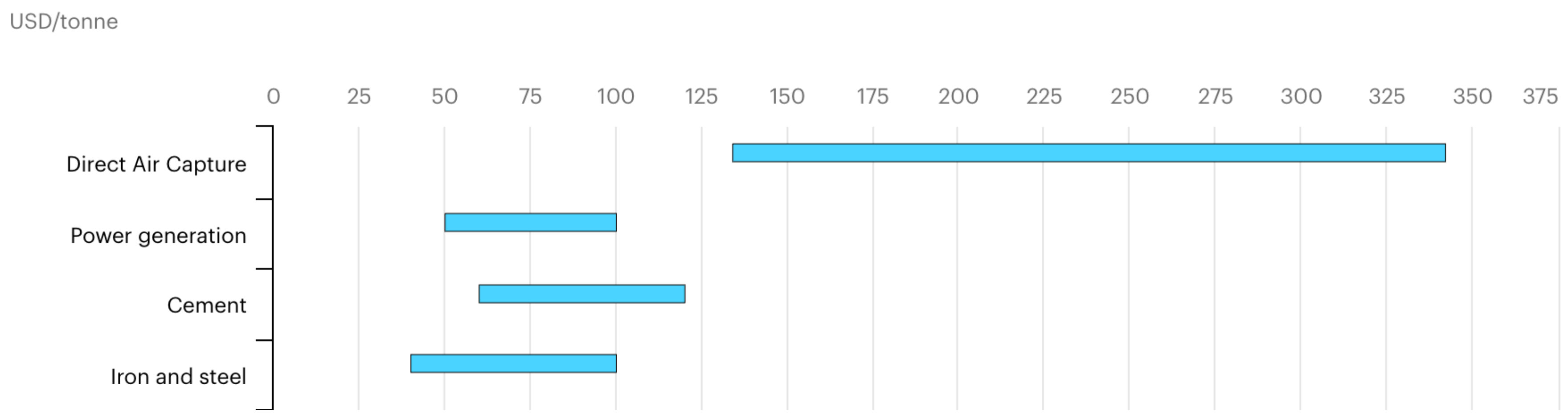
- 28 large-scale operational carbon capture plants
- Total capture capacity of 40 $MtCO_2$/year
- Individual facility capacity ranging from 0.1 to 7.0 $MtCO_2$/year
- 16 facility under construction
- 21 in early development state

https://onlinelibrary.wiley.com/doi/epdf/10.1002/ghg.2131

CO2 CONCENTRATION OF THE SOURCE



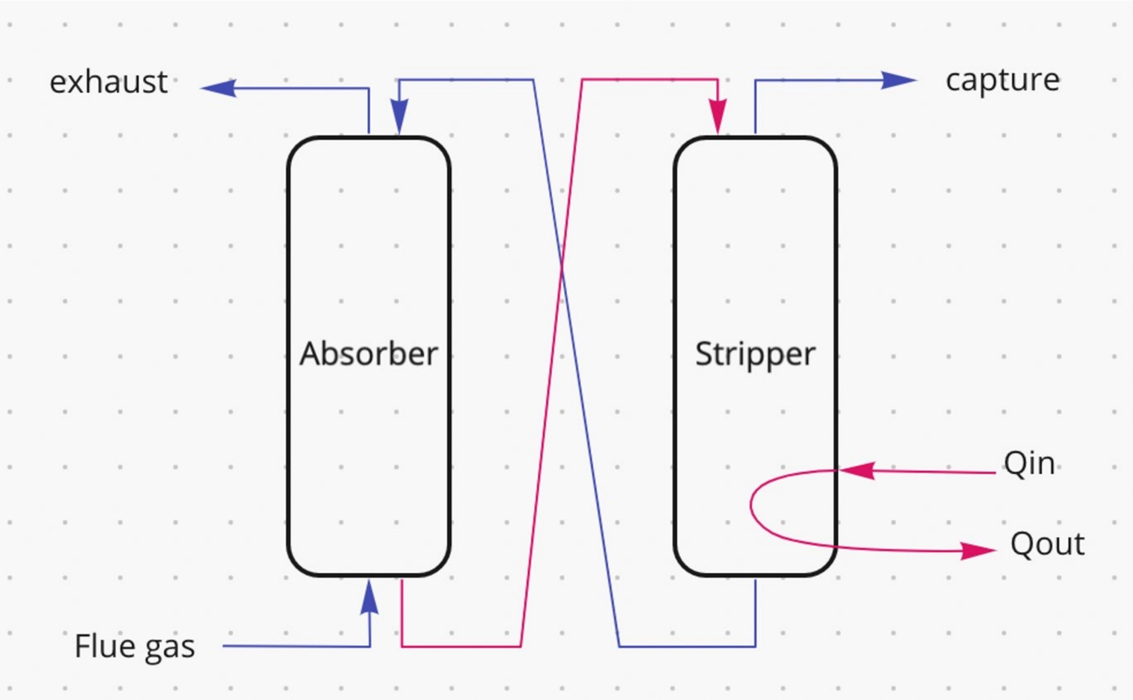
LEVELIZED COST OF CO2 CAPTURE BY SECTOR



https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019

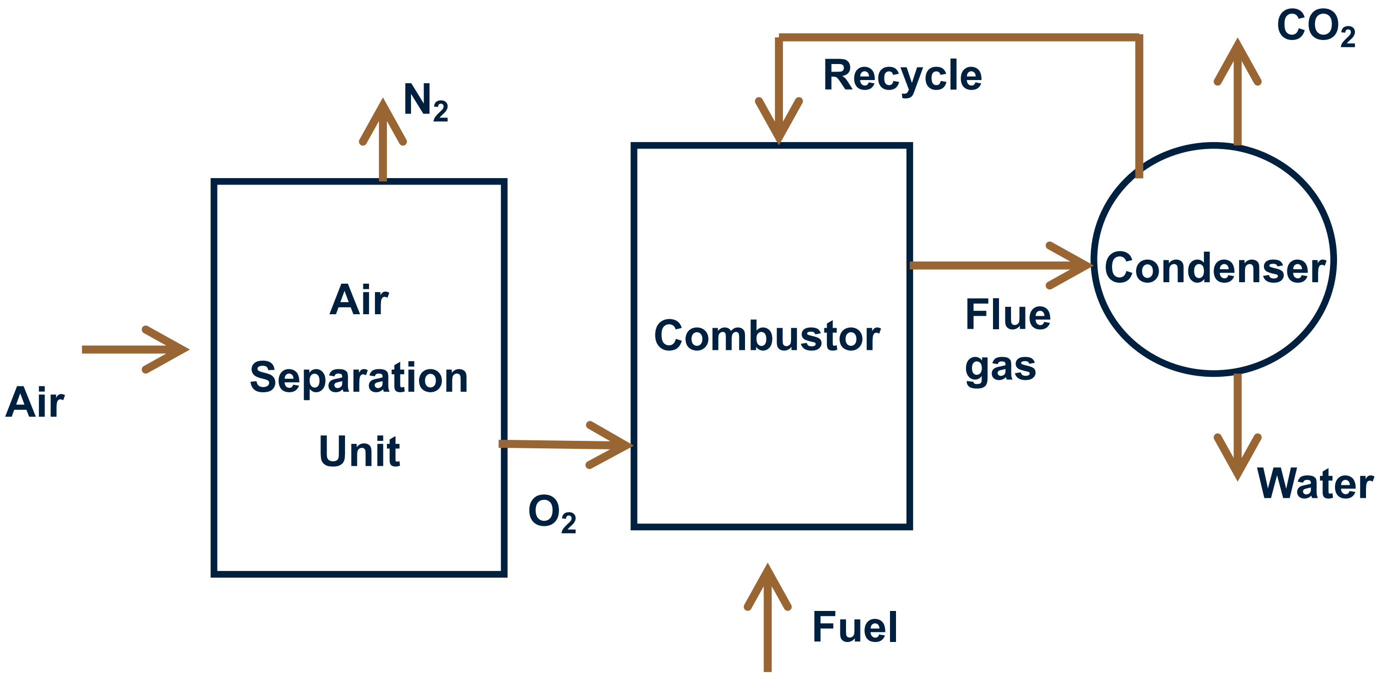
POST-COMBUSTION CARBON CAPTURE

- Liquid solvent capture has been practiced in industry for > 50 years, e.g. in natural gas plants, ammonia, hydrogen streams.
- May also capture other components like H_2S and NO_x.



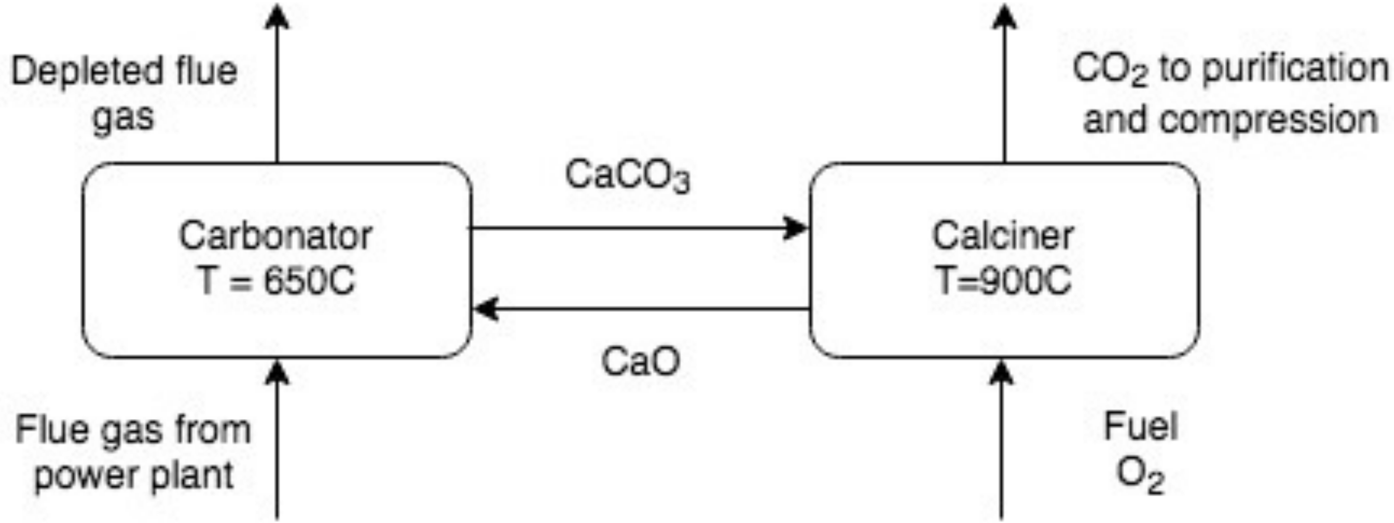
OXY-FUEL COMBUSTION – AIR SEPARATION UNIT

- Air Separation Unit before the Combustion separates O2 from the N2
- Flue gas contains almost no nitrogen, and the water vapour can be condensed, so that the flue gas is nearly pure CO2

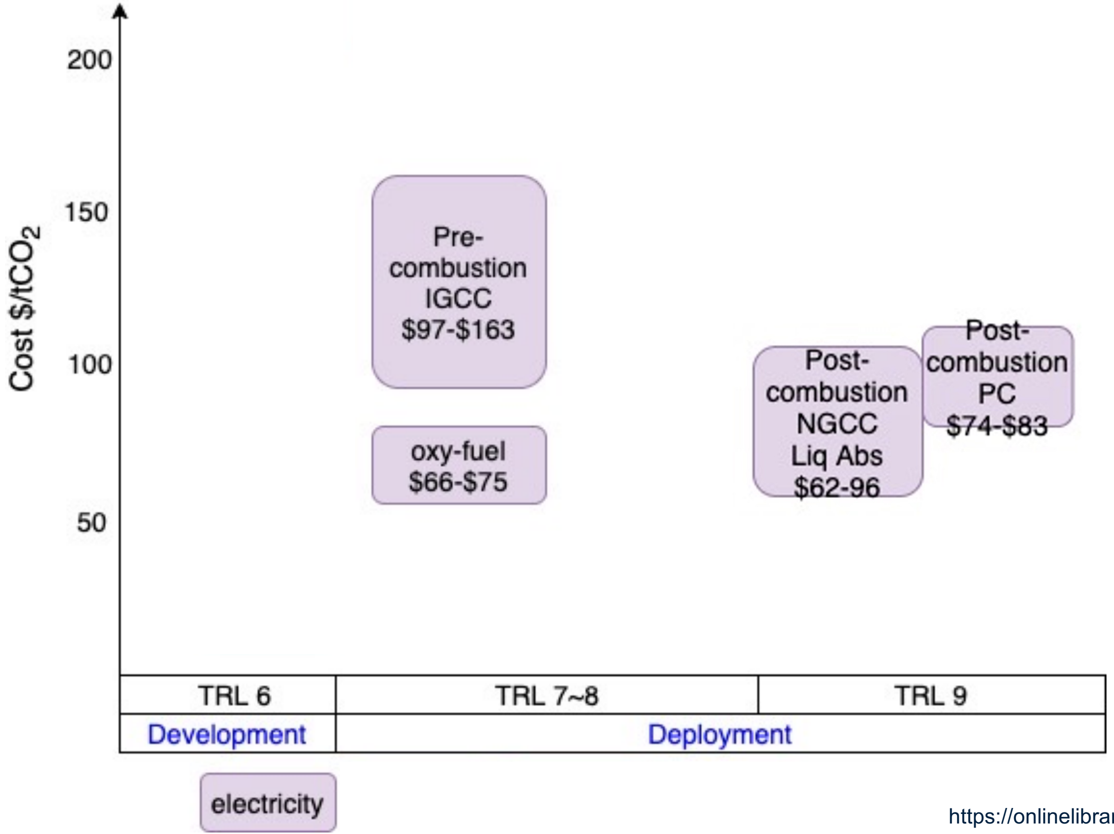


CHEMICAL LOOPING SYSTEMS

- General scheme using lime as sorbent
- Solid sorbent is cycled through carbonator and calciner



CARBON CAPTURE COST AND READINESS



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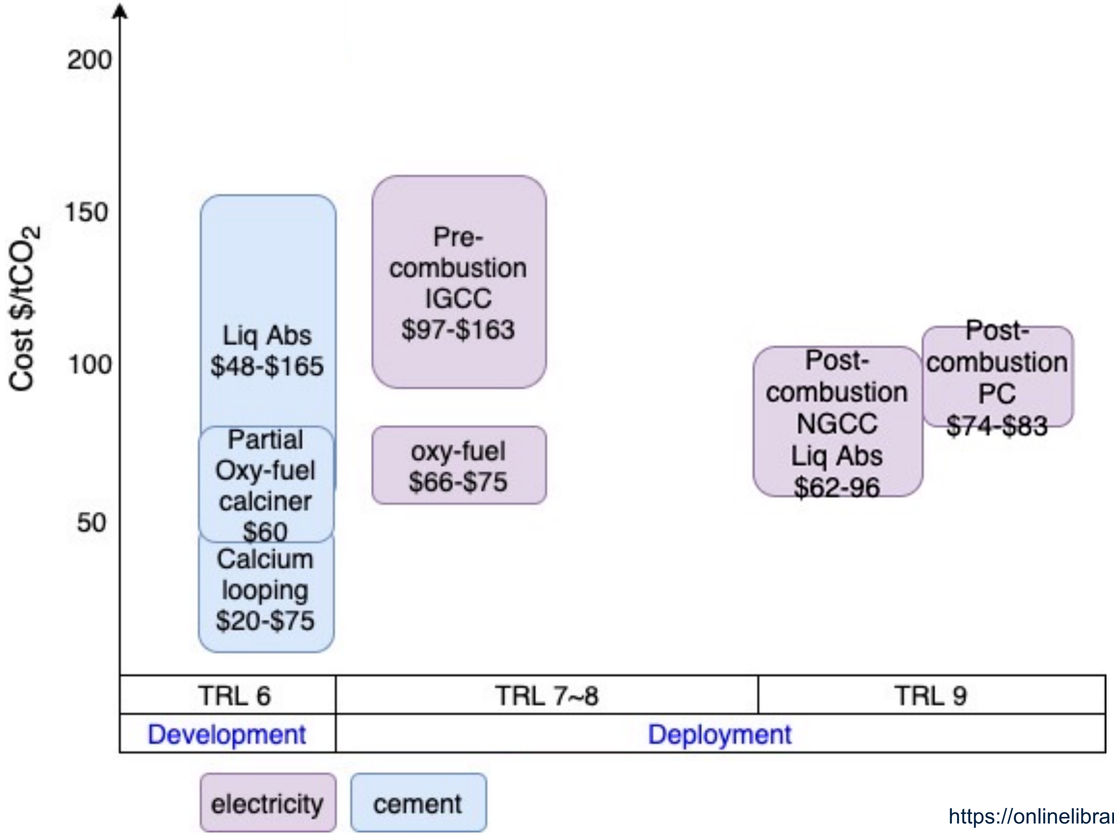

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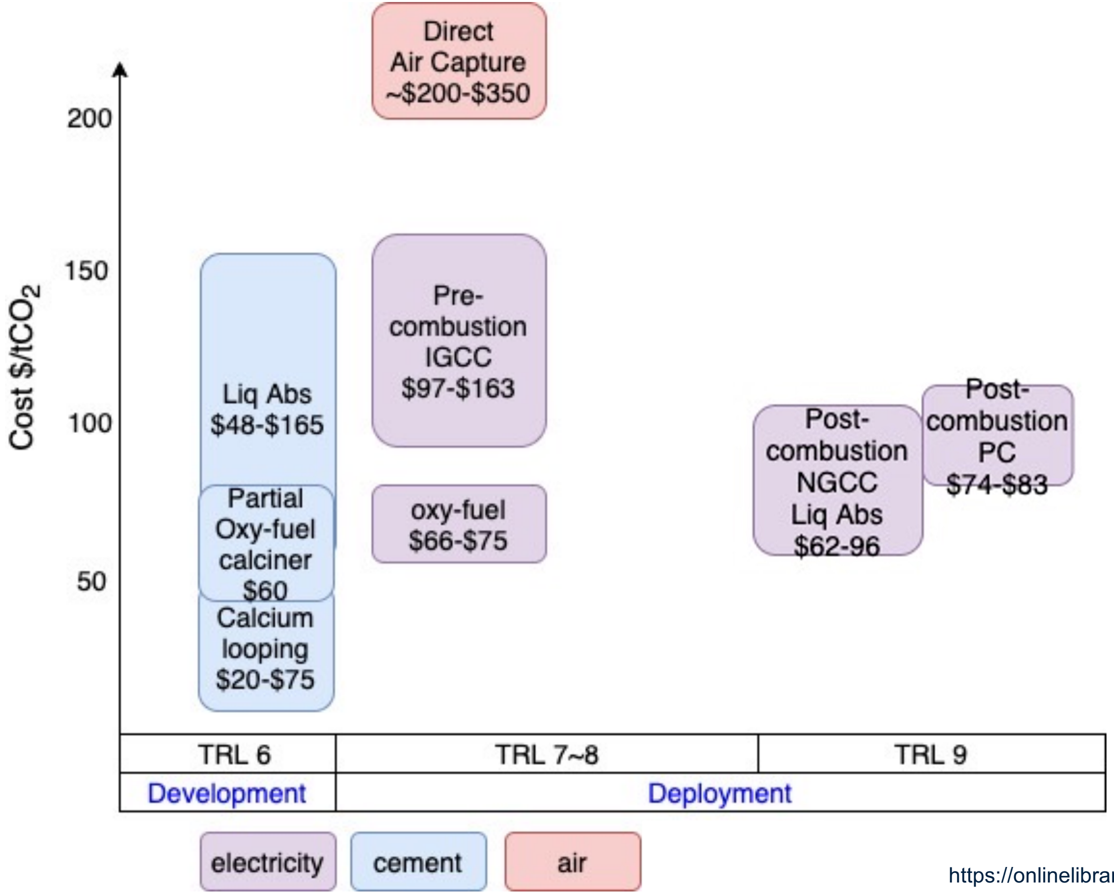

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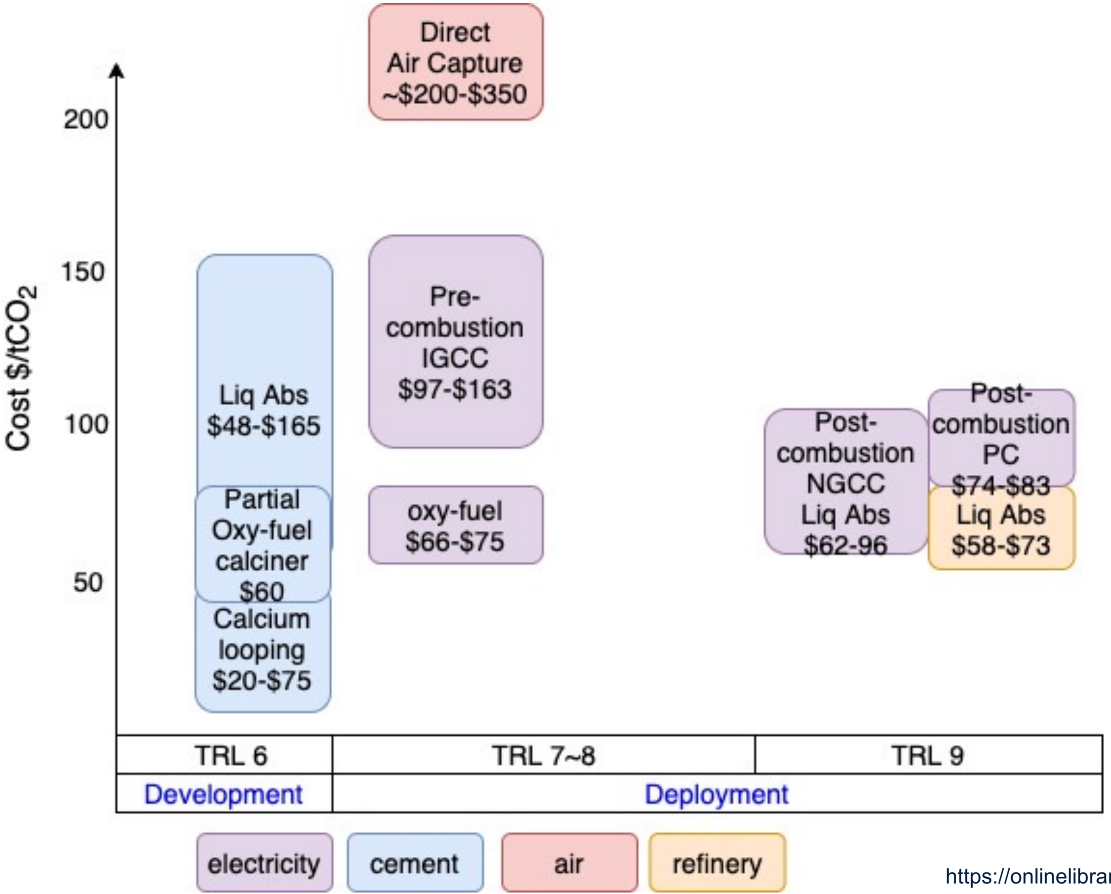

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RICHARD TRUMAN
Vice President, External Relations
Geoscience BC

Geoscience BC

GEOLOGICAL KNOWLEDGE TO PROGRESS CCS IN BC

ABOUT GEOSCIENCE BC

Geoscience BC

Minerals Energy Water

Not-for-profit society established in 2005: independent, **public earth science research** and data about minerals, energy and water resources that:

- Improves our collective level of geoscience knowledge;
- Informs responsible natural resource development and investment decisions;
- Catalyzes socio-economic opportunities; and
- Stimulates innovation and geoscience technologies.

Identifying Critical Minerals and Metals

- Regional geophysics and geochemistry.
- Innovative earth science tools to attract new investment.

Advancing Carbon Capture and Storage (CCS)

- Industrial need for CCS geological atlas: identify and assess carbon storage targets in BC.
  - ✓ Carbon mineralization.
  - ✓ Sedimentary basins (deep saline aquifers) as carbon sinks.

Catalyzing Clean Energy

- Regional projects advancing geothermal power generation, electrification of industrial sites and low-carbon hydrogen generation.

RELEVANT RESEARCH: EXAMPLES

Geoscience BC

Garibaldi Volcanic Belt Geothermal

https://www.geosciencebc.com/projects/2018-004/

- Collaboration with Geological Survey of Canada; seven universities: detailed study of geology.
- Informing decisions and attracting investment in geothermal energy in southwest BC – including potential low-carbon hydrogen production near Pemberton.
- Community and Indigenous input and involvement.

Carbon Mineralization Potential

https://www.geosciencebc.com/projects/2018-038/

- Part of wide collaboration. Geoscience BC role: funding BC carbon mineralization potential map and index.
- Ultramafic rocks react with carbon dioxide, forming carbonate minerals to store carbon.
- Interim report published; final report and data due 2022.

Sedimentary Basin Research

- History of sedimentary basin research since 2006: geophysics; stratigraphy.
- Past focus on Western Canadian Sedimentary Basin, especially water-related research.
- Also Nechako Basin and supporting projects in Bowser Basin.

CCS: WHAT NEXT?

Geoscience BC

- Building consortia: funding, technical input, users

Including launch of Geoscience BC membership opportunities: https://www.geosciencebc.com/membership/

- A **geological carbon capture and storage atlas for British Columbia**: identify and assess carbon storage targets in BC.

Phased approach

1. Northeast BC (Western Canadian Sedimentary Basin)

- Other sedimentary basins: interest from Central, NW, SE, SW
- Potential for further carbon mineralization research

THANK YOU

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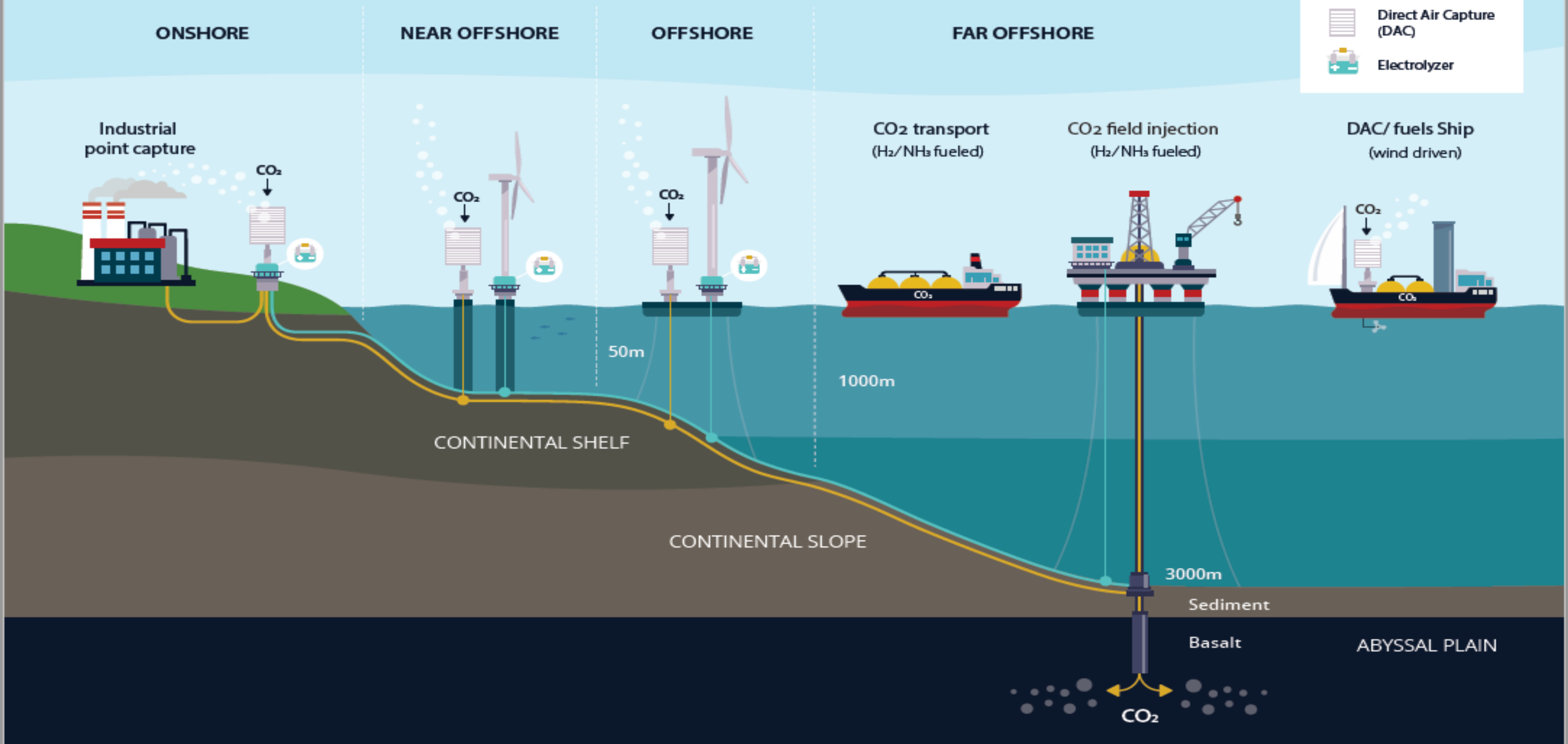
DR. CURRAN CRAWFORD

Professor, Mechanical Engineering
University of Victoria

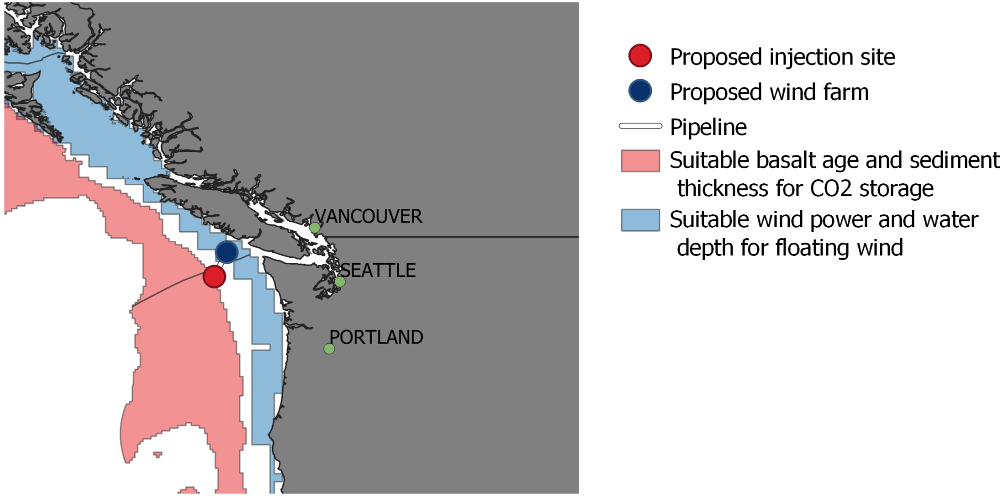
University
of Victoria

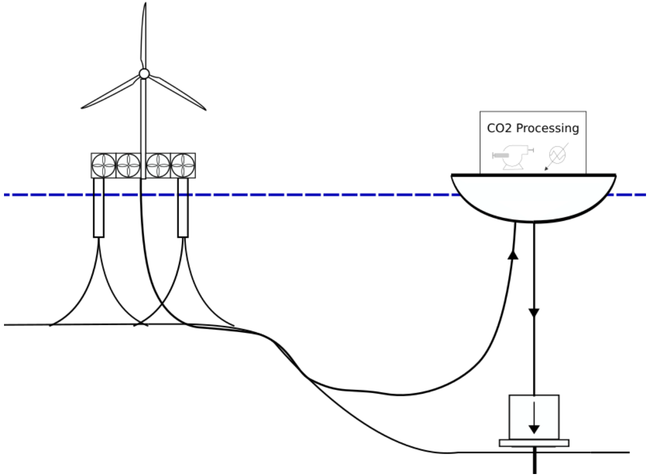
OFFSHORE CARBON CAPTURE AND STORAGE POTENTIALS

SYSTEM CONFIGURATIONS



CONCEPT STUDY CURRENT STATE





University of Victoria
Institute for Integrated Energy Systems

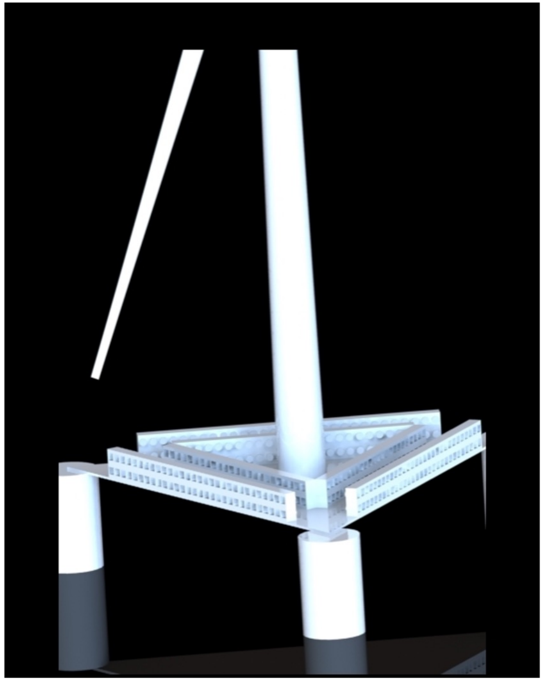
Break-even price (full system) :
approx. 850 USD/t CO_2

DIRECT AIR CAPTURE WITH FLOATING OFFSHORE WIND

Assumptions:

Capture rate = α = 74.5%
Exergy efficiency = η_{2nd} = 7.8%
15 MW wind turbine @ Cf = 45%
DAC utilization = 90%

		X = 400 ppm	X = 300 ppm	X = 160 ppm
Minimum work	[kWh/t-CO2]	123	137	147
Real work	[kWh/t-CO2]	1580	1637	1764
Annual captured CO_2	[t-CO2/y]	33,687	32,500	30,176



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OFFSHORE INJECTION

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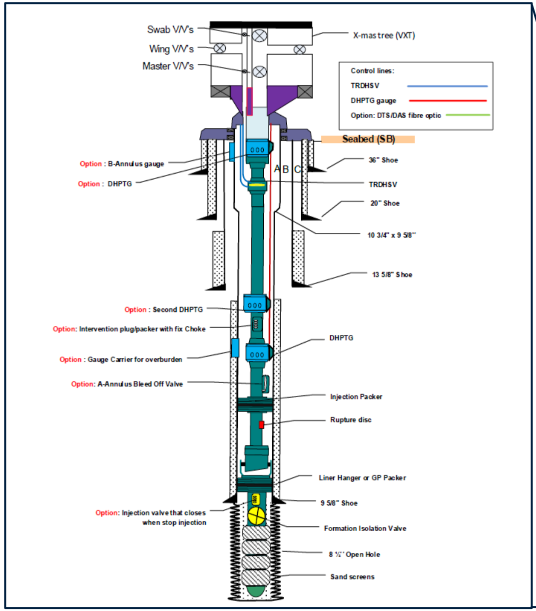
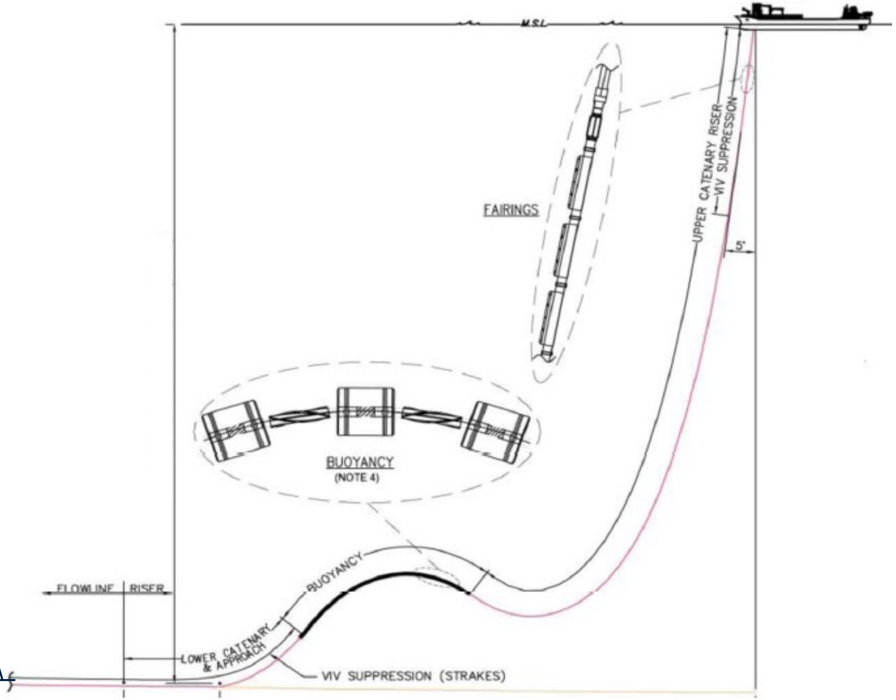
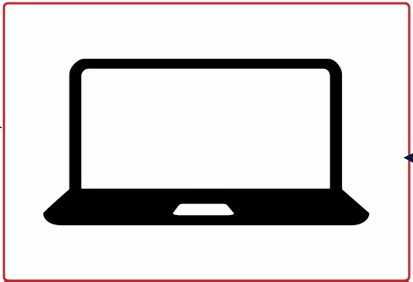


Northern Lights Project Concept report (2019). RE-PM673-00001. Equinor.

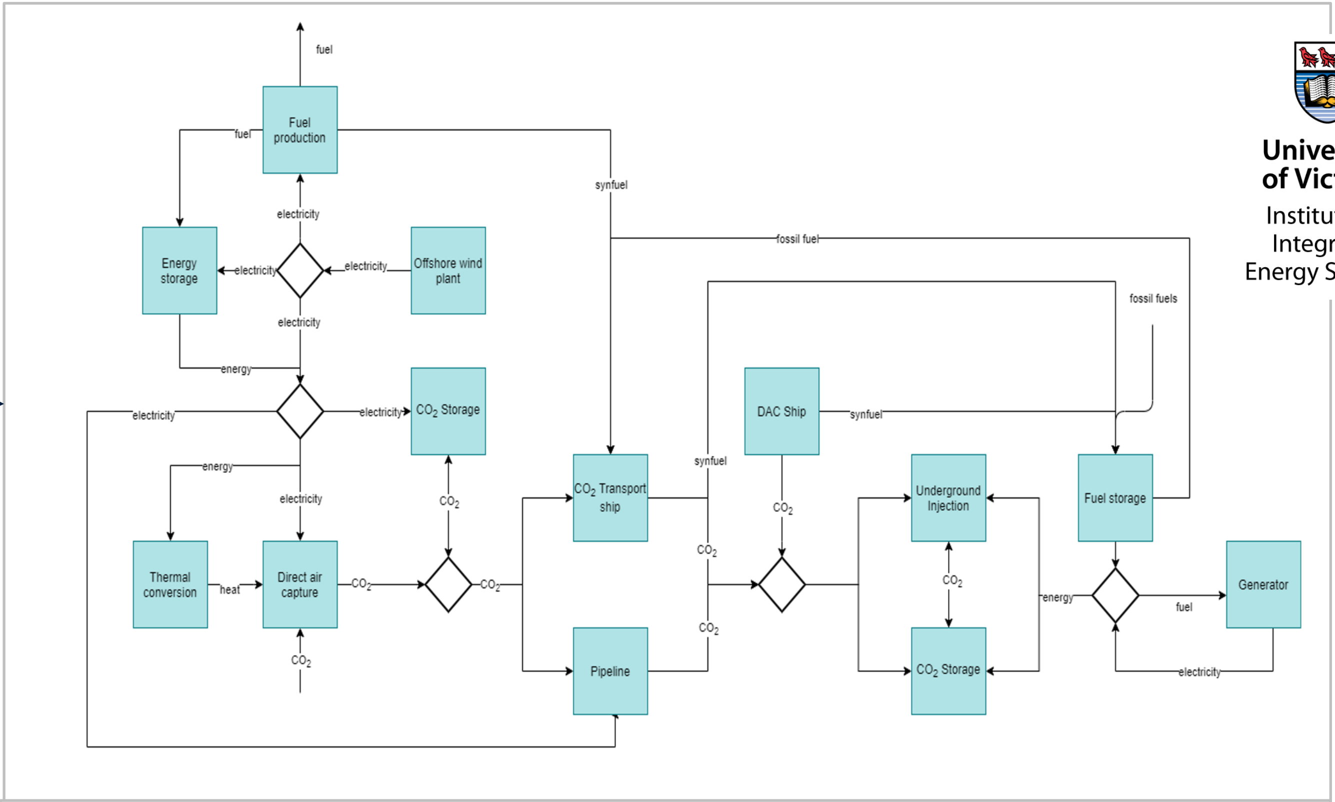


Hoffman, J. *et al.* (2017) 'The Stones Project: Subsea, Umbilical, Riser and Flowline Systems', in. *Offshore Technology Conference*, Offshore Technology Conference. doi:10.4043/27569-MS.

SYSTEM OPTIMIZATION FRAMEWORK



Control System Optimization



Component sizing and costing

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Institute for Integrated Energy Systems

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Professor, Geological Sciences
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CARBON MINERALIZATION; 3 APPROACHES FOR B.C.

CARBON MINERALIZATION FOR CO_2 REMOVAL

<u>Cations</u>

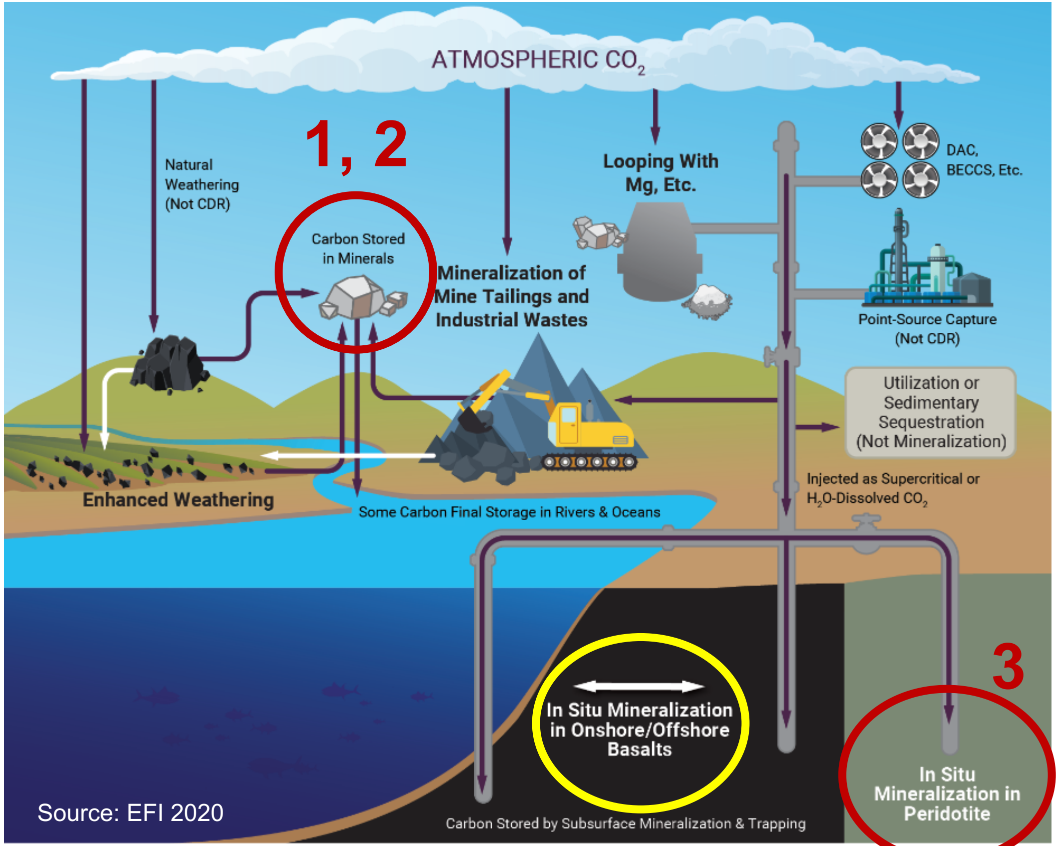
Minerals or industrial solid waste

<u>CO_2</u>

Air capture

DAC

BECCS (BICRS)



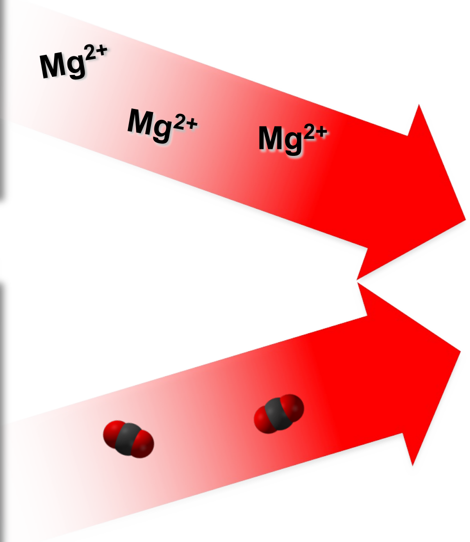
Opportunities for B.C.

1) Mine Tailings with CO_2 capture from air
2) Injection of DAC CO_2 into tailings
3) Injection of DAC CO_2 into subsurface

GEOCHEMICAL FRAMEWORK

Mineral dissolution

Cation source (Mg2+)
and pH buffer

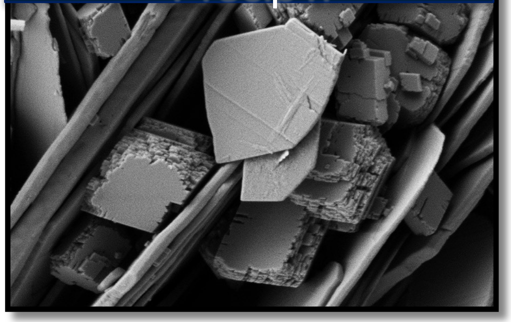


CO_2 supply

Source of CO2
(air or point source)

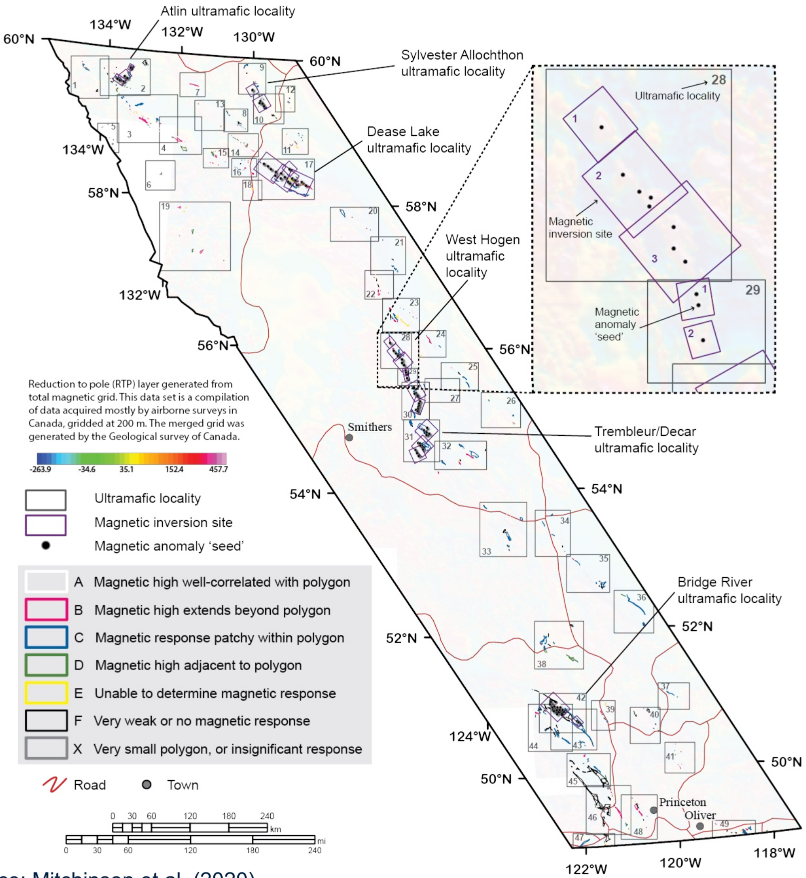
- Carbon dioxide from industrial emissions and from air
- Reacts with waste from mine tailings
- To store carbon dioxide in safe, permanent mineral form
- Costs in range $20-$100 / tonne CO2

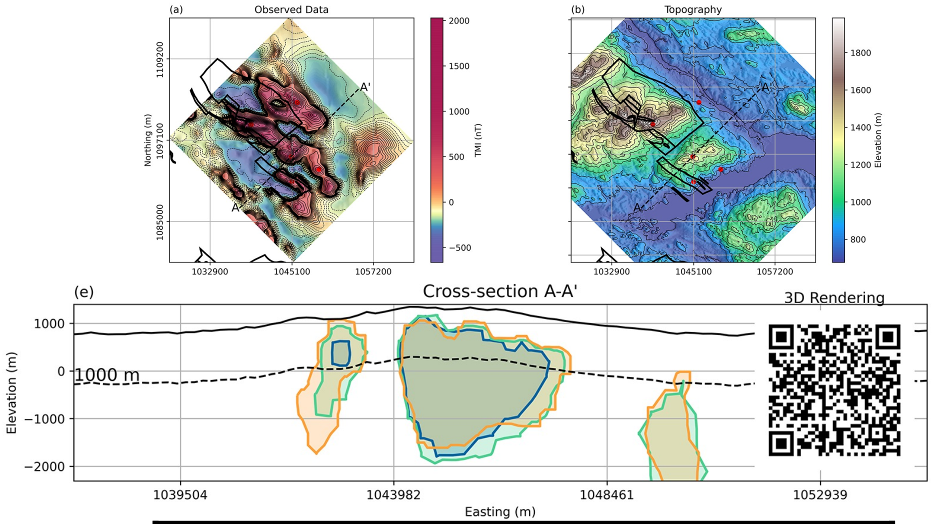
Mineral Carbonate Precip'n



Permanent CO2 Storage

INVENTORY OF CAPACITY AND (AT) RATE (CaMP BC)





Depth Interval (km)	Serpentinite Volume (km^3)	Sequestration Capacity (Gt CO^2)	Method
0 to 1	988	56	*ex-situ & in-situ*
0 to 2	3,689	210	
2 to 4	4,162	5,139	*in-situ*
2 to full depth	4,292	5,300	

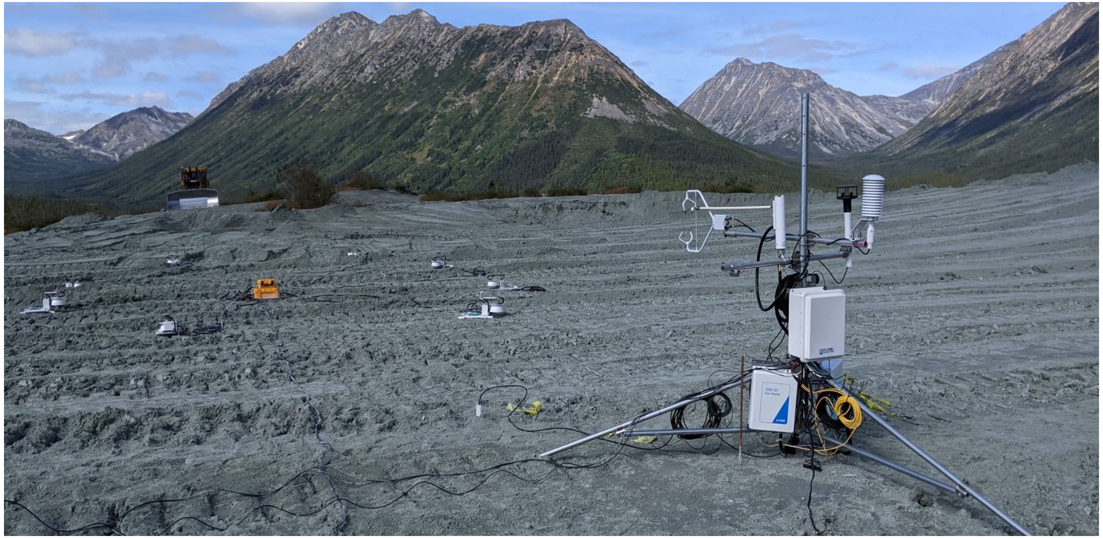
Source: Mitchinson et al. (2020)

ACCELERATED AIR CAPTURE TRIALS

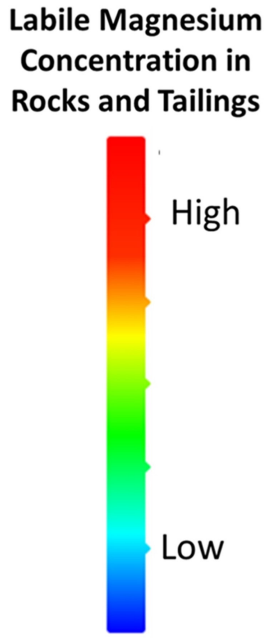
- Tailings from Baptiste and Turnagain Ni Deposits, Cassiar Chrysotile mine
- Carbon is mineralized in real time under field conditions
- Acceleration of air capture rates three to five over baseline air capture rates
- Capture experiments at 1-2,000 m^2 footprint, tonnes tailings
- Sustained under field conditions for two weeks to eight months
- Gas phase and solid phase CO_2 balances match

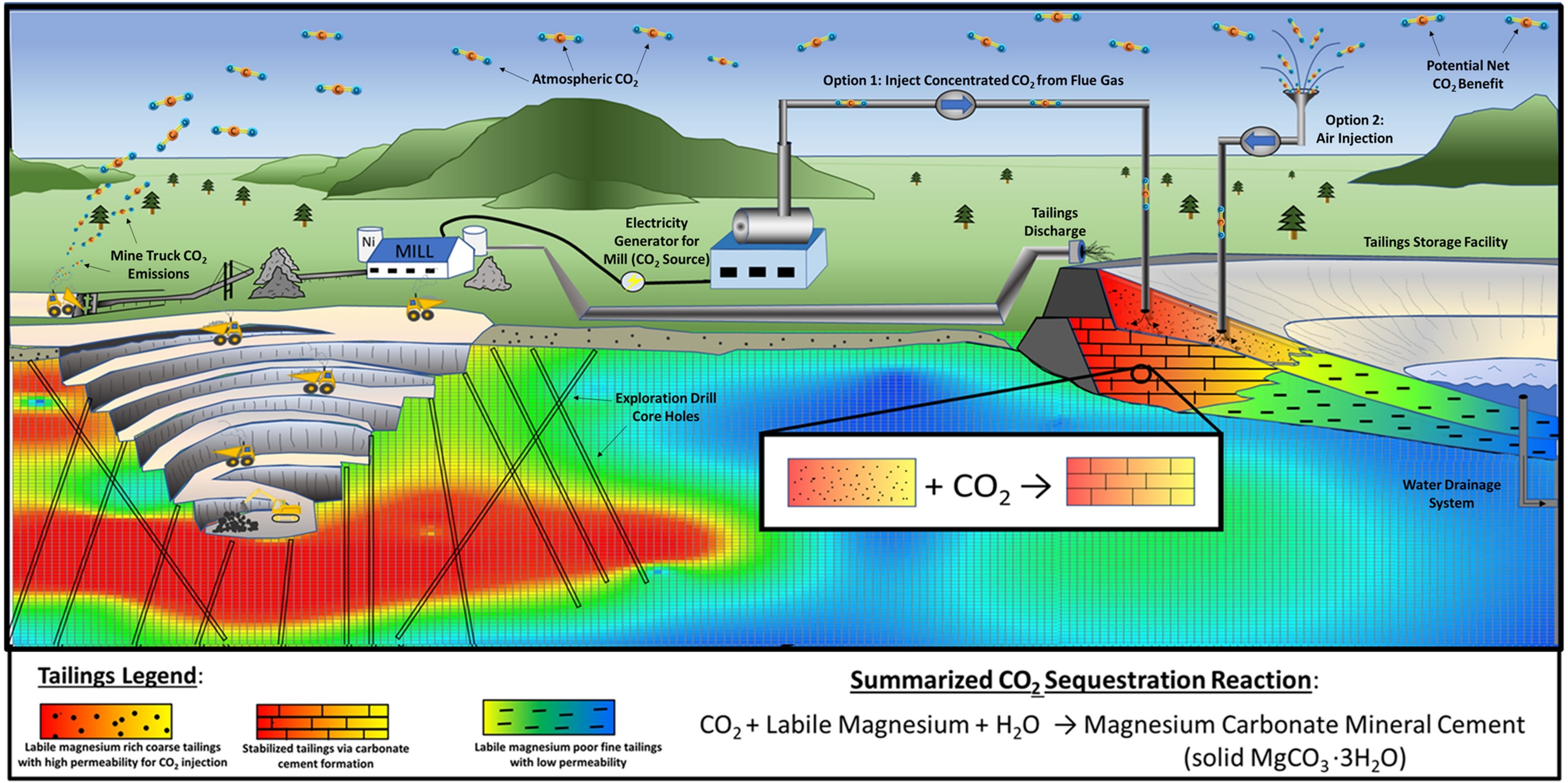
FPX Nickel Corp.
TSX-V:FPX

GIGAMETALS
CORPORATION



CARBON NEGATIVE BATTERY METAL MINING





(Vanderzee et al., 2019)

DR. ELOD GYENGE

Professor, Chemical & Biological Engineering
University of British Columbia

Co-Founder & CSO
Agora Energy Technologies

NOVEL UTILIZATION OF CARBON DIOXIDE FOR ENERGY STORAGE

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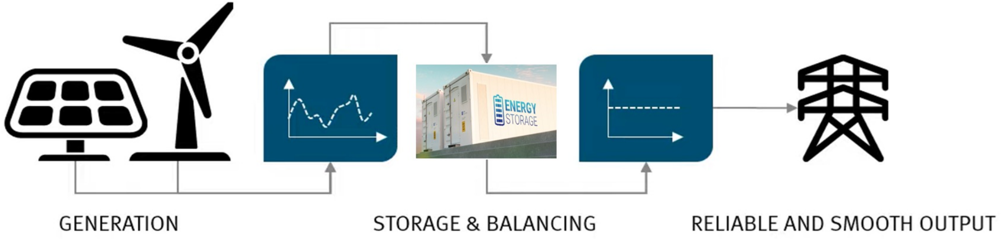
Inventing the Next™

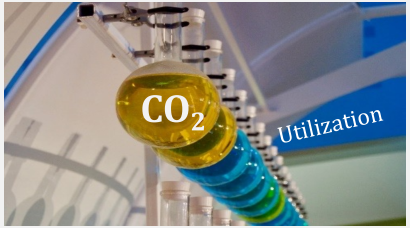
Challenges to decarbonization

- **The energy transition to renewable sources requires long-duration and cost-effective storage**



- **Mitigation of CO_2 emissions requires cost-effective large-scale solutions**

Batteries for Energy Storage: Metal/Mineral Supply Chain and Price Challenges



Can we utilize CO_2 in a battery ?

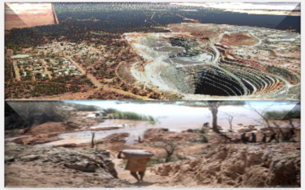
Cost of CO_2 capture from industrial emissions:
$ 50 – 150 /t

Vanadium

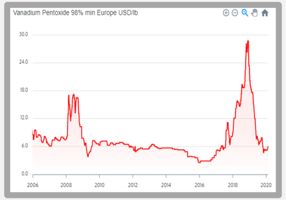
$27,500/t V_2O_5

Lithium

Cobalt



$45,000-50,000/t $LiCO_3$
$82,000/t Co

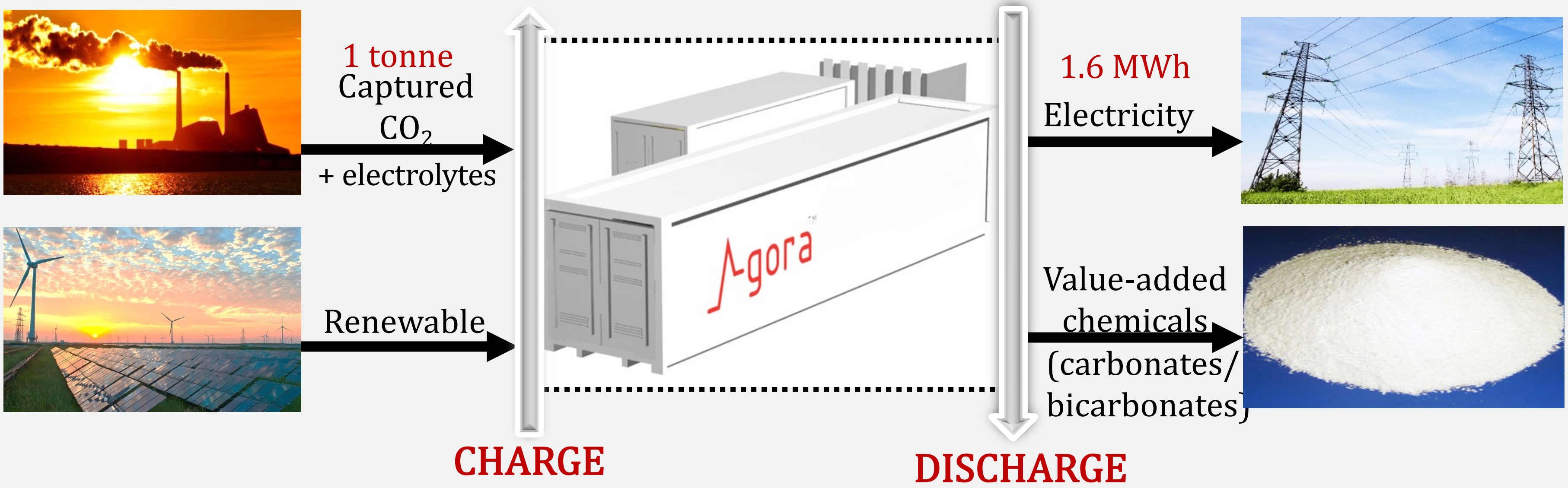


Zinc

$ 3,800/t Zn

Our Solution: The CO_2 Redox Flow Battery (CRB)

|Global IP 52 Countries|



Objective: To develop a large-scale CO_2 battery that stores renewable energy with the following characteristics:

- High energy density
- Long-duration storage at a low cost
- Long cycle life

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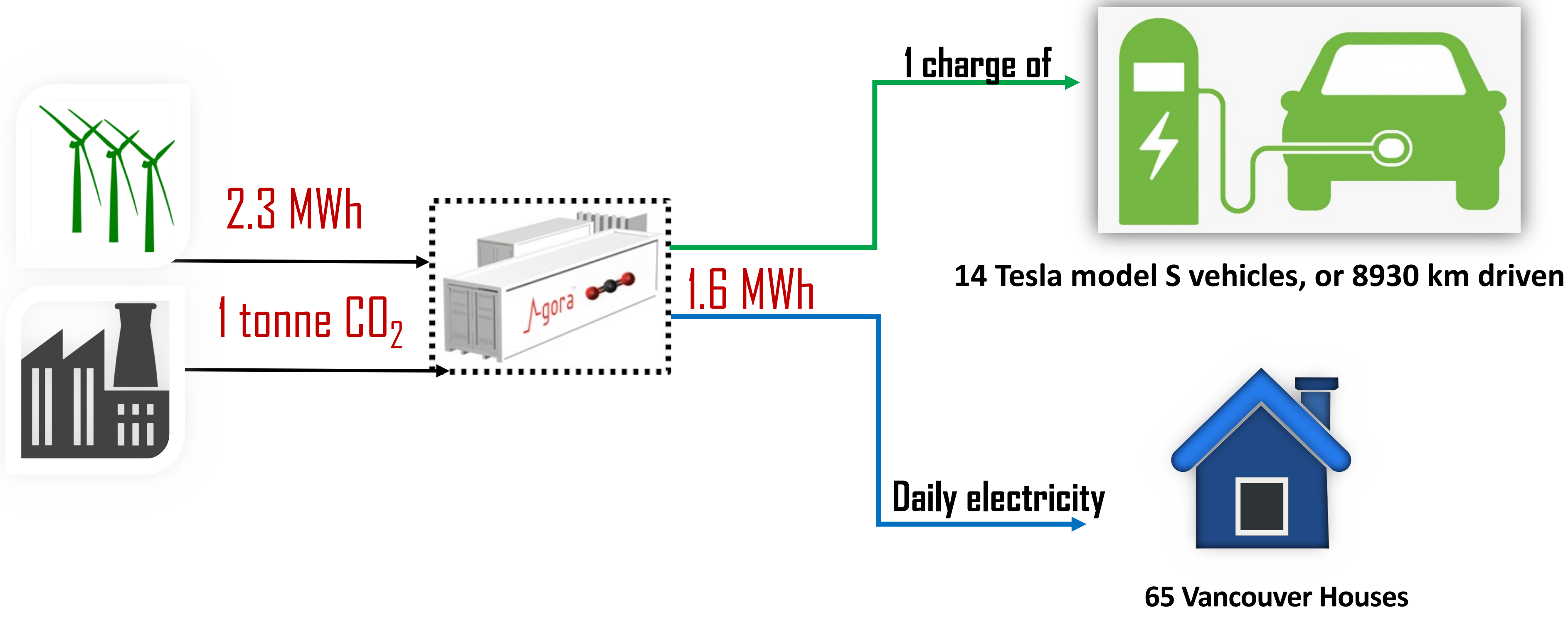
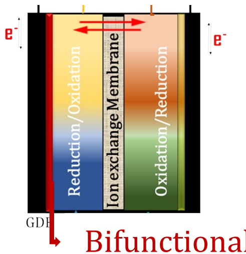
CRB Potential

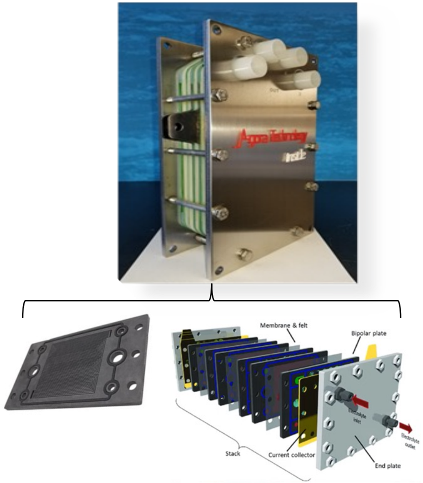


Milestones Towards Commercialization



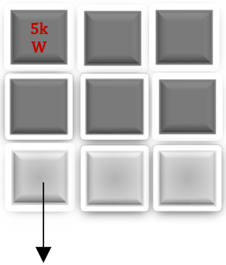
Bifunctional catalysts

- First company to advance, innovate and develop Bifunctional catalysts for CO_2-based redox couple



- Prototypes scale-up

0.5 MW … 100 MW



Largest module (5 kW)

Strong IP

Partnerships Development

Industrial GDE
(TRL = 6)

JV Agreements

Catalysis
(TRL=8)

Bench scale validation

Functional Prototypes
200W |1 KW |**5KW**

Large scale Demonstration

PILOT

2017
Incorporation

2018

2019

2024

2025

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AGORA: AWARDS 2020/2021

ALIBABA ENTREPRENEURS FUND
阿里巴巴創業者基金

2020
Environmental Champion Award

hello tomorrow

2020
Global Challenge Grand Prize
&
Energy Prize
Winners

Cartier Women's Initiative Awards

2021
Fellow: Science and Technology Pioneer Award

KEELING CURVE PRIZE
A GLOBAL WARMING MITIGATION PROJECT

2021
Capture and Utilization
Winners

impact canada

2020
Charging the Future
Finalist

Breakthrough Energy Solutions Canada

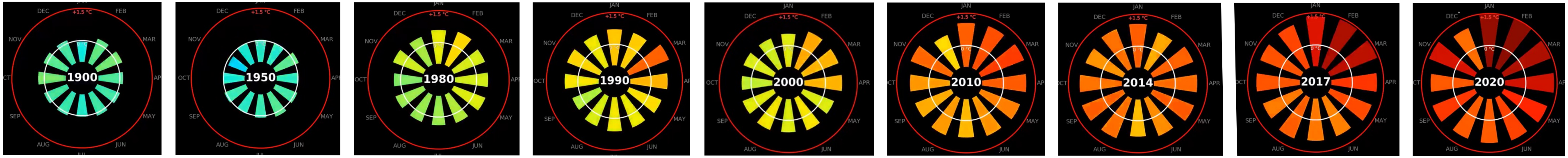
2020
Finalist

Thank you

120 years of atmospheric temperature change

+ 0.65 ^{0}C

+ 1.1 ^{0}C



Framing the problem

Designing Engineering options

Incorporation

Agora™

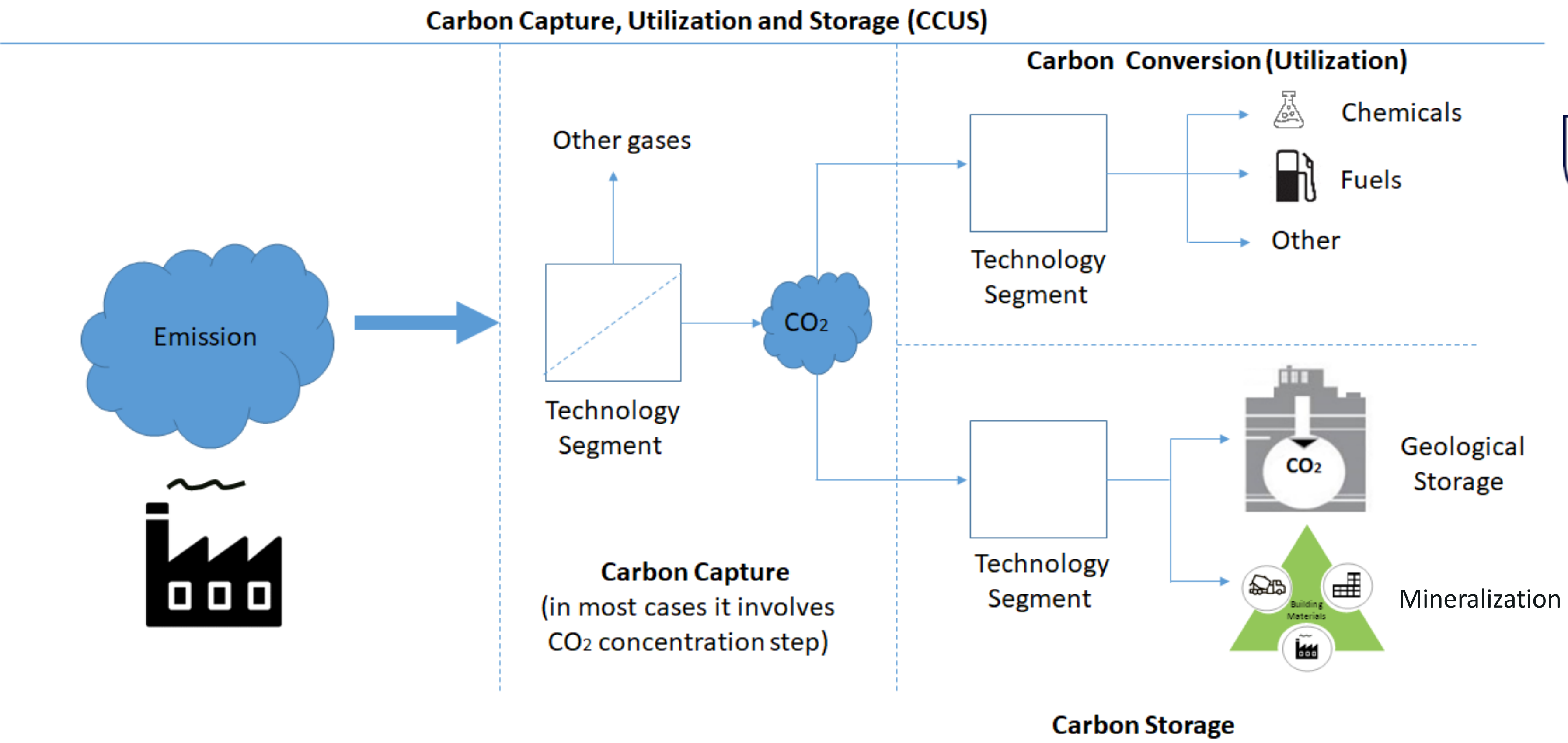
ENERGY TECHNOLOGIES

Inventing the Next™

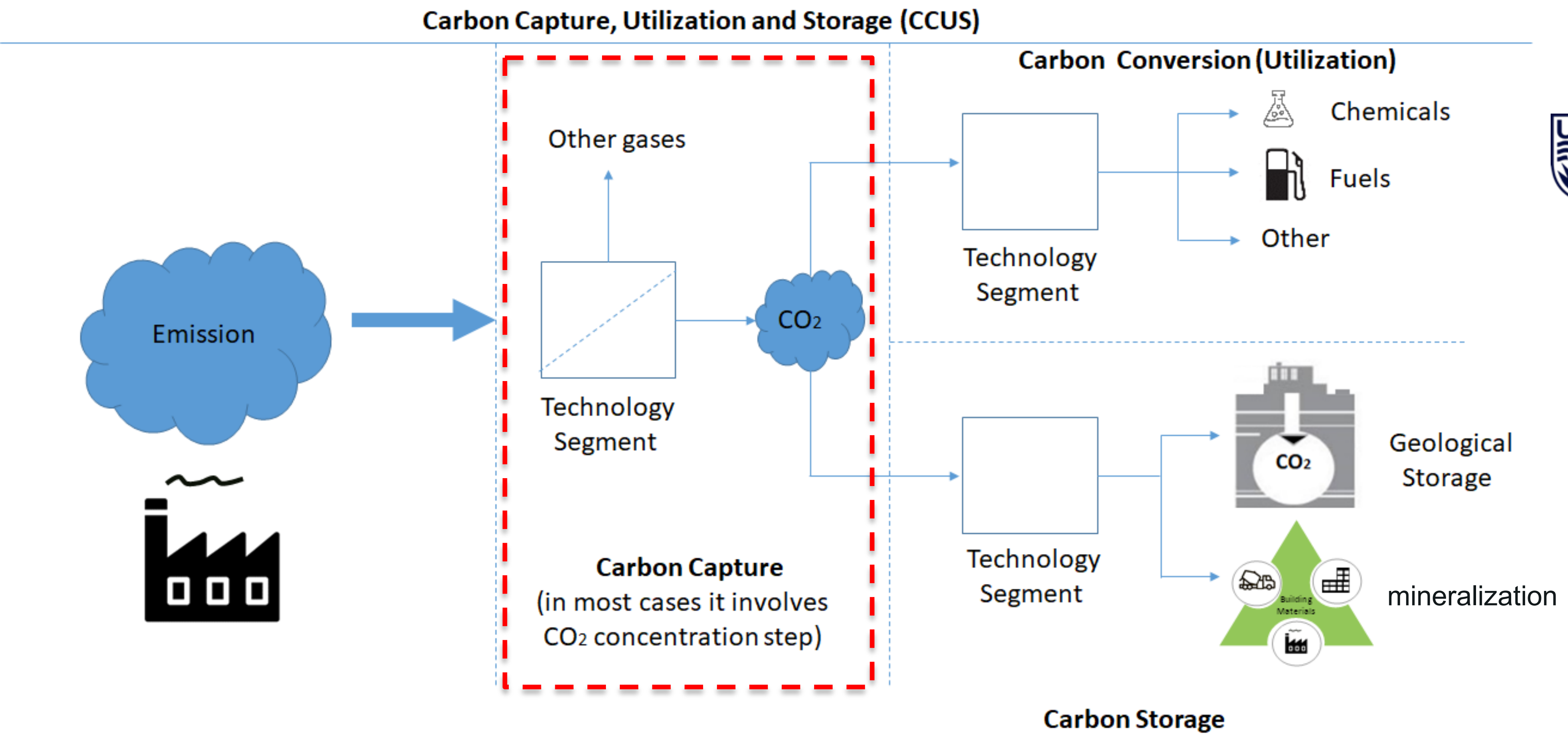
SERGIO BERETTA
Adjunct Professor, Chemical & Biological Engineering
University of British Columbia

CARBON CONVERSION READINESS & CCUS ECONOMICS

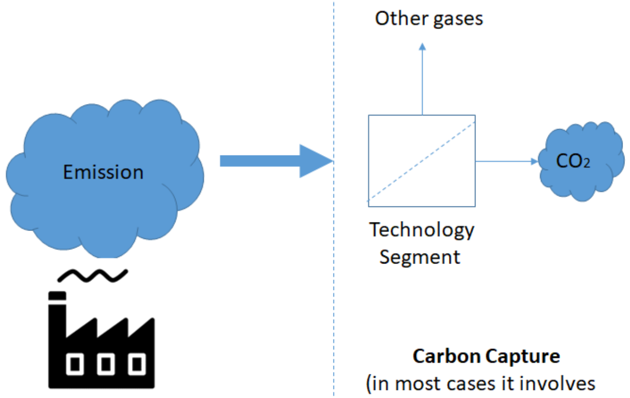
CCUS PROCESS PATHWAY



CCUS PROCESS PATHWAY



CARBON CAPTURE (CC) READINESS & ECONOMICS

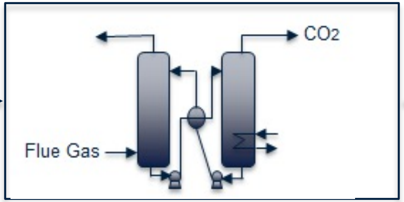


Carbon Capture
(in most cases it involves CO_2 concentration step)

TRL: Technology Readiness Level

Point Source Capture (PSC) (Absorption or Adsorption)

Gas /CO_2 From Point Source →

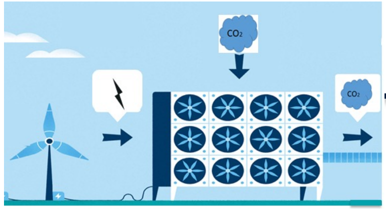


→ CO_2

TRL = 9

Direct Air Capture (DAC)

Air /CO_2 From atmosphere →



→ CO_2

TRL = 7

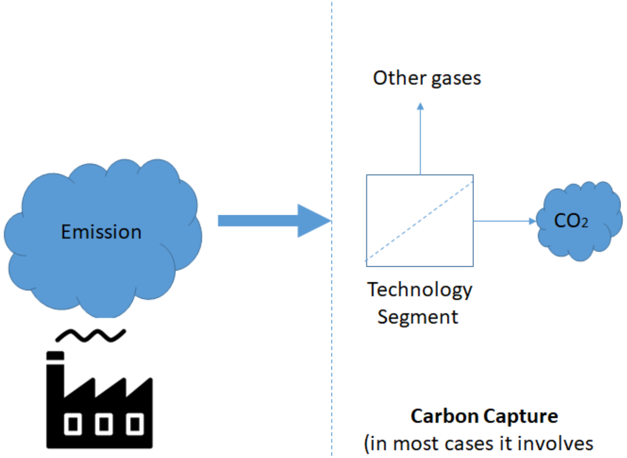
Biological Capture (DAC or PSC)

Air /CO_2 From atmosphere or Gas /CO_2 From Point Source →

→ Algae

TRL = 7-9

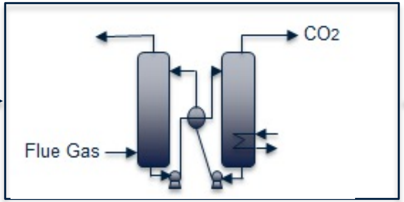
CARBON CAPTURE (CC) READINESS & ECONOMICS



Carbon Capture
(in most cases it involves CO_2 concentration step)

Point Source Capture (PSC)
(Absorption or Adsorption)

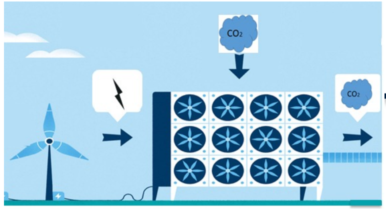
Gas /CO_2
From Point Source



CO_2

Direct Air Capture (DAC)

Air /CO_2
From atmosphere



CO_2

Biological Capture
(DAC or PSC)

Air /CO_2
From atmosphere
or
Gas /CO_2
From Point Source

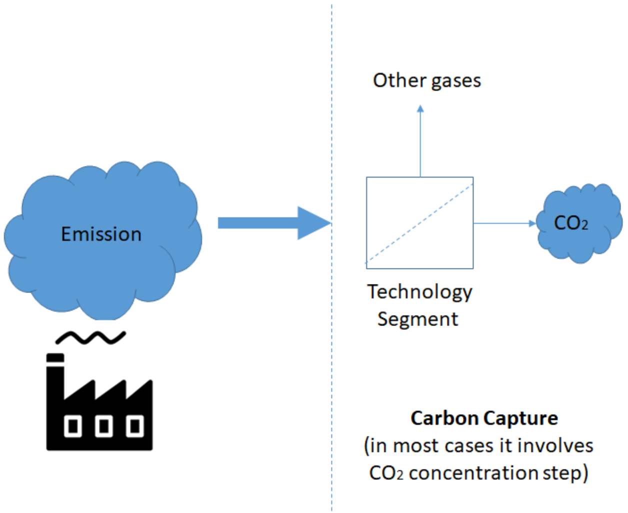
Algae

Cost of Capture

\$60-80/
tonne of CO_2

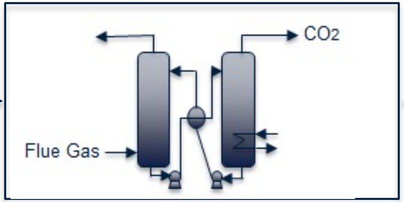
\$200-400/
tonne of CO_2
(today > \$600)

CARBON CAPTURE (CC) READINESS & ECONOMICS



Point Source Capture (PSC) (Absorption or Adsorption)

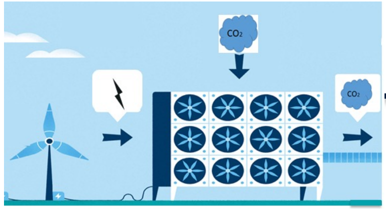
Gas /CO_2 From Point Source →



→ CO_2

Direct Air Capture (DAC)

Air /CO_2 From atmosphere →



→ CO_2

Biological Capture (DAC or PSC)

Air /CO_2 From atmosphere or Gas /CO_2 From Point Source →

→ Algae

Cost of Capture

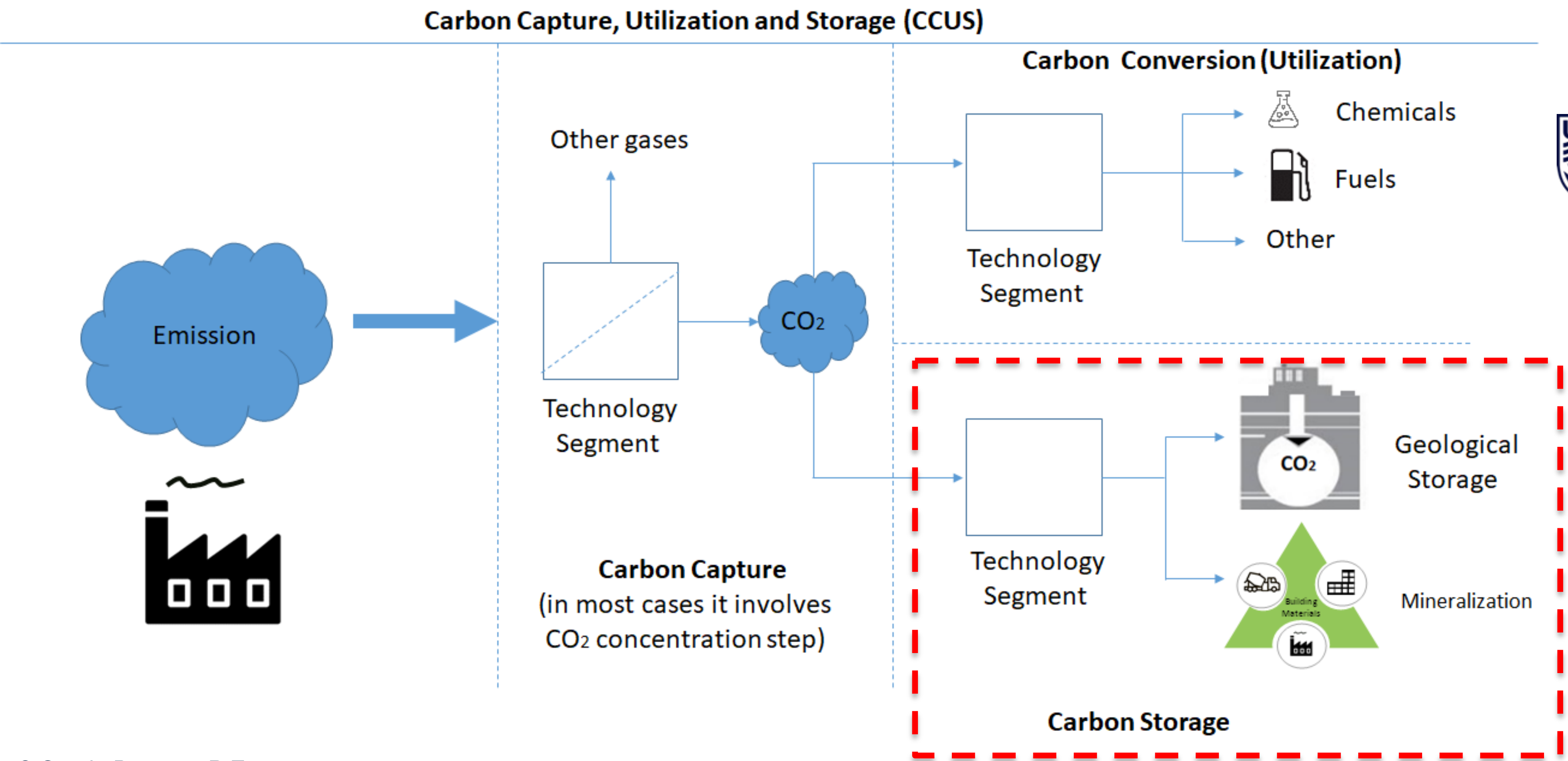
$60-80/ tonne of CO_2

$200-400/ tonne of CO_2 (today > $600)

CO_2 from air < $0/tonne

CO_2 from point source > $1,000/tonne of CO_2

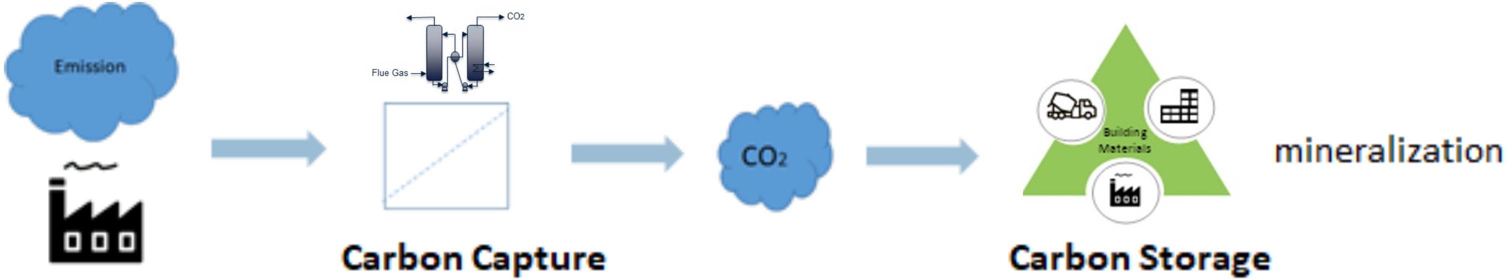
CCUS PROCESS PATHWAY



CARBON CAPTURE AND STORAGE (CCS) READINESS & ECONOMICS

Thermodynamically, one of the few conversions of CO_2 not requiring energy input

(not including the carbon capture step)

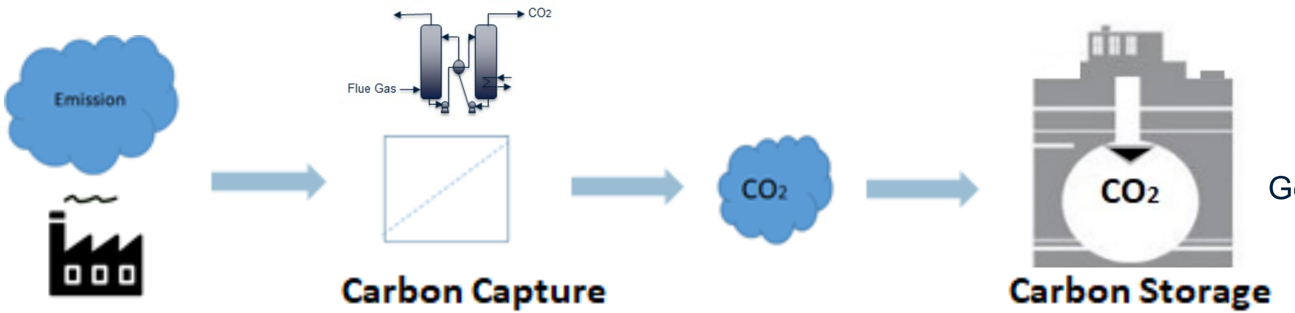


TRL = individual parts 9

Cost of Capture and Storage (CCS) = $ < 0 to 70 / tonne of CO_2

This strategy is **partially** used in some cement/concrete plants, and it is being expanded to other industries/ applications (e.g., mine tailings)

CARBON CAPTURE AND STORAGE (CCS) READINESS & ECONOMICS



Geological Storage

TRL = 9

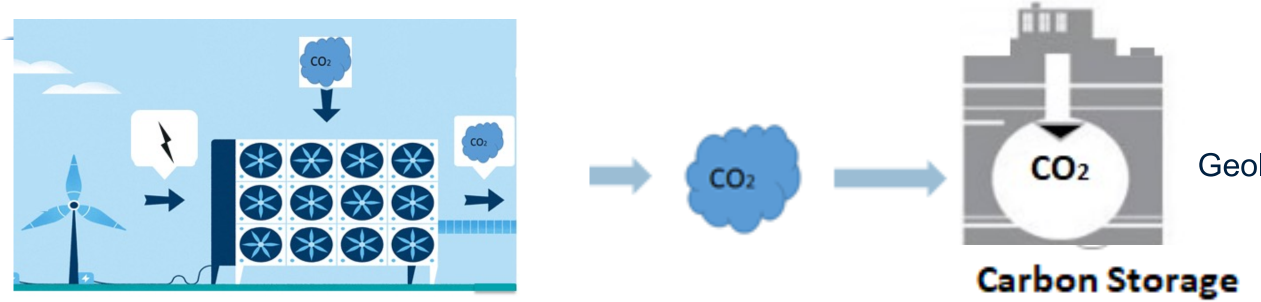
Cost of Capture and Storage (CCS) = $ 100 to 150 / tonne of CO_2

Carbon Capture coupled with Geological Storage is already being used at a commercial scale (in the North Sea) in Europe, US, and Canada

CARBON CAPTURE AND STORAGE (CCS) READINESS & ECONOMICS

Carbon Negative Strategies

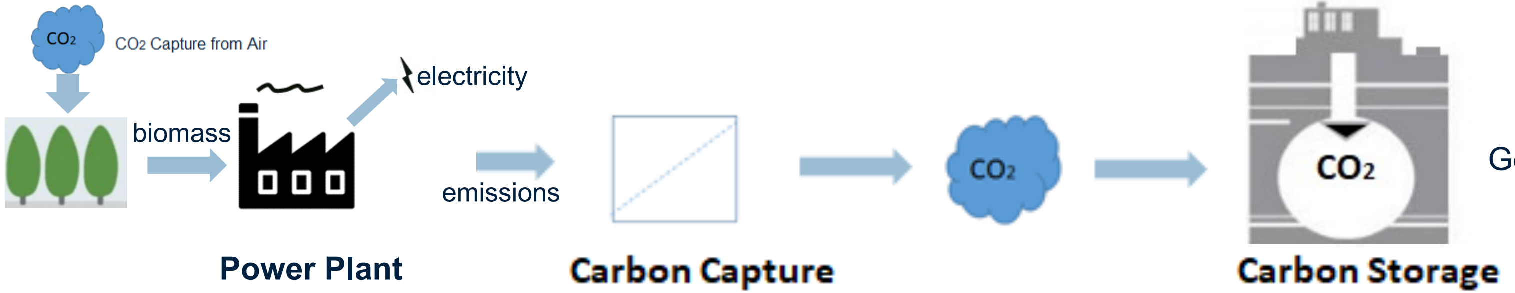
CO_2 Capture from Air



Geological Storage

TRL = 7

Cost of Capture and Storage (CCS) = $ 240 to 440 / tonne of CO_2
(today > $600)



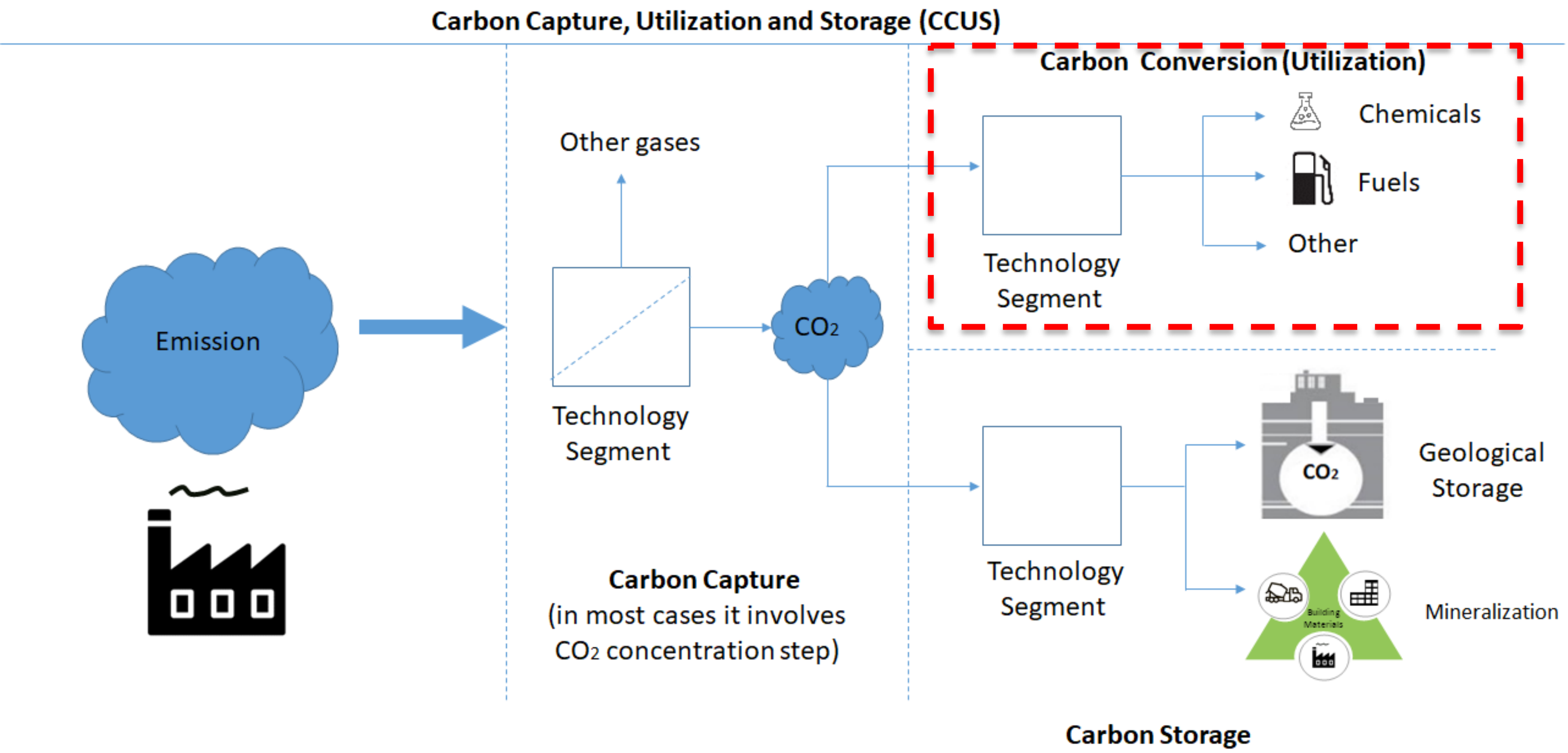
Geological Storage

Bioenergy with Carbon Capture and Storage (BECCS)

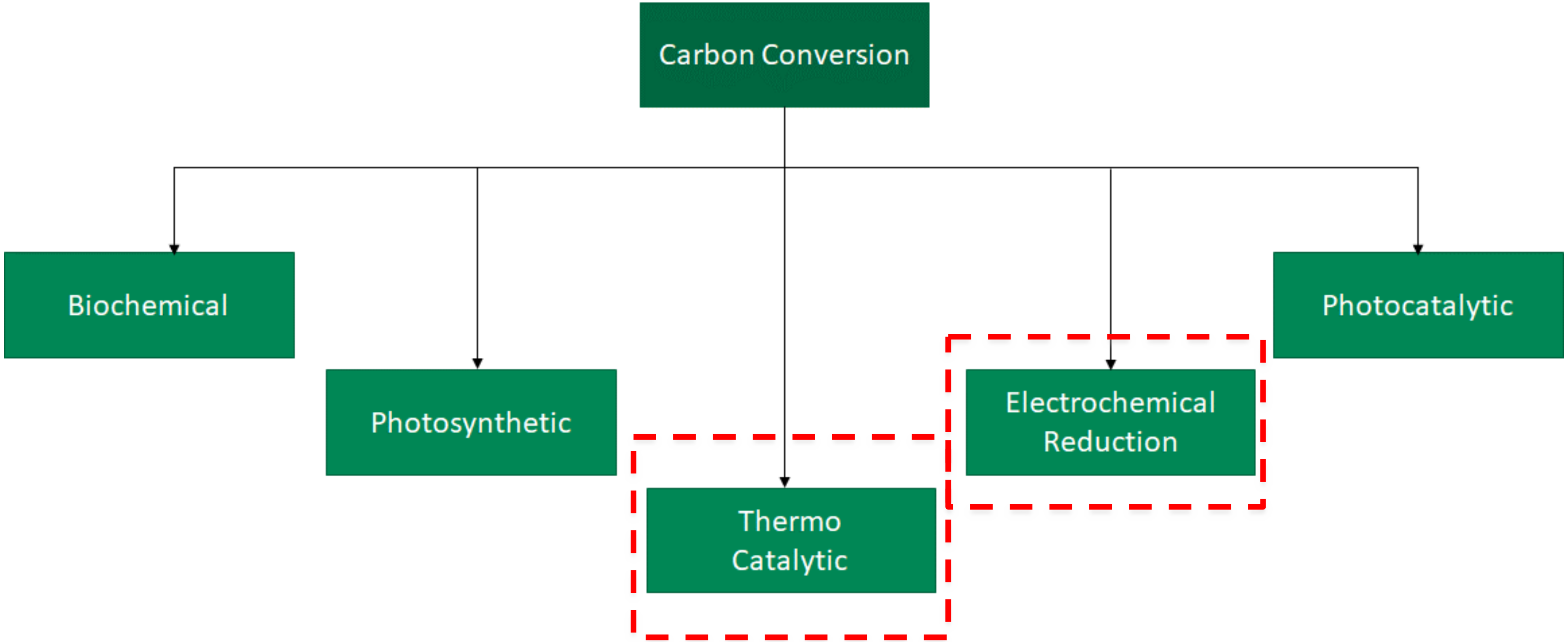
TRL = all individual parts 9

Cost of Capture and Storage (CCS) = $ 60 to 160 / tonne of CO_2

CCUS PROCESS PATHWAY

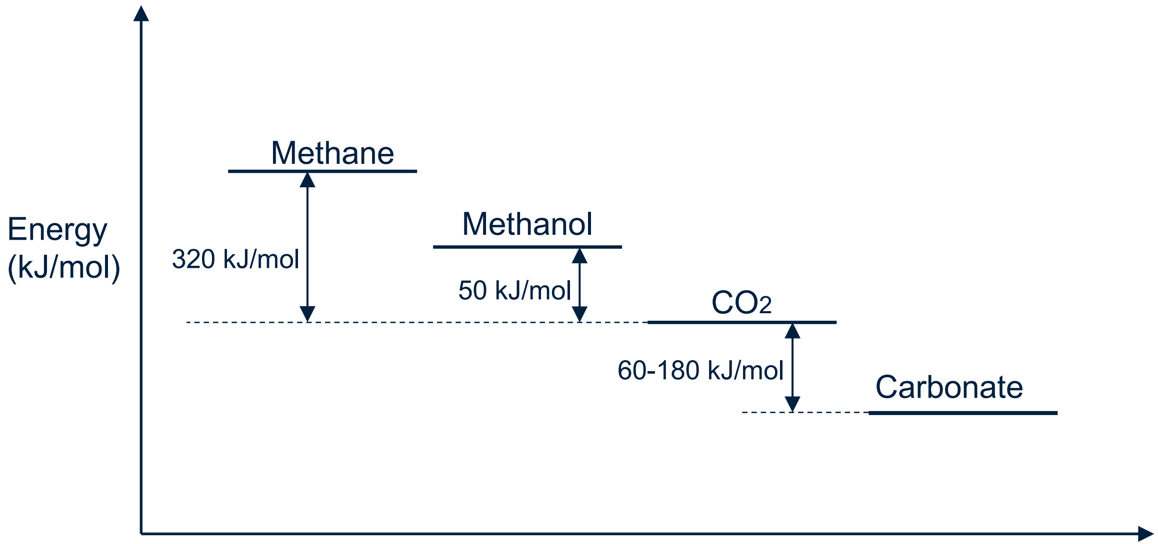


CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS

CO_2 is a molecule "without energy", to make it useful, energy must be added (clean energy)



Thermo-catalytic Conversion

$CO_2 + 3\ H_2 + N_2 \rightarrow (NH_2)_2CO + H_2O$ (urea)

$CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$ (methanol)

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$ (methane)

Electrochemical Conversion

Half-reactions:

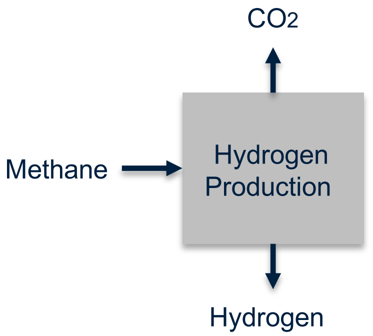
$CO_2 + H^+ + 2\ e^- \rightarrow HCOO^-$ (formate)

$CO_2 + 6\ H^+ + 6\ e^- \rightarrow CH_3OH + H_2O$ (methanol)

$CO_2 + 8\ H^+ + 8\ e^- \rightarrow CH_4 + 2\ H_2O$ (methane)

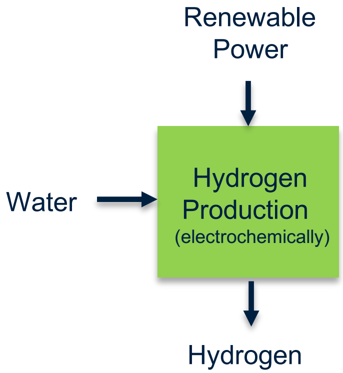
CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS

Grey Hydrogen



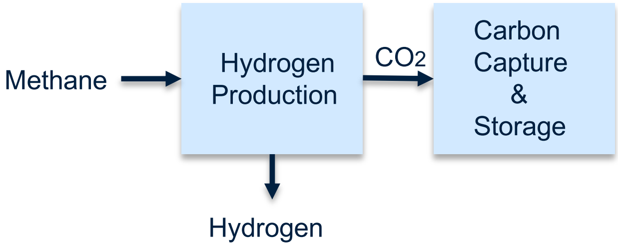
$1.2 - 1.4 / kg of H_2

Green Hydrogen



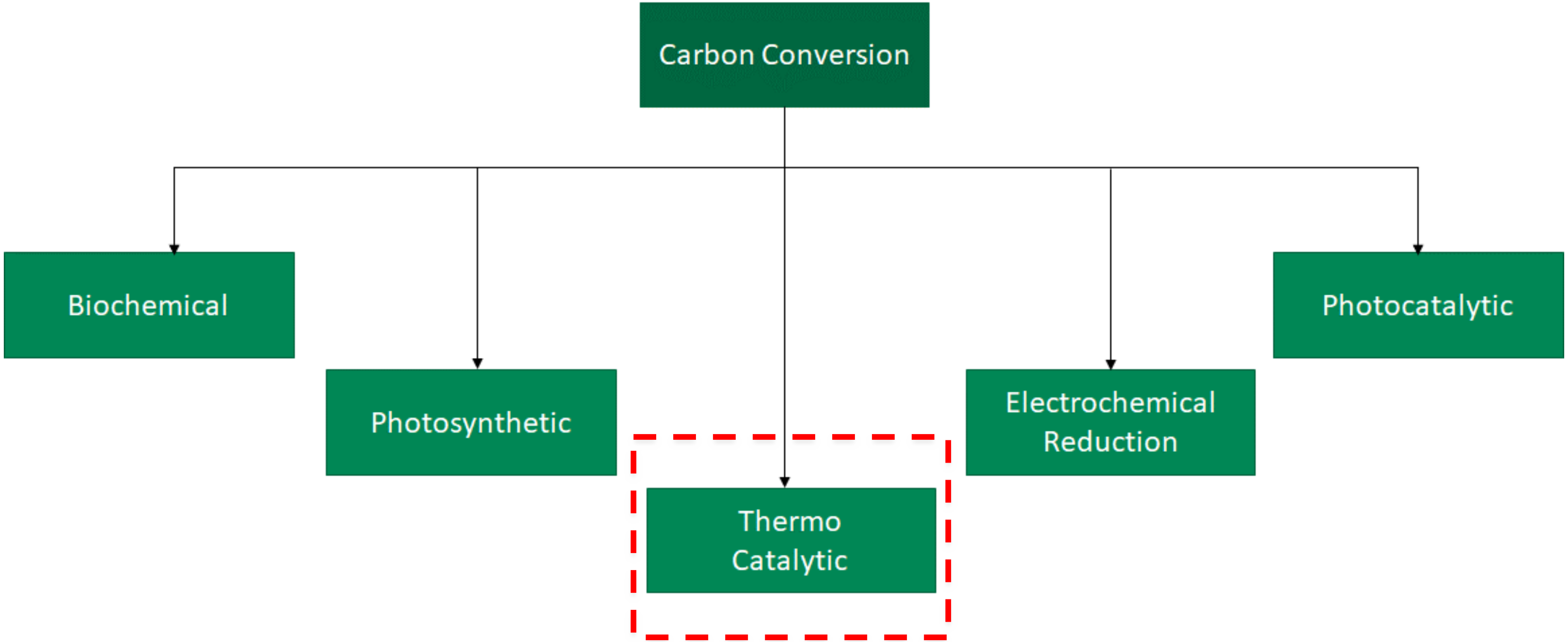
$4 - 5 / kg of H_2

Blue Hydrogen

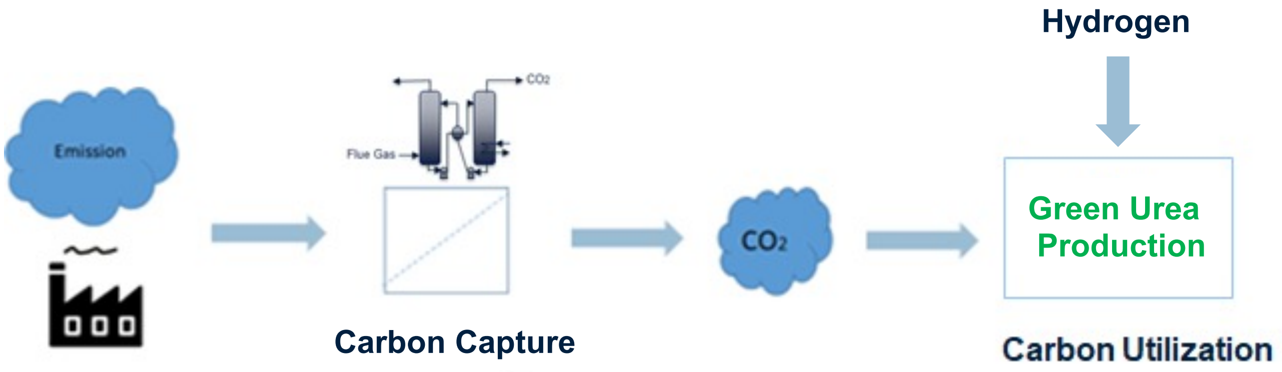


$2.0 – 2.5 / kg of H_2

CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



TRL = all individual parts 9

Cost of Capture and Utilization = $ 350 to 450 / tonne of CO_2 (w/ green hydrogen)

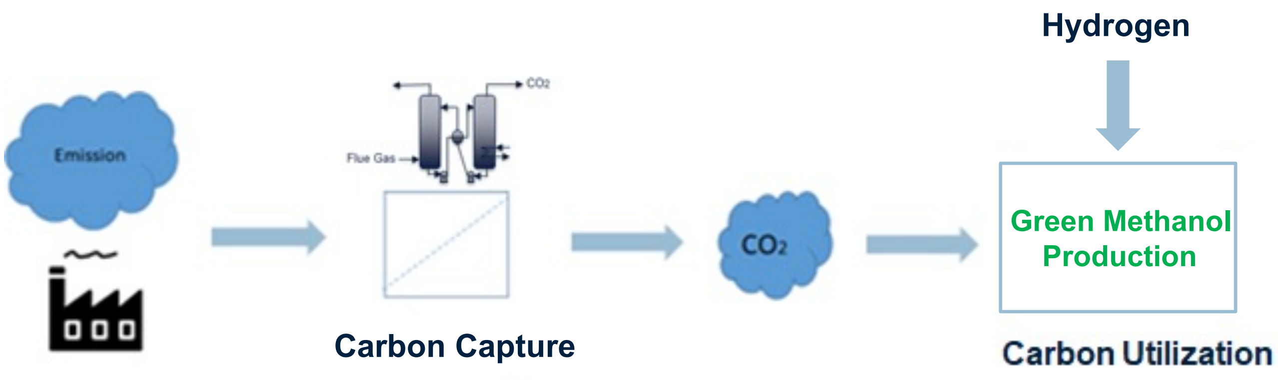
Cost of Capture and Utilization = $ 150 to 250 / tonne of CO_2 (w/ blue hydrogen)

Project – Haber

Australia

1.2 million tonne/year of urea

CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



TRL = 9

Cost of Capture and Utilization = $ 450 to 550 / tonne of CO_2 (w/ green hydrogen)

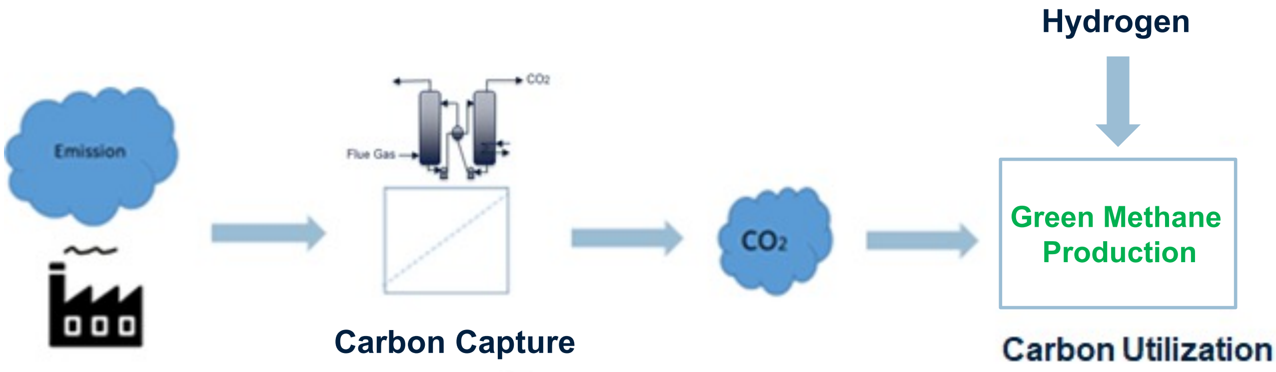
Cost of Capture and Utilization = $ 250 to 350 / tonne of CO_2 (w/ blue hydrogen)

George Olah Renewable Methanol Plant

Iceland

4,000 tonne/year of methanol

CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



TRL = individual parts 9 or 7

Cost of Capture and Utilization = $ > 1,000 / tonne of CO_2 (w/ green hydrogen)

Cost of Capture and Utilization = $ 500 to 700 / tonne of CO_2 (w/ blue hydrogen)

Audi e-gas (methane) Demonstration Plant
Wertle, Germany

CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS

Project – Haber

Australia

1.2 million tonne/year of urea

George Olah Renewable Methanol Plant

Iceland

4,000 tonne/year of methanol

Audi e-gas Demonstration Plant

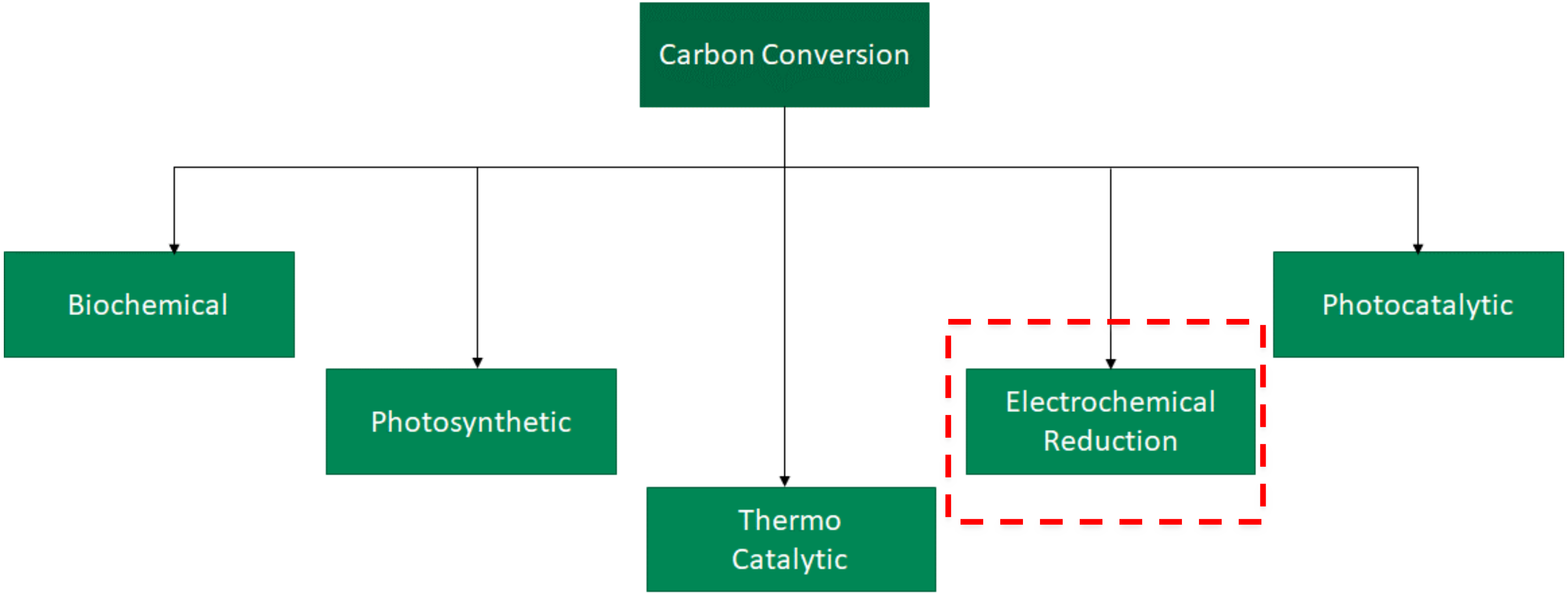
Germany

Methane

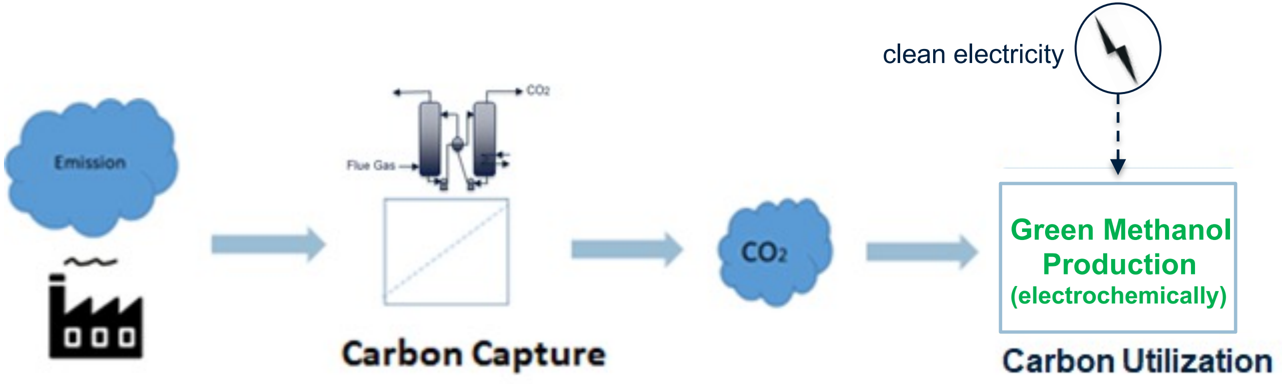
Higher Energy / Higher Cost

The more energetic the compound we are trying to make is, the higher the cost of carbon capture and utilization is!

CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS



CARBON CAPTURE AND UTILIZATION (CCU) READINESS & ECONOMICS

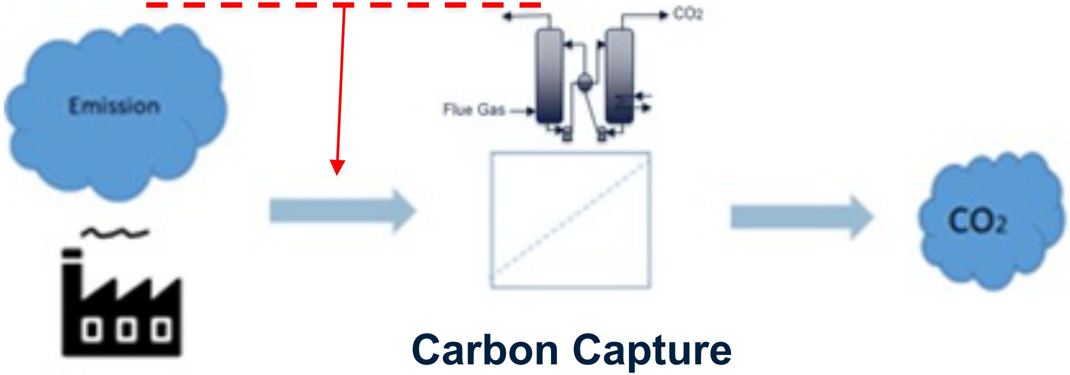


TRL = 4-5

Cost of Capture and Utilization = > $1,000 / tonne of CO_2

Final thought

1 Megatonne of CO_2 per year



Carbon Capture

Carbon Utilization

urea,
methanol,
methane,
or ….
production

Green Hydrogen OR clean electricity

Any significant production of green hydrogen or electrochemical conversion of CO_2 would require massive amounts of renewable power

Approximately, 10% of all the electrical production of BC

DR. AMY KIM

Associate Professor, Transportation Engineering
University of British Columbia

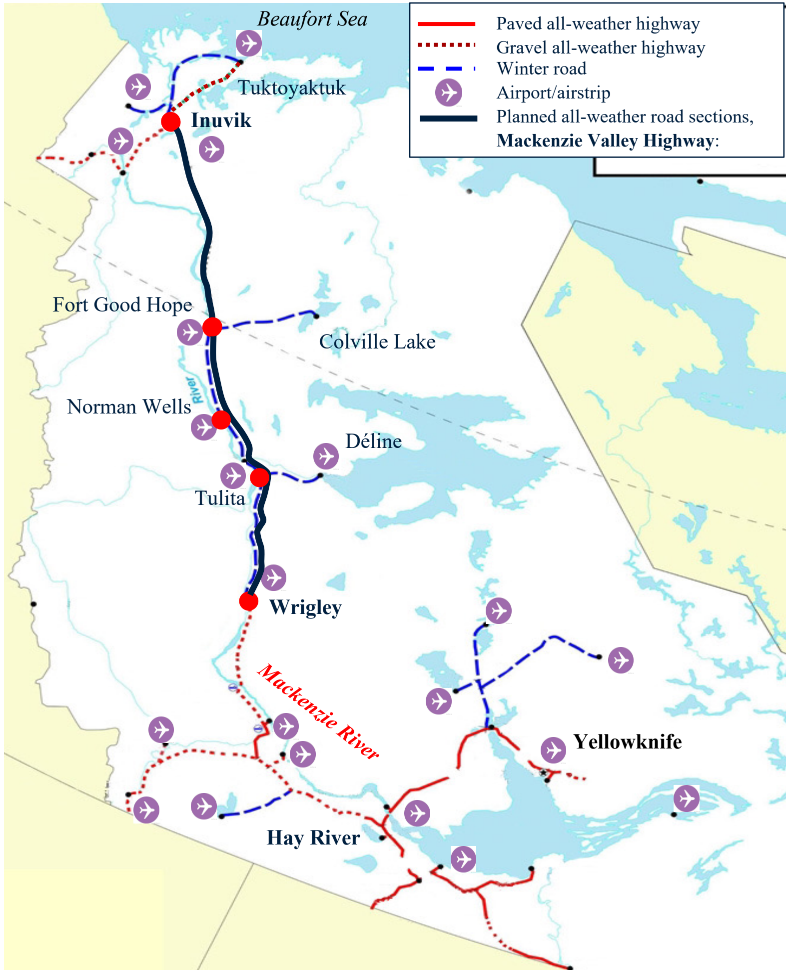
PLANNING ADAPTABLE, MULTIMODAL NETWORKED SYSTEMS

TRANSPORTATION INFRASTRUCTURE DECISIONS UNDER UNCERTAINTY AND CHANGING CONDITIONS

1. Transportation infrastructure decisions are made in the presence of many uncertainties
   - Demands
   - Climate change impacts
2. Long distance systems versus urban systems
   - Distances cost $$
   - Little to no redundancy
   - If redundancy → another mode(s)
3. Costly, complex decisions must be made in these conditions

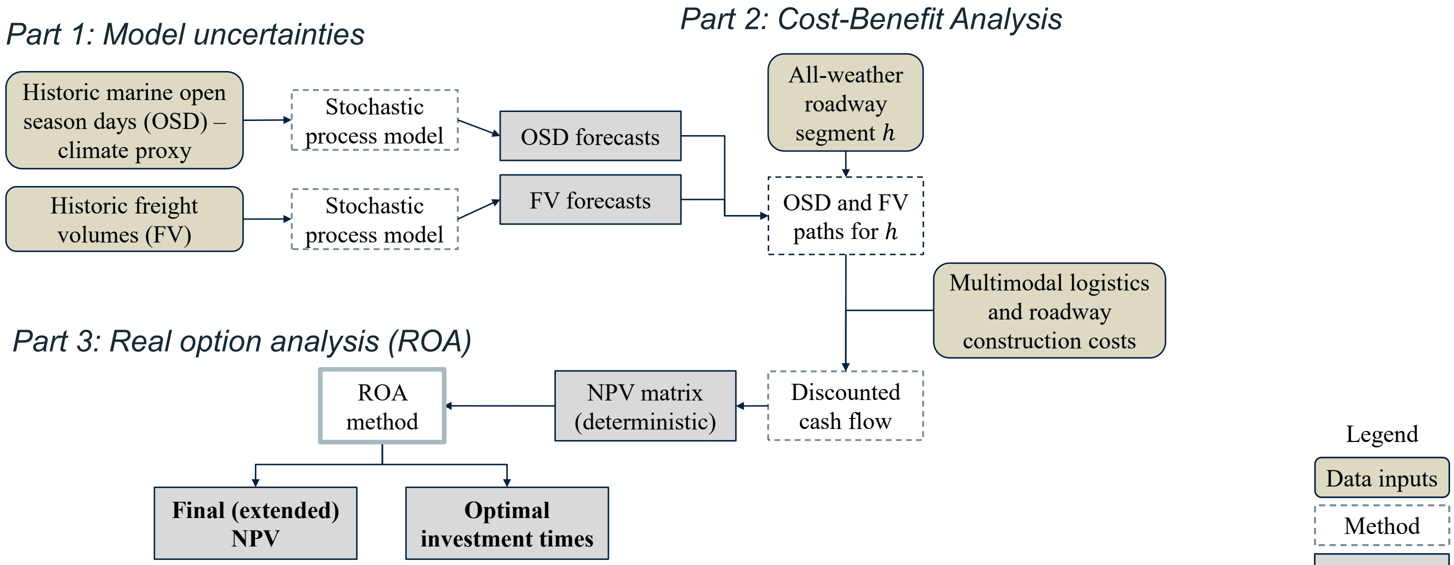
TRANSPORTATION INFRASTRUCTURE DECISION FLEXIBILITY IN RESPONSE TO UNCERTAINTIES:

Mackenzie Valley Highway, NWT



DO WE CONTINUE WITH THE CURRENT SYSTEM, KNOWING THAT BAD WATER SEASONS WILL RESULT IN HUGE COSTS? OR CONSTRUCT ALL-WEATHER ROAD ($B), AND WHEN?

Benefit-Cost Analysis using real options approach → Flexible decisions

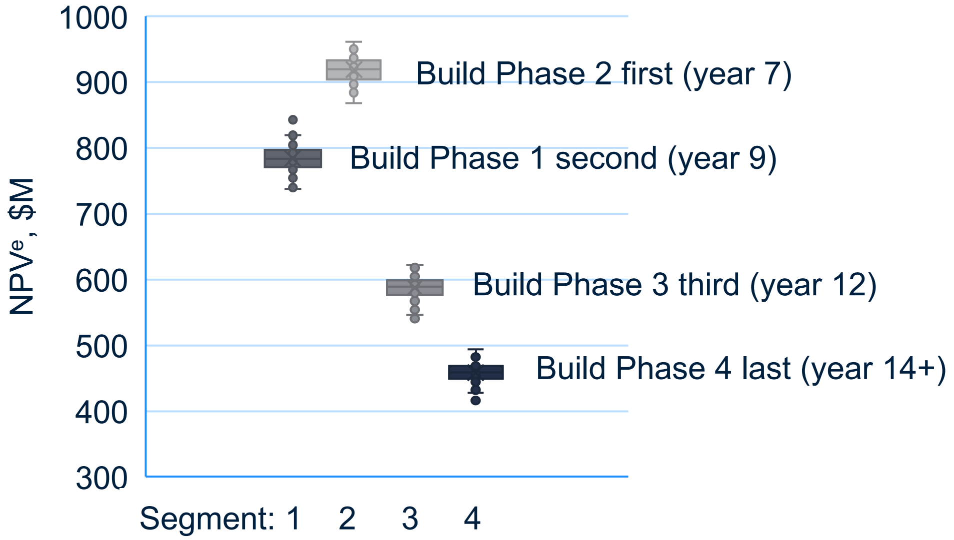


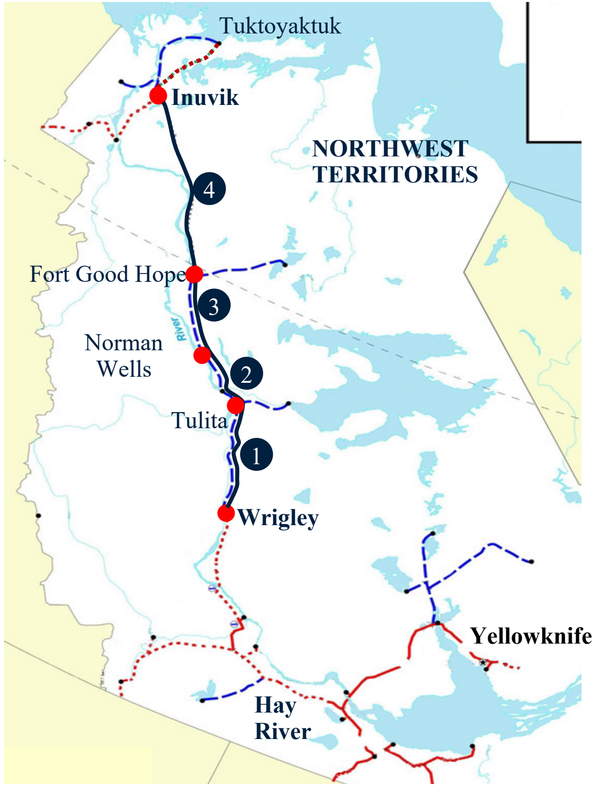
Kim & Li, 2020
Li, Jin, & Kim, 2021

MACKENZIE VALLEY HIGHWAY DECISION MODEL RESULTS

1) Construct or not construct? Wait until Year 6

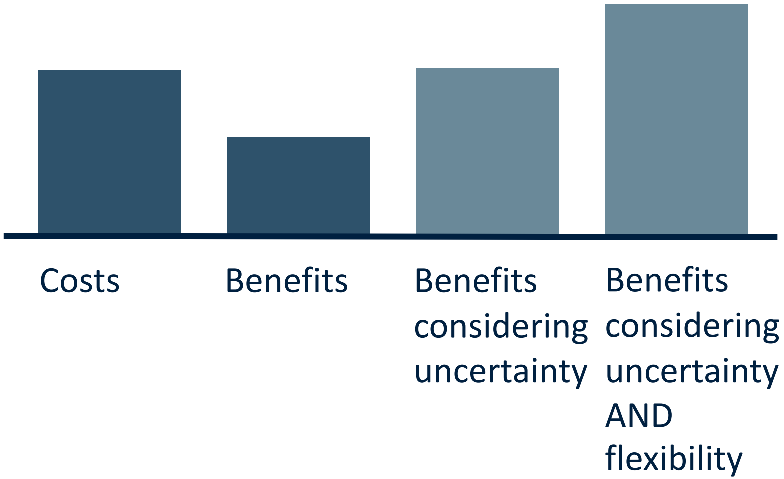
2) Construct in four phases?





ADAPTIVE AND RESILIENT MULTIMODAL TRANSPORT INFRASTRUCTURE DECISIONS

- Governance, ownership, operational characteristics differ from one mode to another
- Flexibility around decisions of infrastructure investment and operations – in the face of climate change impacts and changing/variable economic conditions – has value



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