DECARBONIZATION STRATEGIES TO ENSURE LONGEVITY OF HYDROCARBON BUSINESS MODELS & ENABLING THE NECESSARY ENERGY TRANSITION

(CLICK EACH OPTION FOR FURTHER DETAILS)

- **The Business case for CC(U)S – Opportunities**
- **CC(U)S – some technical details**
- **Geothermal Energy - Opportunities**
- **Generate Solar energy and Export more gas**

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CO_2 GEOLOGICAL STORAGE

SCREENING & MATURATION OF MARKETABLE VOLUMES

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Technical Director | Principal Carbon/GHG Storage Consultant

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CO_2 GEOLOGICAL STORAGE

SCREENING & MATURATION OF MARKETABLE VOLUMES

Terms of Reference

The Energy industry faces a unique opportunity to learn from the experience of successful industrial scale CO_2 storage projects around the world.

Aiming to aid develop viable projects within an optimal timeline, there are key selection criteria that can be used to rank prospective geological storage sites within the nominated areas, either if they are depleted fields or saline aquifers.

These criteria help establish what available data is needed to carry out an adequate risk assessment and estimation of CO_2 storage resources, but also potential data acquisition/appraisal plans.

The ultimate intention is to support operators, and authorities alike, mature reliable CO_2 storage resources, following the SPE SRMS system, but also ensure permanent containment through a multidisciplinary Containment Risk analysis, resulting in strictly risk-based Monitoring and Verification plans that meet International and Australian technical standards and requirements.

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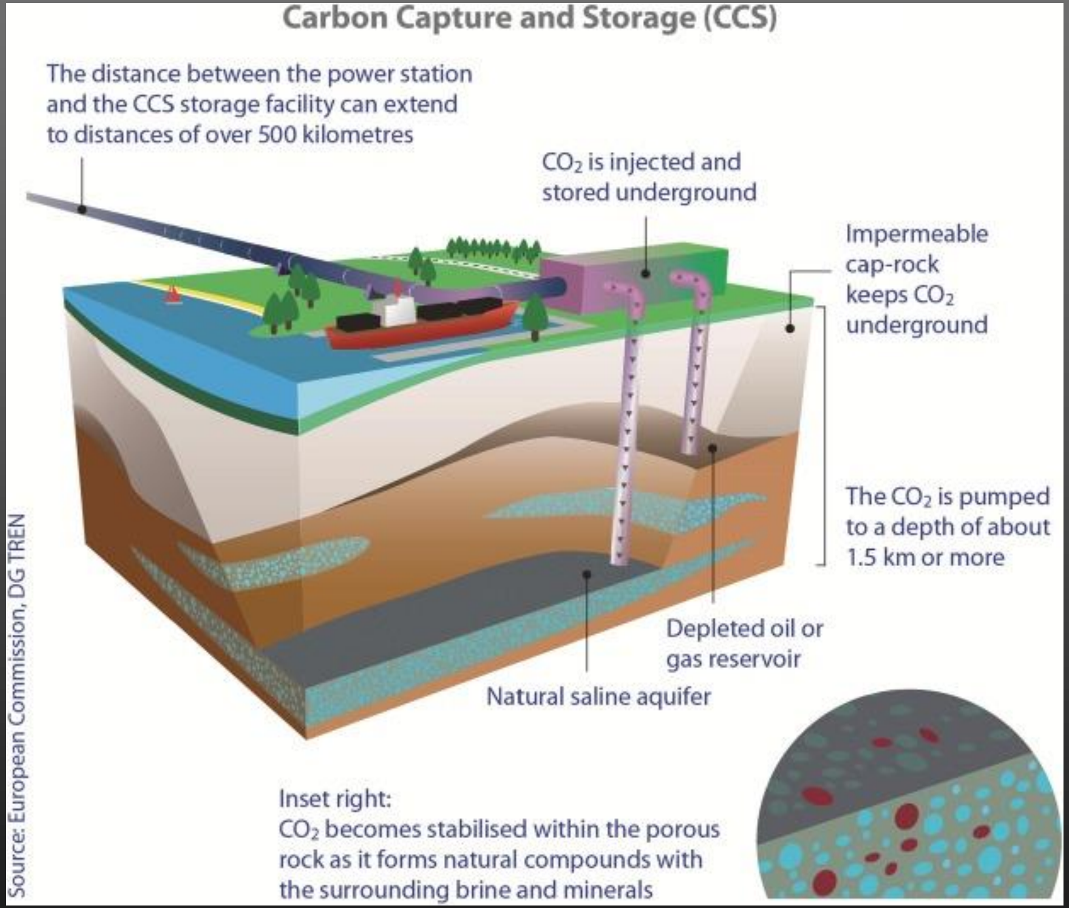
Executive Summary – CC(U)S Business models

- **Proven technology – capture exist since 1930's and geological storage since the 90's**
- **Business Value chains developing by the day**
- **Unified International Carbon price is expected**
- **Average cost of CCS is higher than today's carbon pricing levels**
  - **However, Wood Mackenzie reports expectation of carbon price of US$120/tone in 2030 and US$100/tone in 2050, which is needed to cover the average CCS project in the power sector**



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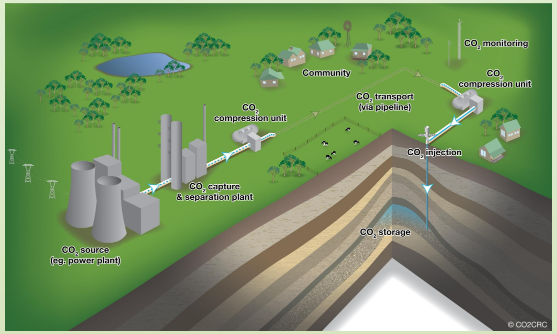
Carbon Capture & Storage: The Business Models

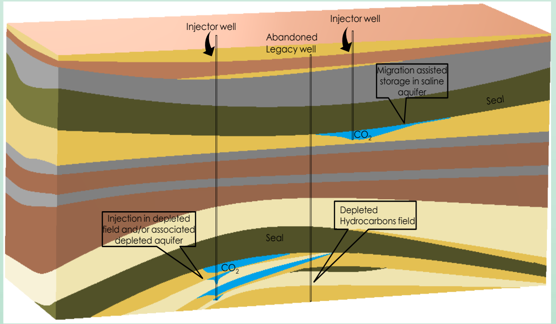


Model 1 - Underground Disposal

- Tariffs per tone of CO_2 safely stored and contained
- Sources usually hard-to-abate industries (e.g., Cement, Steal manufactory)

Examples: Northern Lights (North Europe), DEEPC (Australia)

1



Model 2: Decarbonize traditional Fossil Fuels – Ensure Business Longevity

- Cleaner LNG
- Net Zero Coal Fired plants

Examples: Sleipner (Norway), Gorgon (Australia), Bayu Undan (Australia-Timor Leste), Kasawari (Offshore Sarawak), CTSCo - Glencore (Australia)

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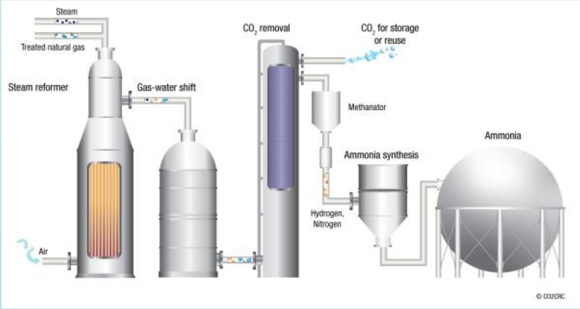
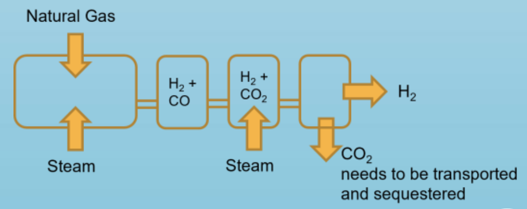


Model 3: Blue Hydrogen/Ammonia

Examples: Quest (Canada), H2H Saltend (UK), ADNOC Blue Ammonia (UAE)



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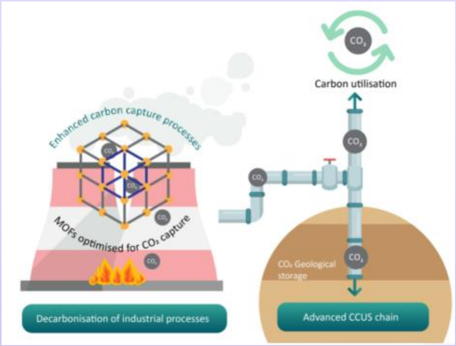

Model 4: Hybrid

- Examples: Aramis (Netherlands), Teesside (UK), Singapore LNG

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Carbon Capture & Storage: The business models I

- Model 1: CO_2 Underground Disposal – tariffs per tone of CO_2 safely stored and contained

  → Sources usually hard-to-abate industries (e.g., Cement, Steal manufactory)

  Example: Northern Lights (North Europe), DEEPC (Australia)

- Model 2: Decarbonization & Carbon abatement of traditional O&G production (e.g., cleaner LNG)

  Examples: Sleipner (Norway), Bayu Undan (Australia-Timor Leste), Kasawari (deepwater Borneo), CTSCo - Glencore (Australia)

Business Justifications

Expected carbon prices over the next decade are higher for all major emissions trading systems, with EU ETS prices predicted to average €47.25 over 2021-25 (compared to €31.71 estimated for the whole of Phase 4 last year) and €58.26 over 2026-30. IETA 2021

The path ahead in Asia-Pacific

"Driven by the global shift to ambitious climate action, **Australia's** carbon market has surged 21 per cent in the calendar year to date, according to market analyst RepuTex, with the spot price rising to AU$20 a tonne. It expects demand to rise over the decade and push the spot price over AU$50 a tonne by 2030."

The Sydney Morning Herald – July 2021

"Carbon neutral-related investments of up to JPY50b (US$500m) as certified under an environment adaptation plan made by 31 March 2024 will either be eligible for a 5% to 10% tax credit or for 50% special depreciation.

Japan's 2021 Tax Reform

China fires up carbon trading as Asia turns onto greener path - Nikkei Asia – July 2021

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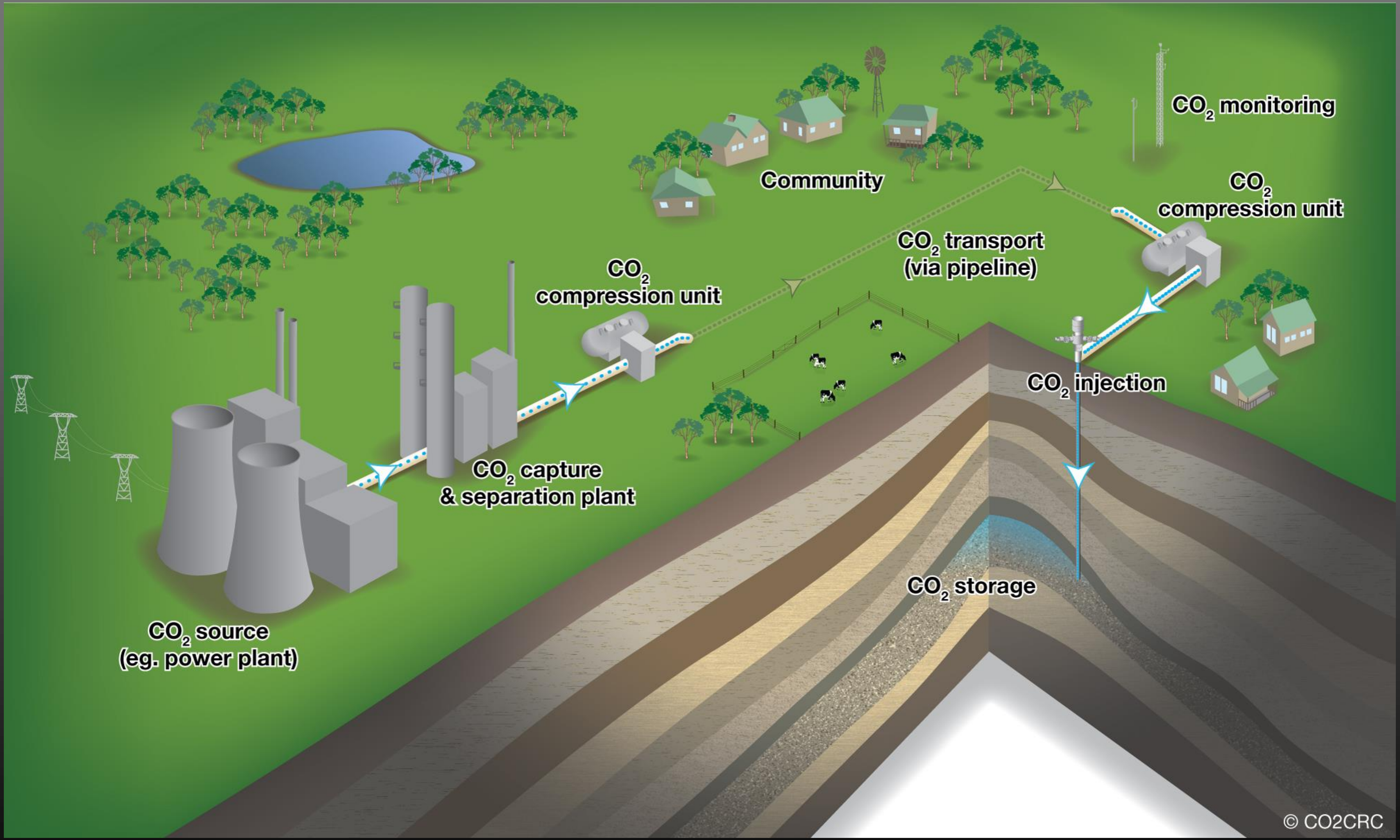
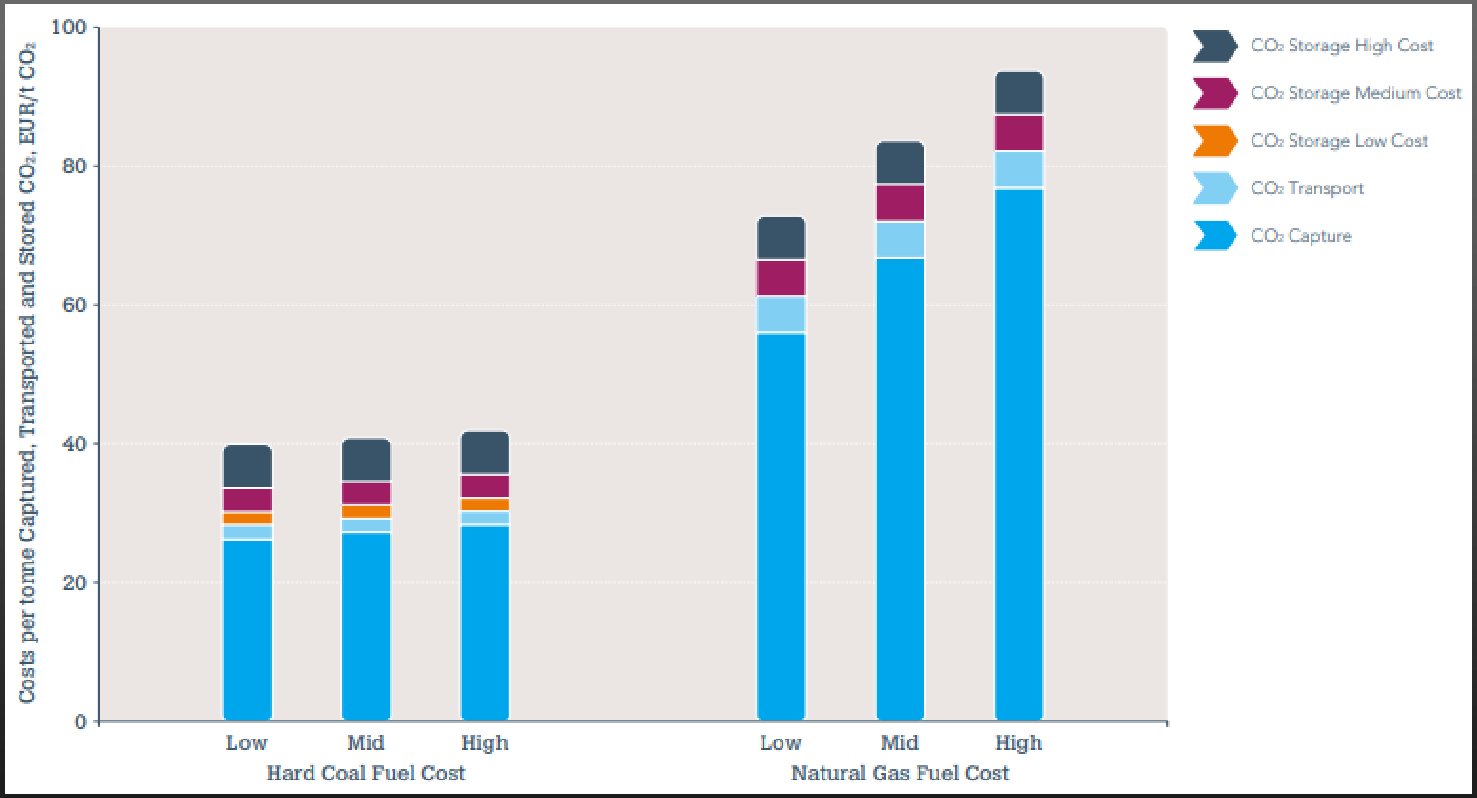
Model 1: CO_2 Underground disposal



Model 1 & Model 2 – CCS solution Investments

From Zero Emissions Platform (ZEP) - 2020

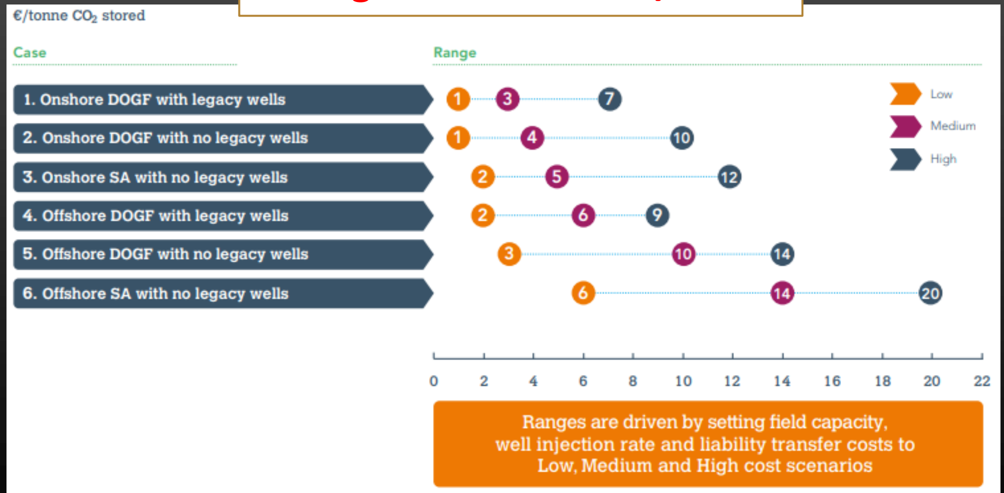
Capture– Single source-Single sink– Ave. ~ 65 EUR/tonne for NG



Transport – Large scale – Ave. ~ 10 EUR/tonne

Spine Distance km	180	500	750	1500
Onshore pipeline	1.5	3.7	5.3	n. a.
Offshore pipeline	3.4	6.0	8.2	16.3
Ship (including liquefaction)	11.1	12.2	13.2	16.1

Storage – Ave. ~ 6 EUR/tonne



Model 1 Example: CCS in Singapore – Impact on Emissions

FROM SINGAPORE NATIONAL CLIMATE CHANGE SECRETARIAT - 2013

2011 Emissions		2015		2030		2050	
% CO_2 Stream	Amount mtpa (%)	Reduction % (mtpa)	Cost $/tonne (Total M$)	Reduction % (mtpa)	Cost $/tonne (Total M$)	Reduction % (mtpa)	Cost $/tonne (Total M$)
3	23.7 (50.9)	0 (0.0)	228 (0)	15 (3.5)	155 (543)	40 (9.4)	93.5 (879)
8	14.0 (30.4)	5 (0.7)	193 (135)	20 (2.8)	131 (367)	50 (7.0)	79 (533)
15	0.00 (0.00)	40 (0.0)	169 (0.0)	80 (0.0)	115 (0.0)	80 (0.0)	69 (0.0)
20	0.01 (0.02)	50 (0.005)	158 (0.79)	80 (0.008)	107 (0.86)	90 (0.009)	65 (0.59)
100	0.71 (1.54)	80 (0.57)	70 (40)	95 (0.68)	48 (33)	95 (3*)	29 (87)
Total	38.12					19.4 mtpa (51%)	($1520M) ($78.4/tonne CO_2)

~51 % reduction in CO2 emissions – 78.4 SGD/tonne

* Assume additional 2.4 mtpa from an incoming (industry) plant for 100% stream

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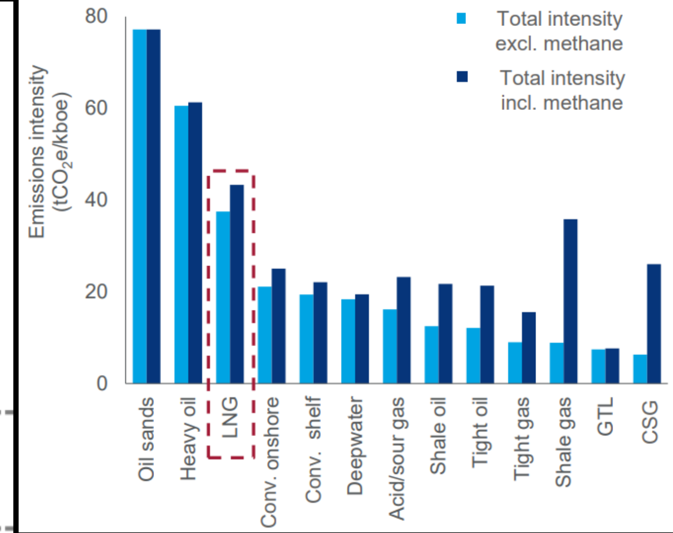
Model 2 Example: Decarbonized LNG – Impact on Emissions

FROM WOOD-MACKENZIE – AUGUST 2021

LNG CO2 emissions ~ 40 t / kboe

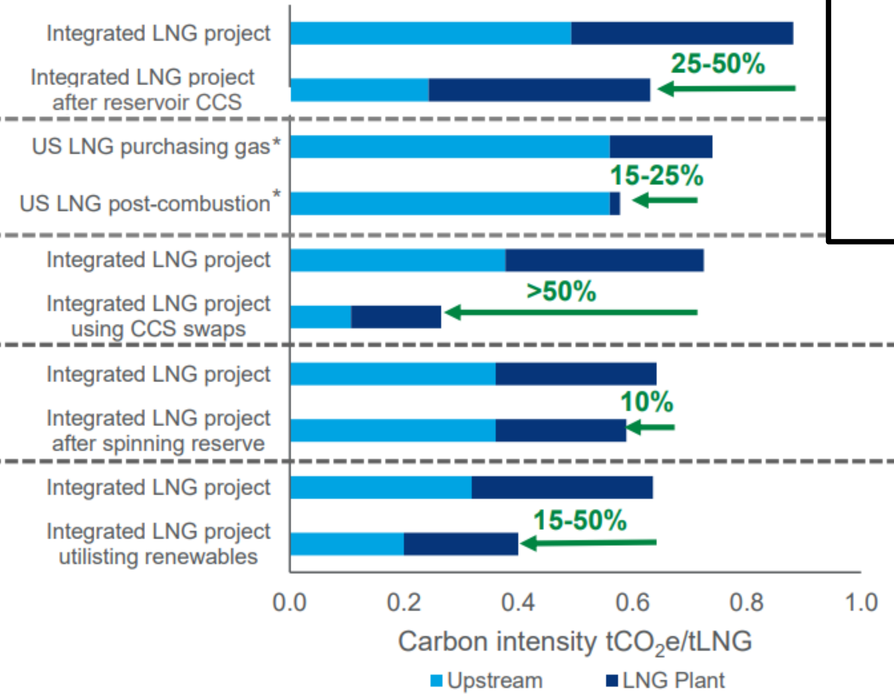


CCS can have a material impact reducing emissions

LNG projects supplied by high CO_2 fields can inject reservoir CO_2. Other LNG projects need to capture CO_2 from flue gas. But CCS alone will not offset all emissions from an LNG project

The impact of pre and post-combustion CCS vs other carbon emission reduction measures

1. **Reservoir CCS** can reduce the overall intensity of LNG projects by **25-50%** when the LNG plant is supplied by fields with >10% CO_2.
2. **Post-combustion CCS** can reduce LNG plant emissions by around **90%**. But overall emissions are only reduced by **25%.** These projects must work with upstream operators to reduce emissions.
3. CCS swaps# can offset both upstream and plant emissions. The impacts of swaps can be greater than pre and post-combustion CCS.
4. By comparison, **using batteries** to reduce spinning reserve at an LNG plant can reduce emissions by around **10%**.
5. **Renewables** can be used to reduce emissions from the upstream and LNG plants. The impact will vary at different LNG facilities.



Some LNG companies may be able to take advantage of commercial swap where they can inject carbon from a cheaper source in their portfolio and use credits or another form of commercial arrangement to offset LNG emissions.

* Assumes US LNG projects are purchasing gas off the US grid, so upstream intensity is based on an average intensity of the plays that typically supply gas to the US Gulf Coast LNG plants. However, several US LNG projects have introduced upstream procurement programmes targeting low-carbon feedgas sources, allowing them to sell LNG with a lower carbon upstream intensity.

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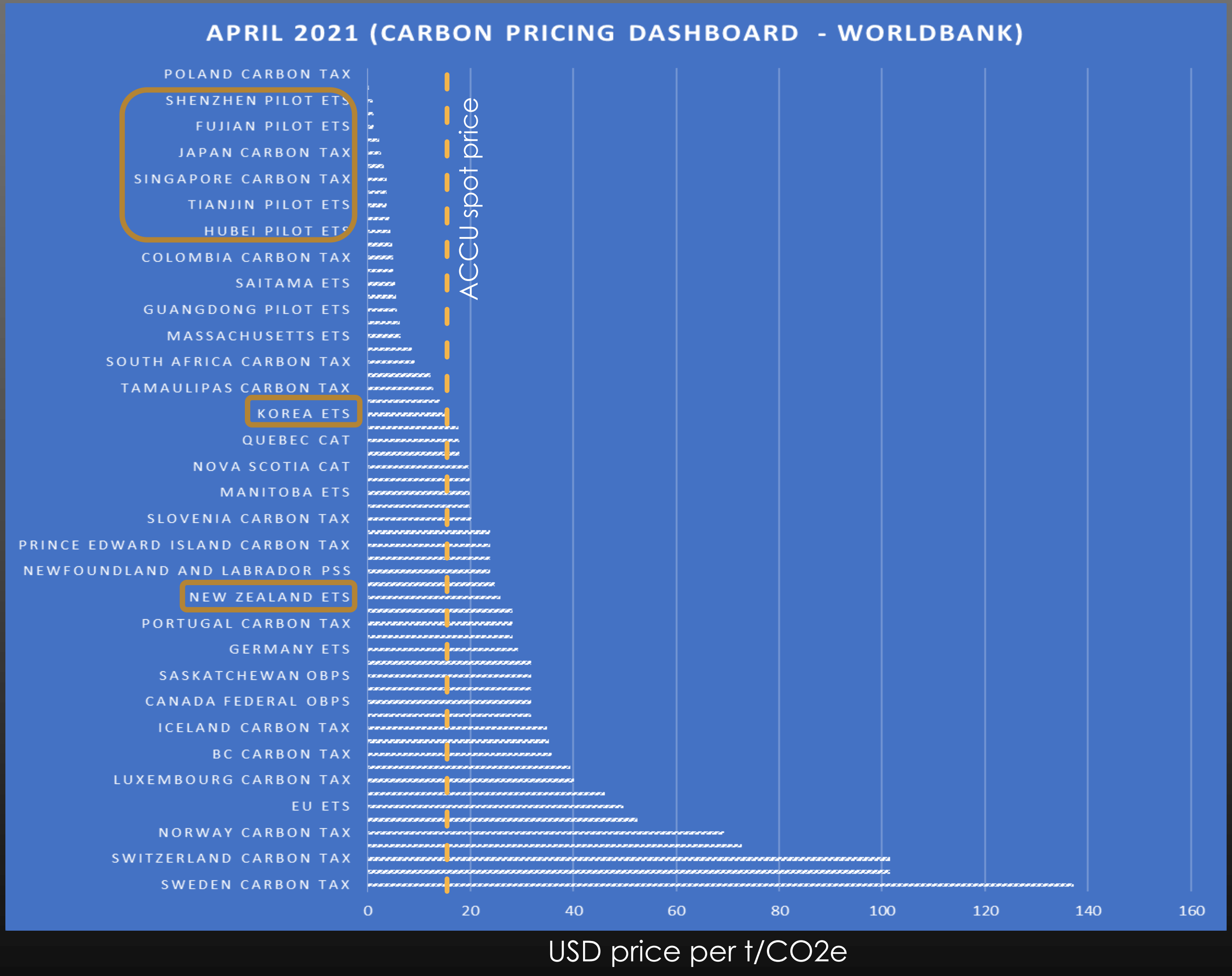
Model 1: CO_2 Underground disposal - Returns

The Challenge today: Uncertainty in predictions for carbon pricing & taxes around the world



Australia

No carbon price/ETS since the end of the Carbon Price Mechanism which set a fixed price for carbon permits. Final 2014 price was AUD24.15/tCO2e

Australia now supports a market for Australian Carbon Credit Units (ACCU). An ACCU is issued by the Clean Energy Regulator for 1tCO2e avoided or stored.

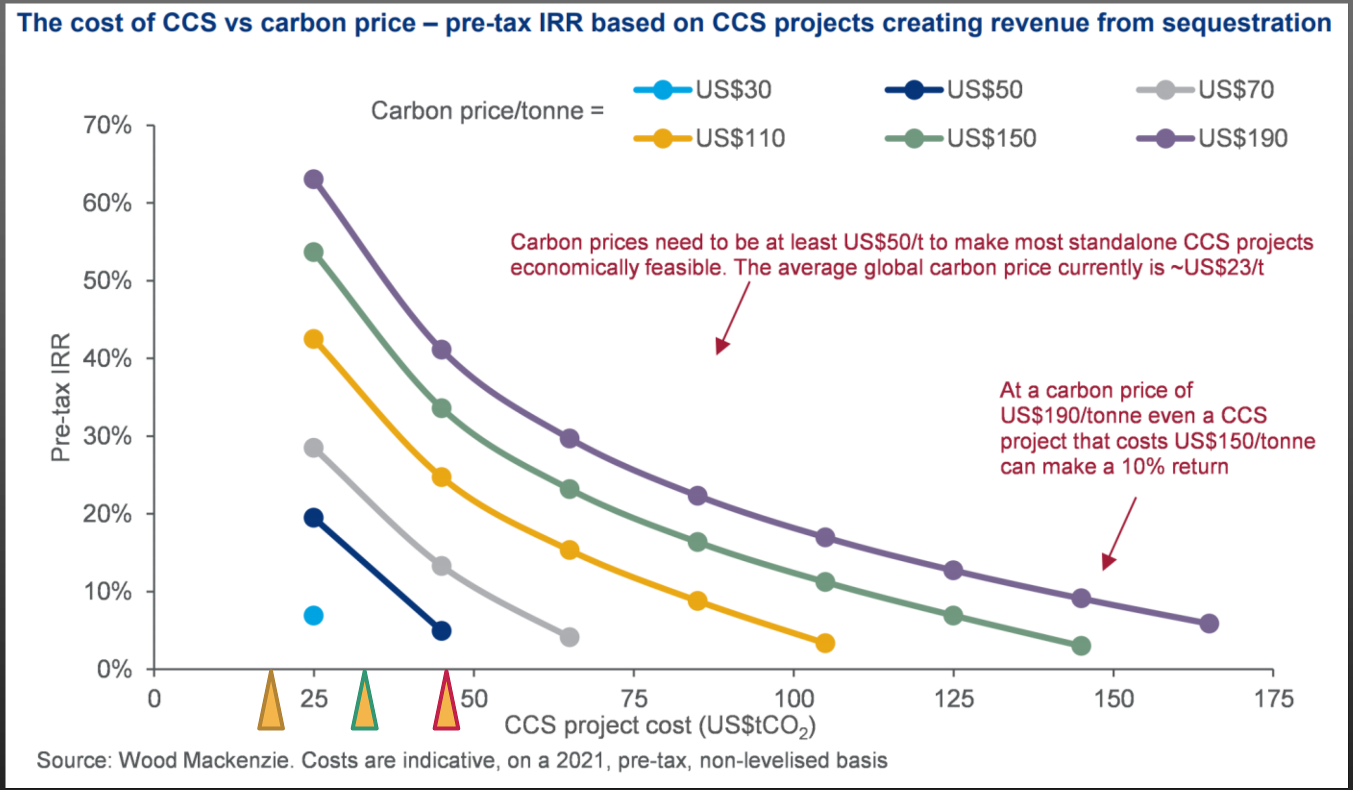
Price fluctuates but has steadily increased in value from AUD15/t to ~AUD 22/t since 2019. Current spot price in USD ~ 17/t

New Zealand

New Zealand ETS – NZU emissions units – cap and trade system via auction

Model 1: CO_2 Underground disposal – Investment & Returns

THE CHALLENGE TODAY: UNCERTAINTY IN PREDICTIONS FOR CARBON PRICING & TAXES AROUND THE WORLD



Australian CCS project cost estimates

Moomba – 30 AUD/t (22USD/t, Santos)
Costs advantaged by location (source to sink proximity, onshore location, leverage existing data knowledge and infrastructure)

Gorgon – 30 AUD/t (based on 3B AUD project cost (to date) to store 100MT (full lifetime), (22USD/t).
(Gorgon Costs will depend on storage capacity changes / further CAPEX needed. Lessons learned from Gorgon can help industry drive down costs).

International comparison – Quest, Canada
>USD $50/t – "gold plated", first of a kind, attracting government subsidy (USD 12/t) the price will be lower. Onshore.

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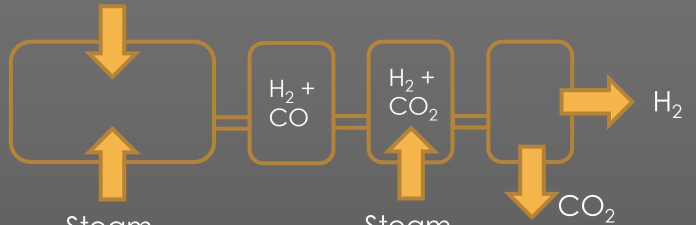
Carbon Capture & Storage: The business models II

- ➢ MODEL 3: BLUE HYDROGEN/AMMONIA (ENABLED BY CCS)

  EXAMPLE: QUEST (CANADA), H2H SALTEND (UK), ADNOC BLUE AMMONIA(UAE)



- ➢ MODEL 4: HYBRID MODELS

  EXAMPLE: ARAMIS (NETHERLANDS), TEESSIDE (UK), SINGAPORE LNG

BUSINESS JUSTIFICATIONS – ALL PUBLICATIONS IN Q1/Q2 2021

AUSTRALIA COULD TRADE $90BN OF LOW-CARBON HYDROGEN ENERGY BY 2050

HYDROGEN HEATING UP AUSTRALIA'S EXPORTS AMBITIONS: TAYLOR

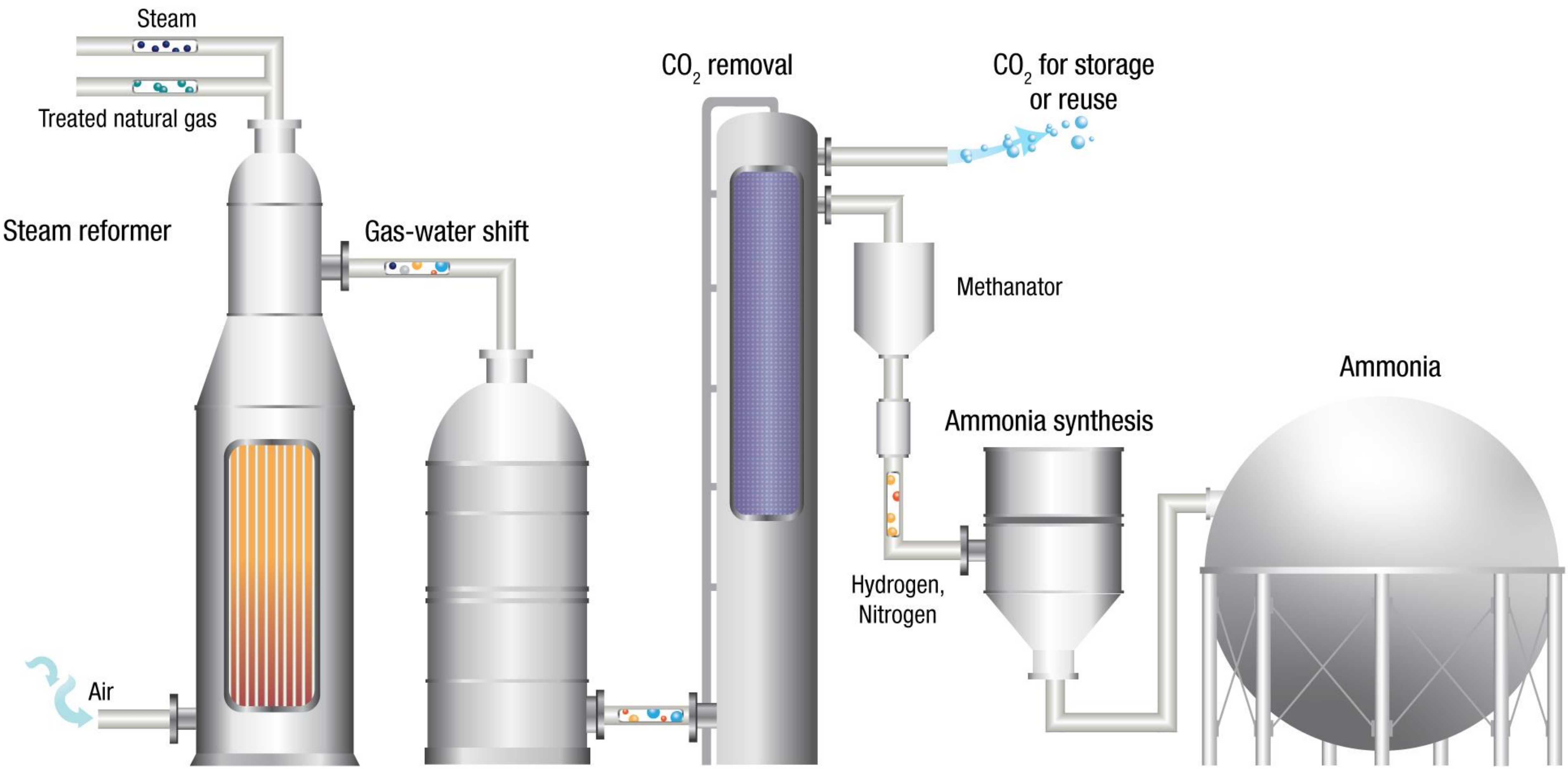
JAPAN HYDROGEN AMBITIONS

INDONESIA MOVES ON CCUS FOR CLEANER AIR AND PRODUCTION BOOST

HYDROGEN: THE MIDDLE EAST'S NEXT BLACK GOLD

UAE SELLS ANOTHER BLUE AMMONIA SHIPMENT TO JAPAN IN PUSH TOWARD HYDROGEN | THE JAPAN TIMES

Model 3: Blue Hydrogen/Ammonia (enabled by CCS)



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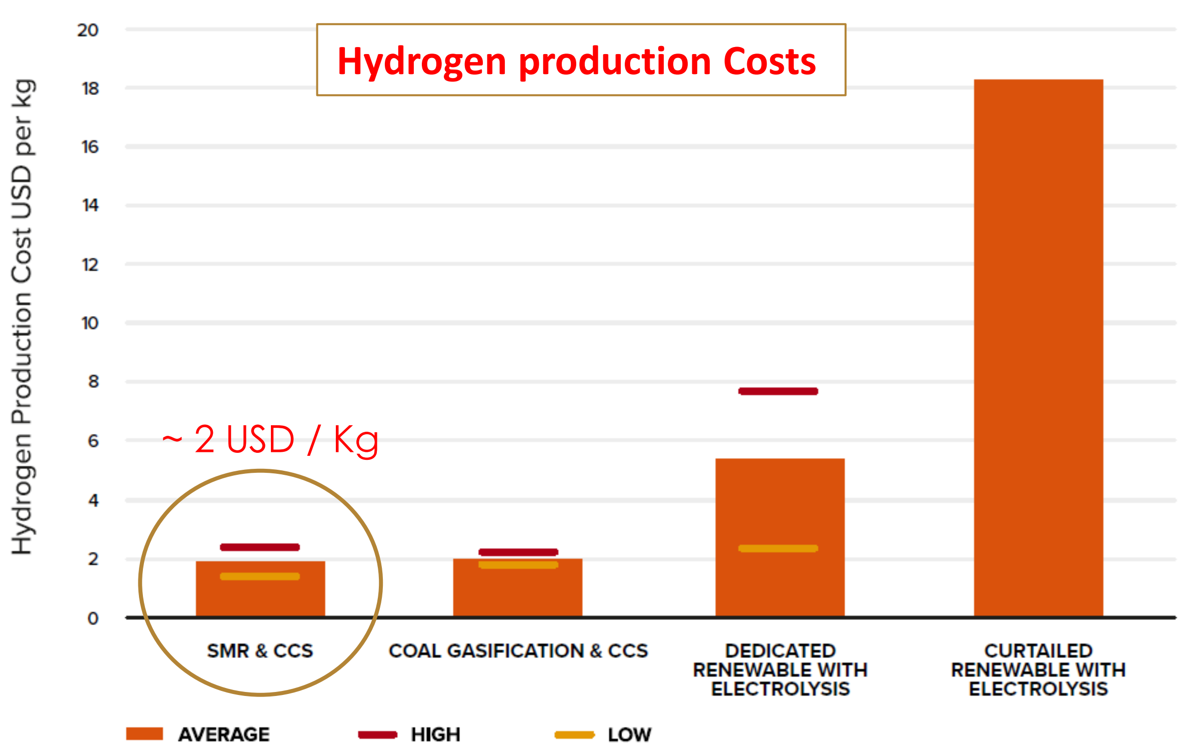
Model 3: H_2 production - Investments

Recent published estimates of cost of clean hydrogen production.(IEA 2019; Bruce et al. 2018; International Renewable Energy Agency 2019; Hydrogen Council 2020)
Source: GCCSI 2021

ALL COSTS IN USD PER KG OF HYDROGEN	DEDICATED RENEWABLE ELECTRICITY SUPPLY	OTHERWISE CURTAILED RENEWABLE ELECTRICITY SUPPLY	STEAM METHANE REFORMATION WITH CCS	BLACK COAL GASIFICATION WITH CCS
CSIRO 2018[3]	$7.70 (35% capacity factor, electricity price 6c/kWh)	$18.20 (10% capacity factor, electricity price 2c/kWh)	$1.60 - $1.90 (Gas price is $8/GJ)	$1.80 - $2.20 (Coal price is $3/GJ)
IEA 2020	$2.30 – $6.60[4] (Low end is 57% capacity factor and electricity cost 2c/kWh. High end is 57% capacity factor and electricity cost 10c/kWh)	N/A	$1.40 – $2.40 (Low end is gas price $3/GJ. High end is gas cost $9/GJ)	$2.05 - $2.20 (Low end is coal price 43c/GJ. High end is coal cost $1.15/GJ)
IRENA 2019	$2.70 – $6.90 (Low end is wind; 48% capacity factor & electricity price 2.3c/kWh. High end is PV; 26% capacity factor & electricity price 8.5c/kWh)	N/A	$1.50 – $2.30 (Low end is gas price $3/GJ. High end is gas price $8/GJ)	$1.80 (Coal price is $1.50/GJ)
Hydrogen Council 2020	$6.00 (50% capacity factor & electricity price 5.7c/kWh)	N/A	$2.10 (assumes "European gas prices")	$2.10 (Coal price is $60/tonne)

Estimated current cost of clean hydrogen production from recently published reports.(International Energy Agency (IEA) 2020 2020b)(International Renewable Energy Agency 2019)(Hydrogen Council 2020)(Bruce et al. 2018) (only one estimate of cost of curtailed renewable with electrolysis).
SMR = steam methane reformation. CCS = carbon capture & storage.
Source: GCCSI 2021



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Model 3: Comparison with Traditional LNG - Investments

From: Al-Breiki & Bicer – Qatar Foundation (2020) & Seddon, 2006

Production Investments

	LNG	Liquid NH_3 (Ammonia)	Methanol / Dimethyl Ether (DME)	Hydrogen
Plant Capacity (Mt/annum)	9,000	1,300	1,300 / 915	450
Production CAPEX MM$	5,225 (762)[(1)]	605 (88)[(1)]	378 (55)[(1)]	378 (55)[(1)]
Total Production Costs (CAPEX + OPEX + Losses) MM$	2,562	314	211	287

[(1)] The discounted cash flow (DCF) rate of 10% for 3 years constructing duration and a plant lifetime of 20 years giving a Return of Investment of 14.6 %

Transport Investments

Ship 160,000 m^3	Tanker CAPEX (MM $)	Tanker OPEX (MM $)	$/$m^3$
LNG (68 Mt)	192	22.5	15.3
Liquid NH_3 (Ammonia) (109 Mt)	162	24.3	13.87
Methanol / Dimethyl Ether (DME) (129 / 118 Mt)	120	23.4	11
Liquid H_2 (11 Mt)	216	19.3	27.66

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Model 3: Comparison with Traditional LNG - Returns

From: Al-Breiki & Bicer – Qatar Foundation (2020) & Seddon, 2006

CASHFLOW	LNG	Liquid NH_3 (Ammonia)	Methanol / Dimethyl Ether (DME)	Hydrogen
Delivered Energy / ship / Annum (2)	80 MM GJ	50,000 MM GJ	70,000 MM GJ	33,000 MM GJ
Market Price $/GJ	1.5 to 12 (5.93 ave)	28.2	16.3	12

(2) Assuming ~24 trips Qatar-Japan / annum

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CC(U)S - Some technical details

Types of CO_2 Geological traps

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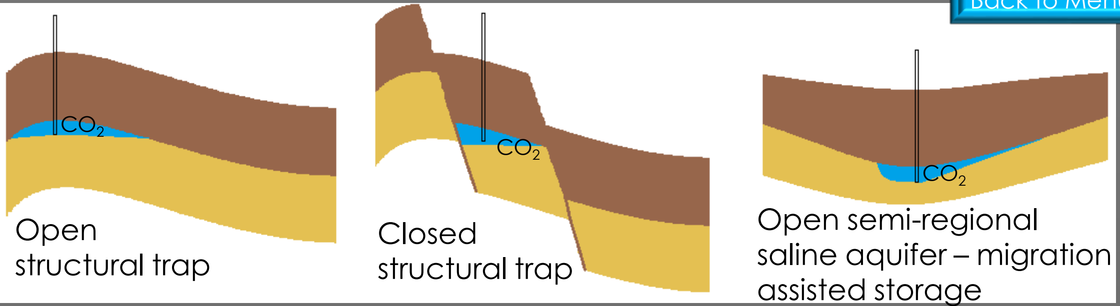

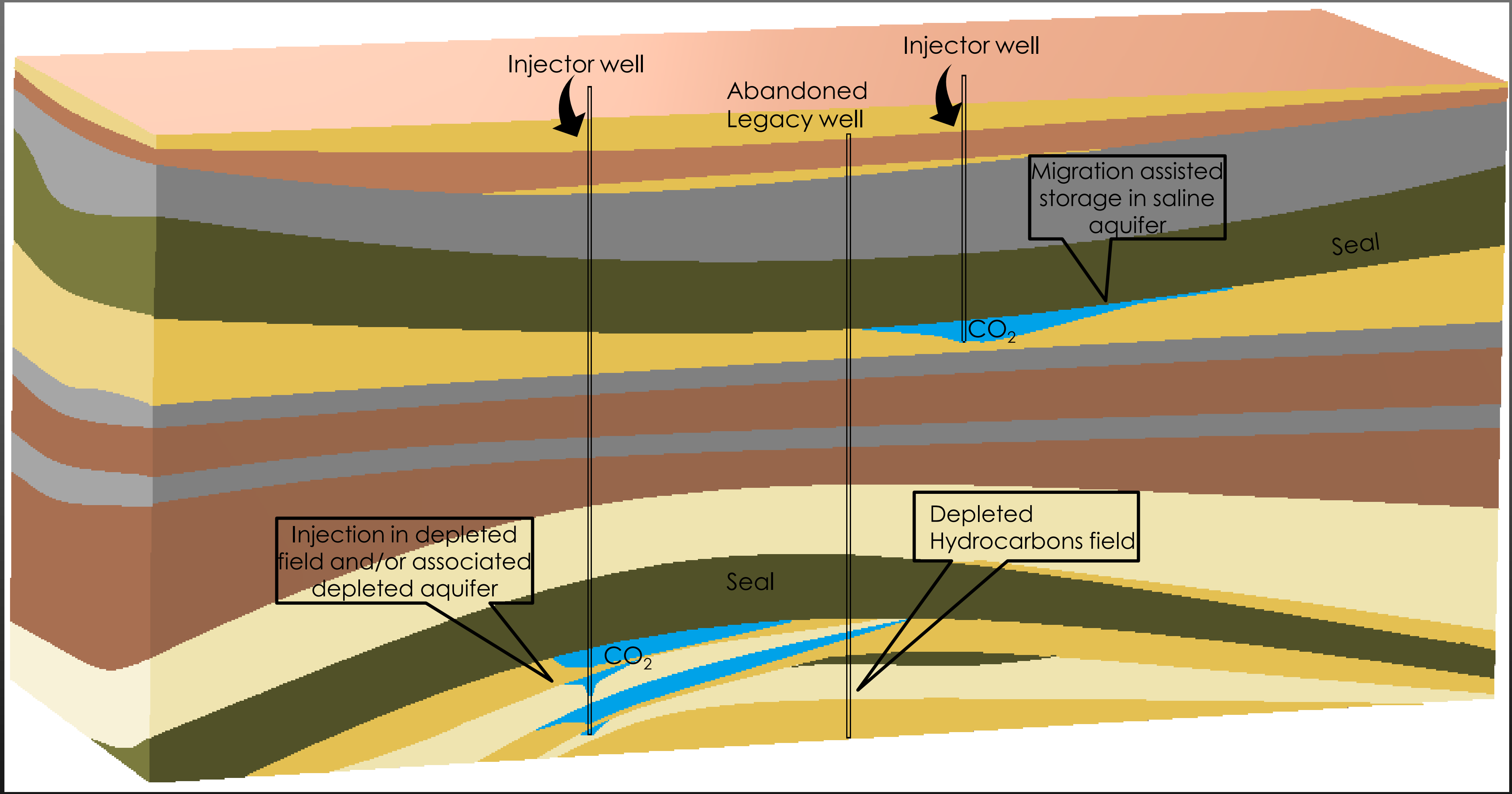

- SALINE AQUIFERS PROVIDE ADDITIONAL CAPACITY TO DEPLETED FIELDS
- AQUIFERS HAVE LOWER EFFICIENCY BUT FEWER INJECTIVITY CHALLENGES
- WELL CONTAINMENT RISK MAY BE LOWER
- DO NOT REQUIRE CONVENTIONAL TRAP

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REQUIREMENTS FOR A SUCCESSFUL GHG STORAGE SITE

Must have – Indispensable
Necessary - Dispensable
Desirable

CAPACITY
- From Prospective Storage Resources to Marketable volumes
- Is it possible to store the total volume required?vi

INJECTIVITY
- Scalability: Sustained rates per well enabling commercial agreements

MONITORABILITY
- Ability to identify or infer location of the injected GHG at all times

CONTAINMENT
- Geological seal systems
- Legacy Wells status
- Can we store the total volume required SAFELY?
- Is the Containment Risk profile acceptable?

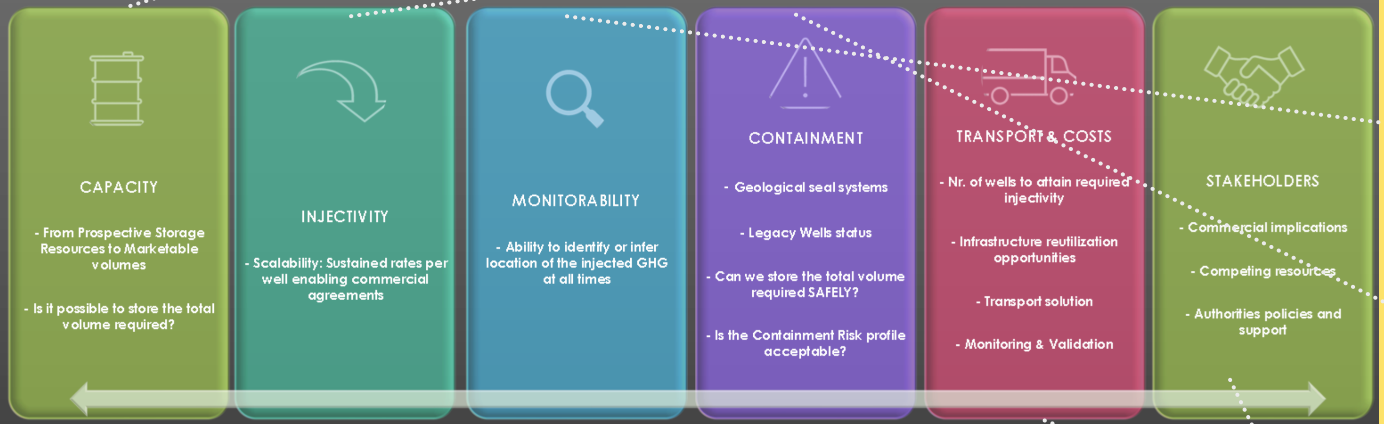
TRANSPORT & COSTS
- Nr. of wells to attain required injectivity
- Infrastructure reutilization opportunities
- Transport solution
- Monitoring & Validation

STAKEHOLDERS
- Commercial implications
- Competing resources
- Authorities policies and support

Selection criteria

- Storage Efficiency (Must have): Trap type; Pore Pressure
- Connectivity (Must have): Connected system / Facies; Fault density
- Reservoir thickness (Necessary)
- Porosity (Necessary)
- Permeability (Necessary)
- Net-to-Gross (Necessary)
- Secondary storage units (Desirable)
- Geological:
  - Seal thickness (Must have)
  - Seal Facies / integrity (Must have)
  - Seal faulting (Desirable)
  - Secondary Seal systems (Desirable)
- Wells:
  - Well density (per Km2) (Necessary)
  - Abandonment status (Must have)
- Distance to GHG source (Necessary)
- Water depth (Necessary)
- Target depth (Necessary)
- Opportunities for Infrastructure reutilization / Possible partnerships (Desirable)
- SIMOPS e.g. drilling, shipping, seabed activities (Desirable)
- Availability of base line environmental data (Desirable)
- Abundance of open acreage (Desirable)
- Operated licenses present (Desirable)

SELECTION OF SUITABLE STORAGE DATA REQUIREMENTS



Data requirements are for both Saline aquifers & Depleted fields Screening

CAPACITY

- Reservoir Facies
- Fault density
- Pressure
- PVT
- Cum. production
- Porosity / NTG
- Water salinity
- Thickness
- Water production

INJECTIVITY

- Core Poro/Perms
- Thickness
- NtG
- Well tests
- PLT
- Production history (analogue)

MONITORABILITY

- Porosity
- Thickness
- Legacy well accessibility

CONTAINMENT

- Facies Seal
- Thickness
- Faulting
- Geomechanical data LT/LOT/VES
- Pressure
- Legacy wells - P&A status
- Well density

TRANSPORT & COSTS

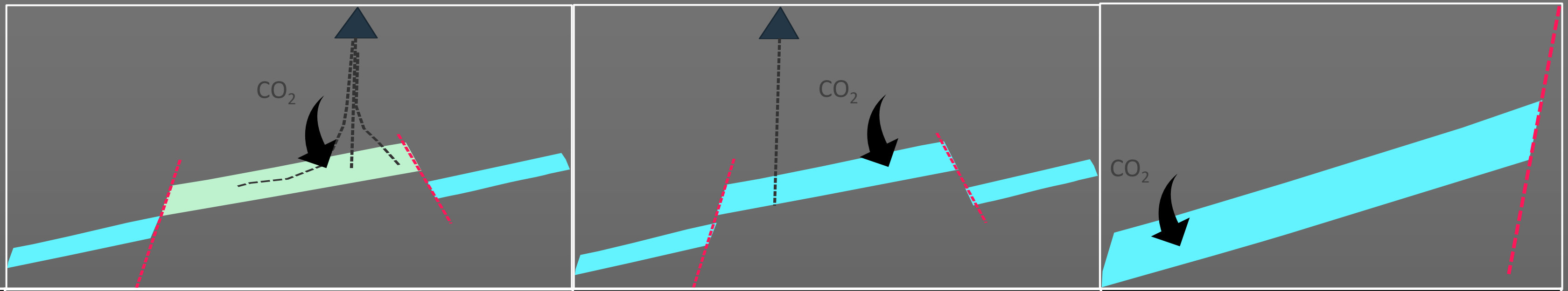
- Depth
- Distance
- Nr. Wells to fix
- Reusable infrastructure

COMMERCIAL ASPECTS - STAKEHOLDERS

- Physical access
- Legal access
- Operated licenses
- Infrastructure
- Open acreage
- Possible partnerships

Types of CO_2 Geological Storage sites

Favourable — Unknown — Unfavourable



Screening criteria		(to be) Decommissioned fields	Confirmed Dry 3/4-way closures	Dipping Saline Aquifers
Reservoir presence and quality	Injectivity			
	Connectivity			
	Monitorability			
Containment Risk	Structural trap			
	Caprock Integrity			
	Fault reactivation risk / Induced seismicity			
	Legacy wells			
Maturation time / Effort / Costs				
Scalability				

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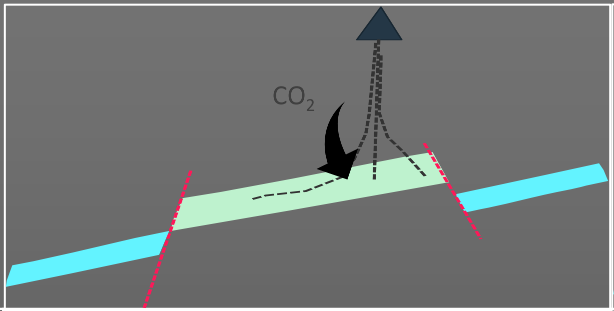
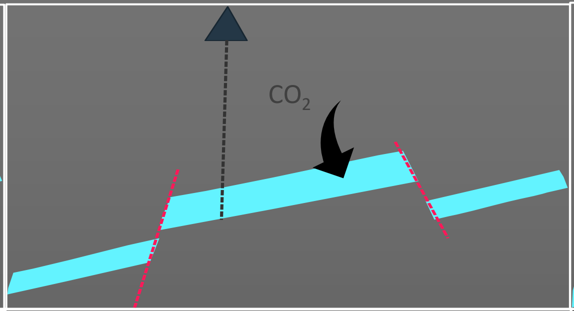
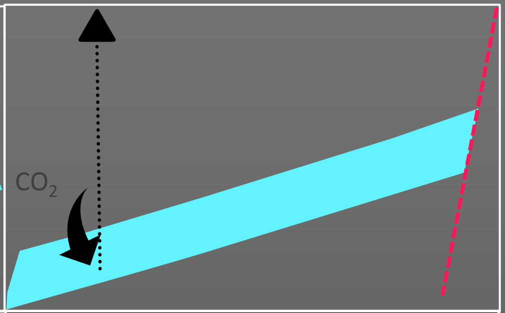
Types of CO_2 Geological Storage sites

Favourable — Unknown — Unfavourable







Screening criteria		(to be) Decommissioned fields	Confirmed Dry 3/4-way closures	Dipping Saline Aquifers
Reservoir presence and quality	Injectivity			
	Connectivity			
	Monitorability			
Containment Risk	Structural trap			
	Caprock Integrity			
	Fault reactivation risk / Induced seismicity			
	Legacy wells			
Maturation time / Effort / Costs				
Scalability				

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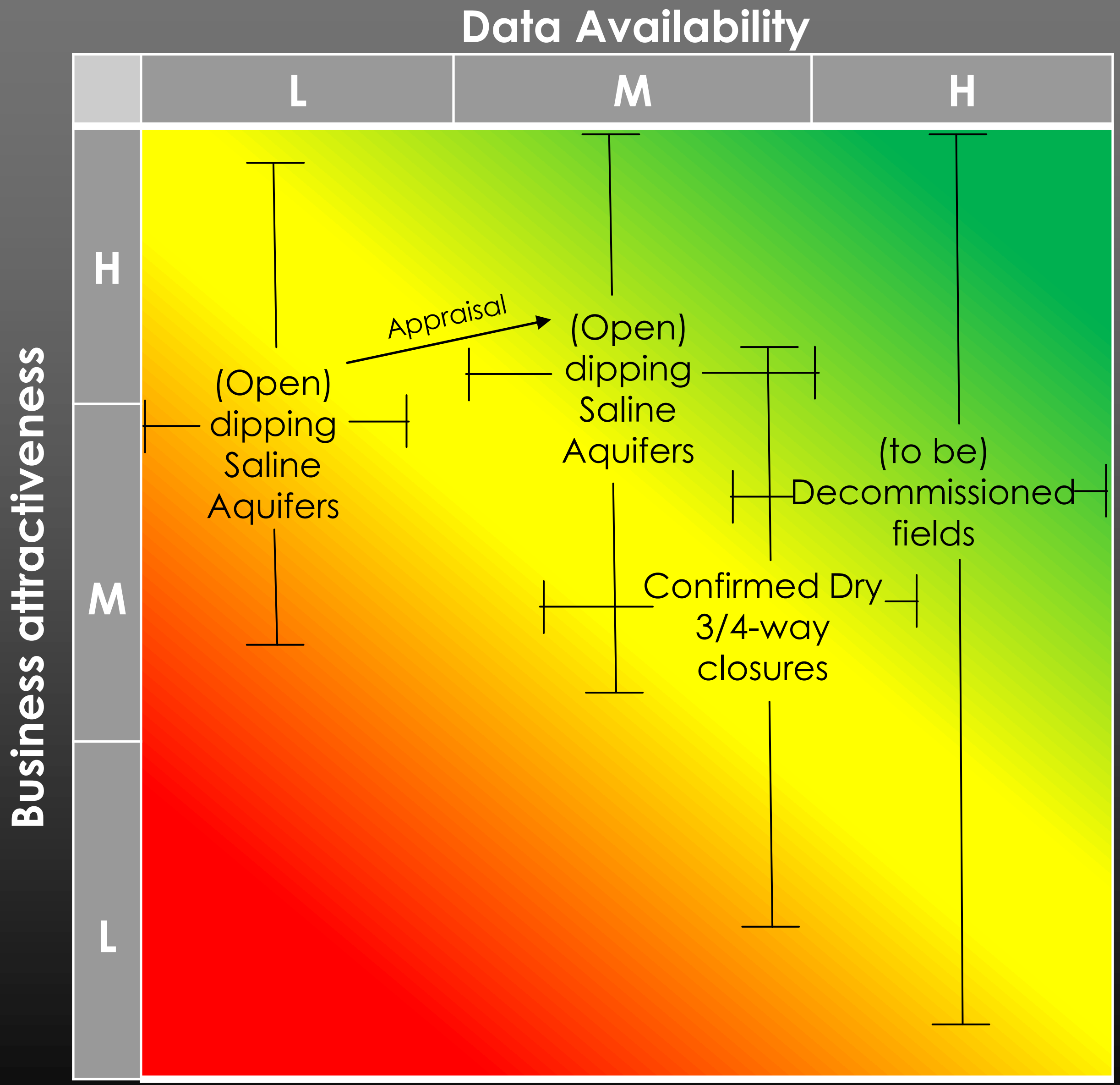
Business attractiveness VS. Data availability



Business attractiveness =

$$\frac{\textbf{Scalability}}{\textbf{(Risk profile x Cost)}}$$

CO_2 STORAGE MATURATION TIMELINE

Storage Resources & Scalability
How much can we store safely?
→ Build Commercial commitments

Risk Assessment
Containment Risks

Cost & Risk Mitigation
Measure, Monitoring & Verification (MMV) Plan, appraisal, # Injectors & infrastructure
Authorities & Stakeholders engagement / trust

Time – Effort

Phase 1: Screening of CO2 storage resources

- High level Containment risk assessment
- How much can we permanently and realistically store within a particular area of interest

Phase 2: Feasibility assessment of CO_2 storage injection in a depleted field or saline aquifer

- Multidisciplinary Containment risk assessment
- Nr. of new wells and wells to be repurposed & adequately abandoned – infrastructure reutilization
- High level assessment of injection profiles

Phase 3: CO_2 storage development planning

- Injection profiles & nr. of new and re-purposes wells
- Complete Monitoring, Validation and Response plan
- Permit application requirements for CO_2 injection
- EU Permit requirements & ISO standards

SPE SRMS for CO2 storage

Prospective Storage Resources estimates "undiscovered"

Contingent Storage Resources "discovered /sub commercial"

Capacity Resources "discovered /commercial"

Proved, Probable or Possible

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CARBON CAPTURE & STORAGE: THE ROLE OF AN INTEGRATED SUBSURFACE TEAM

- Phase 1: Screening of CO_2 storage resources (incl. high level Containment risk assessment)
  - How much can we permanently and realistically store within a particular area of interest

- Phase 2: Feasibility assessment of CO_2 storage injection in a depleted field or saline aquifer
  - Multidisciplinary Containment risk assessment
  - Infrastructure reutilization
  - nr. of new wells and wells to be repurposed & adequately abandoned
  - high level assessment of injection profiles

- Phase 3: CO_2 storage development planning in a depleted field or saline aquifer
  - injection profiles & nr. of new and re-purposes wells
  - Complete Monitoring, Validation and Response plan meeting Authorities requirements
    - EU Permit application requirements for CO_2 injection
    - ISO standards

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ENERGY EVOLUTION

LOW TEMPERATURE GEOTHERMAL ENERGY

Dr Trey Meckel

Monteverde Energy

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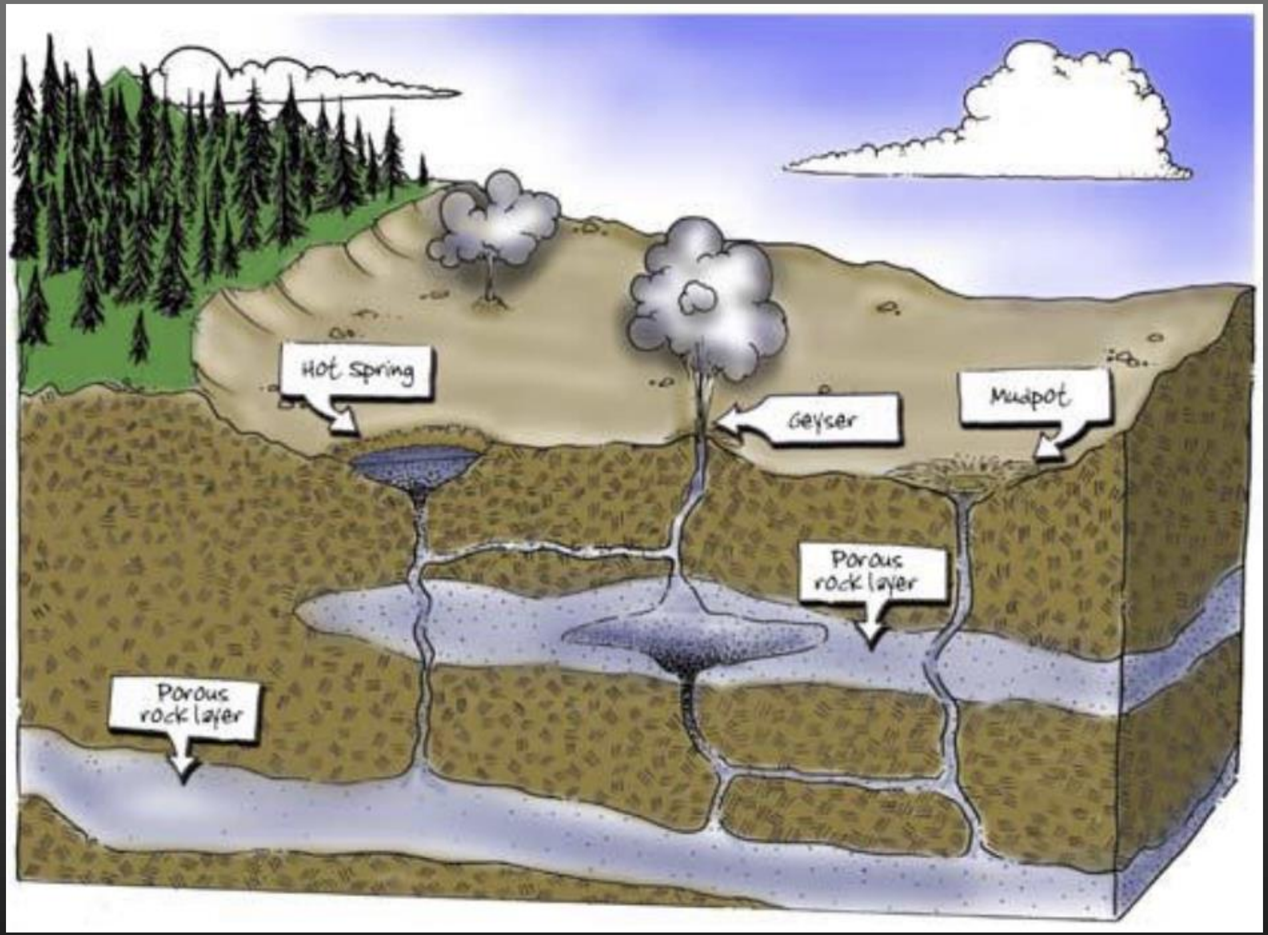
SOME COMMERCIAL GEOTHERMAL APPLICATIONS



- Cooling & heating
  - District solutions (communities)
  - Housing
  - Industry
- Power
  - Public grid
  - Constant supply: 24/7 baseload security for solar/wind projects
  - Energy-intensive activities (e.g., Bitcoin mining)
- Critical minerals
  - Lithium
  - Zinc, silica
- Decarbonization*
  - Oil and gas operations
  - Urea/Fertilizer
  - Biofuels
  - Green hydrogen

**Geothermal electric plants produce ~13 g of Carbon dioxide per kWh, whereas the CO2 emissions are ~450 g/kWh for natural gas, 900 g/kWh for oil and 1050 g/kWh for coal. (Mia, n.d.)*

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GEOTHERMAL BASICS

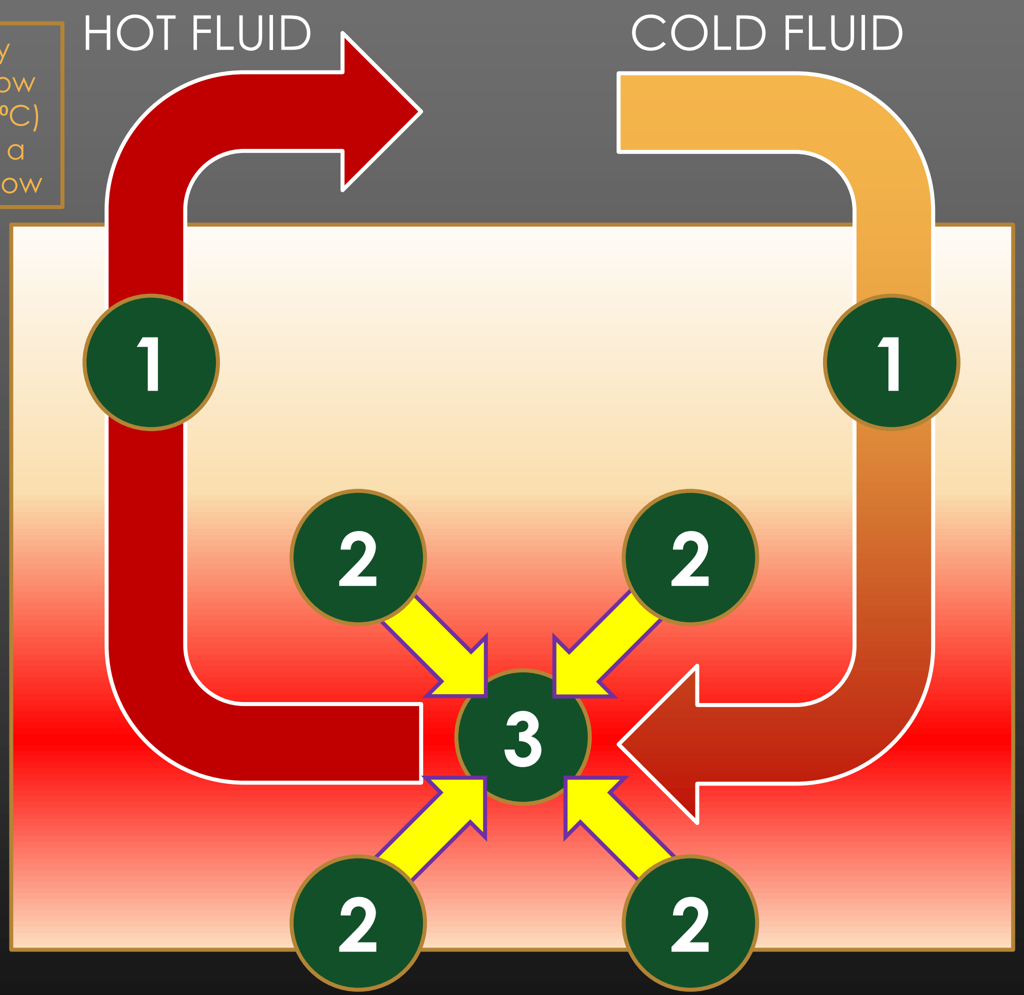
- A GEOTHERMAL RESOURCE REQUIRES CERTAIN GEOLOGICAL CONDITIONS IN ORDER TO GENERATE HEAT OR ELECTRICITY

1. **FLUID**—SUFFICIENT HOT FLUID MUST BE ABLE TO BE CIRCULATED TO SURFACE
   - NATURAL AQUIFER + RECHARGE
   - INJECT-CIRCULATE-PRODUCE (WELL-TO-WELL OPEN OR CLOSED LOOP OR CO-AXIAL CLOSED LOOP)

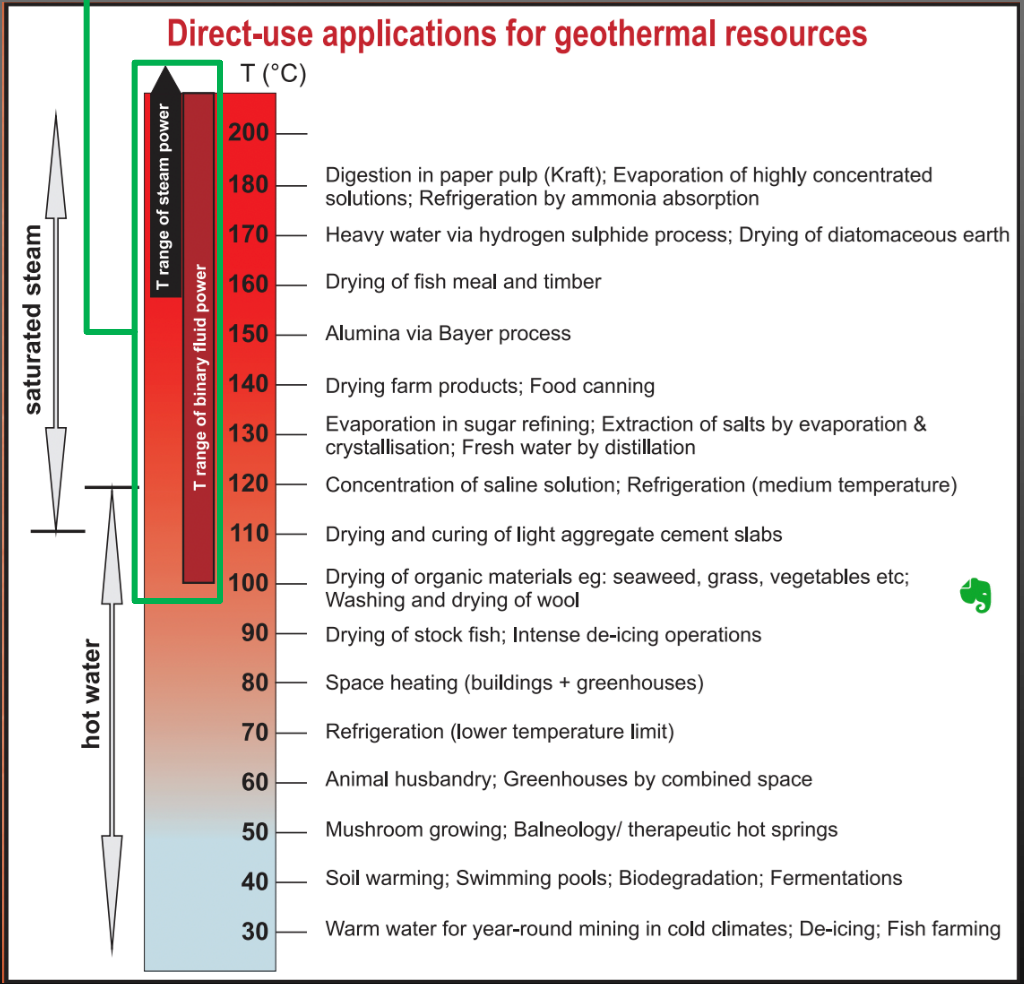
2. **HEAT**—THE TEMPERATURE OF THE EARTH'S SUBSURFACE NATURALLY INCREASES WITH DEPTH AND VARIES BASED ON GEOGRAPHIC LOCATION
   - FOR HEATING PROJECTS, THE IDEAL SUBSURFACE TEMPERATURE IS >80°C
   - FOR ELECTRICITY PROJECTS, THE IDEAL TEMPERATURE AT DEPTH IS ≥150°C (BUT CAN BE LESS IN SOME INSTANCES)

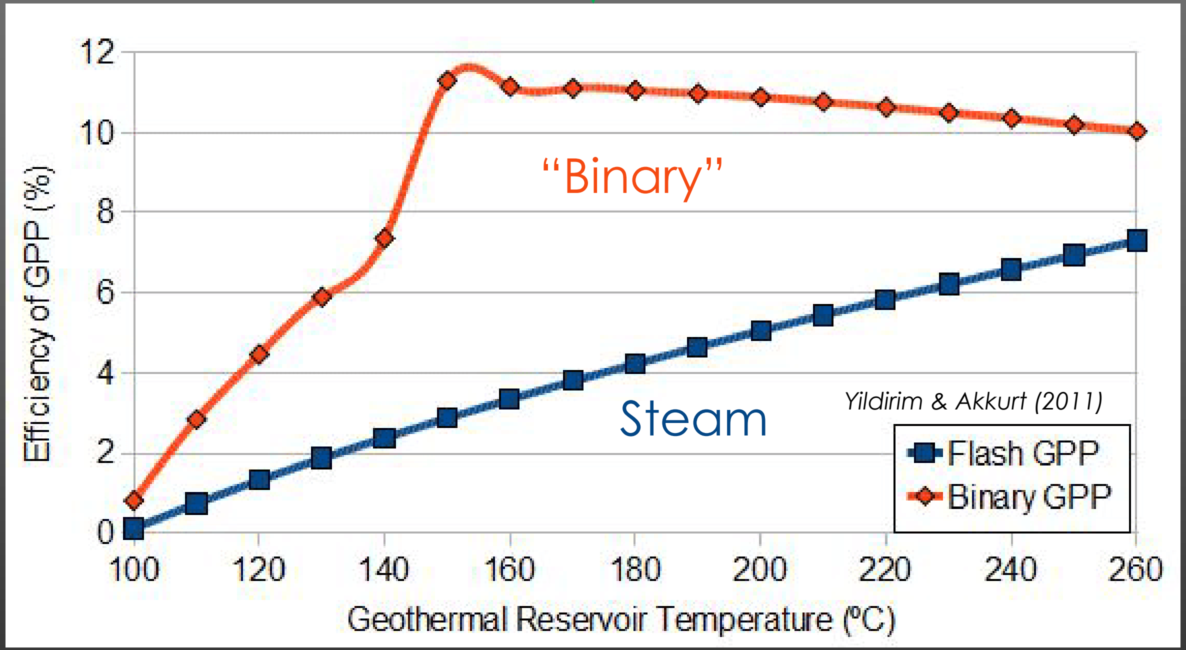
New technology solutions include low temperatures (100°C) providing there is a minimum of 60l/s flow

3. **THERMAL TRANSFER**—FLUID MUST ACCESS HEAT SOURCE
   - CONDUCTIVITY: FLUID IS HEATED BY DIRECT/INDIRECT CONTACT WITH HEATED MEDIUM
   - CONVECTION: WARMER FLUID IS PRODUCED; COOLER FLUID REPLACES



TEMPERATURE VS UTILITY





- WIDE RANGE OF APPLICATIONS AT TEMPERATURES > 30°C
- EFFICIENCY OF TRANSFER OF GEOTHERMAL POWER TO ELECTRICAL POWER REACHES A MAXIMUM AT ~150°C

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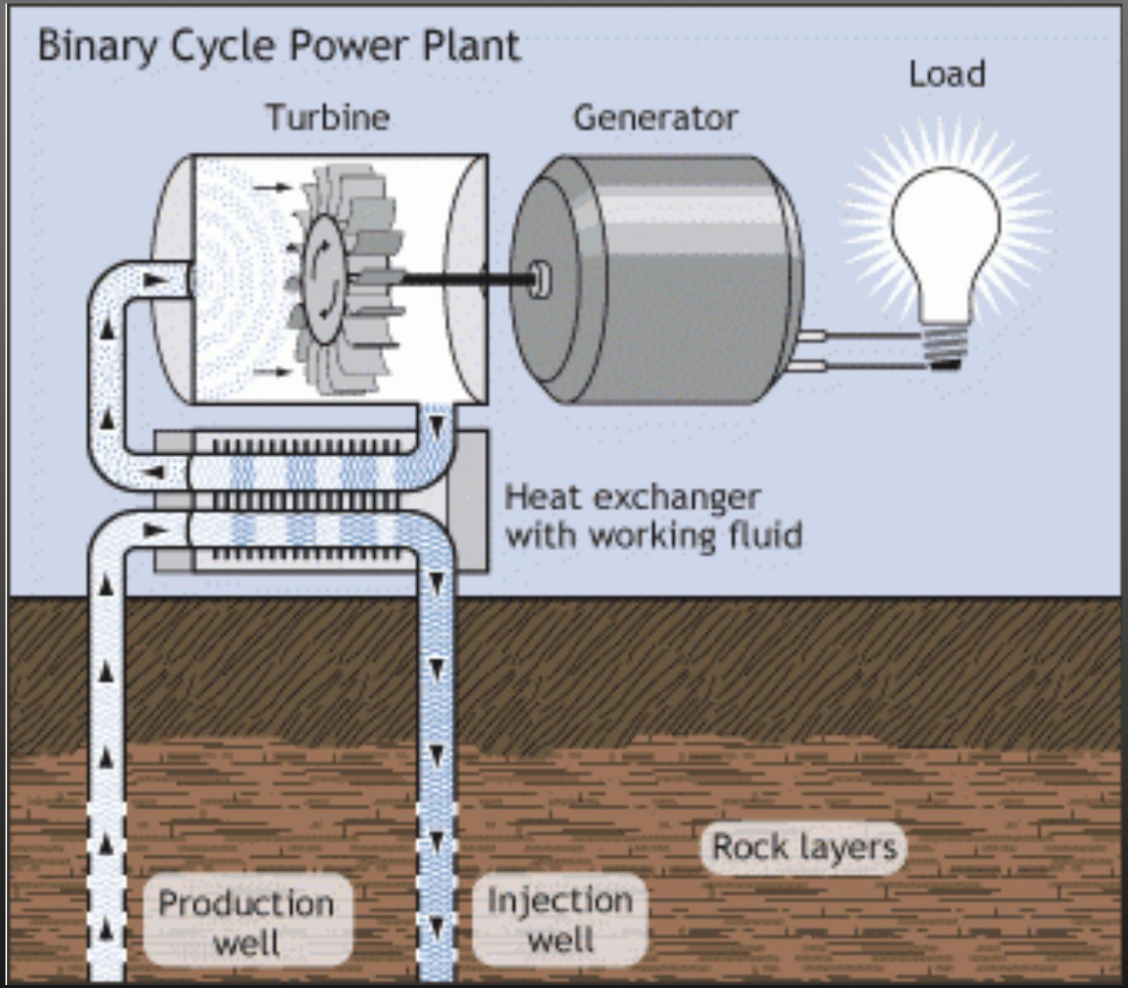
WHAT IS BINARY ELECTRICITY GENERATION? (ALSO CALLED ORC: ORGANIC RANKINE CYCLE)



- Useful when temperatures do not generate sufficient quantities of steam to turn a turbine unassisted
- Requires a second "working" fluid at surface with a lower boiling point than water
- Heat exchanger transfers heat from geothermal fluid to working fluid
- Cool geothermal fluid is returned to subsurface to reheat
- Between 2007 and 2019, the levelized cost of electricity (LCOE) of geothermal varied from USD $0.04/kWh for second-stage development of an existing field to as high as USD $0.17/kWh for greenfield developments in remote areas

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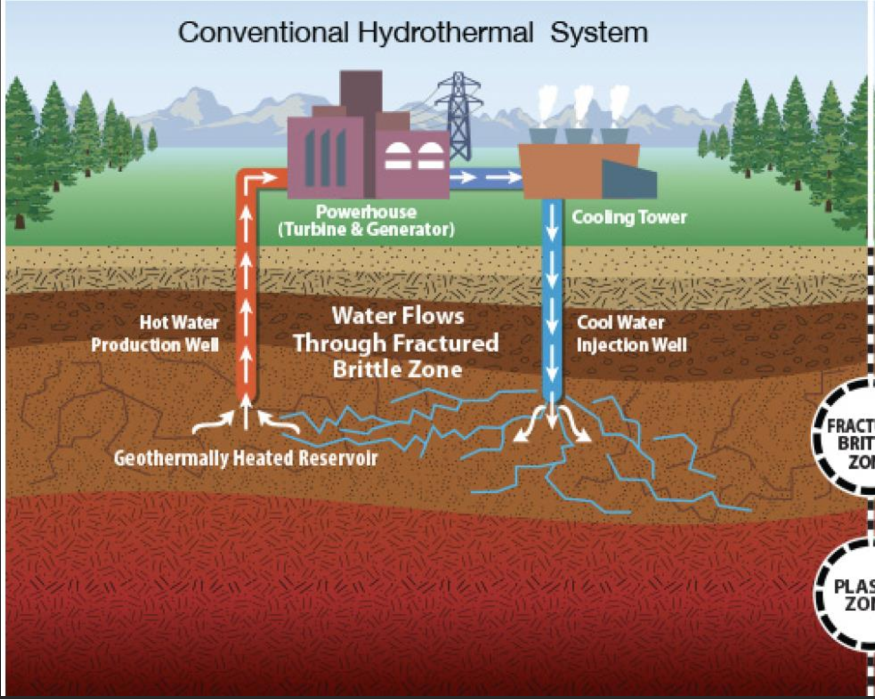
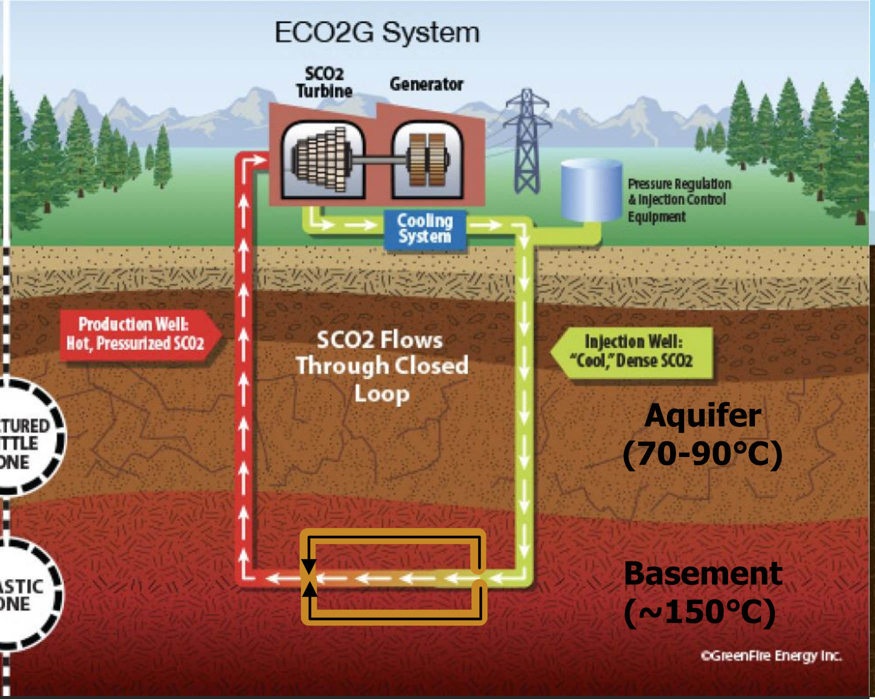
LOW TEMPERATURE TECHNOLOGIES
OPEN LOOP VS CLOSED LOOP ENHANCED GEOTHERMAL SYSTEMS

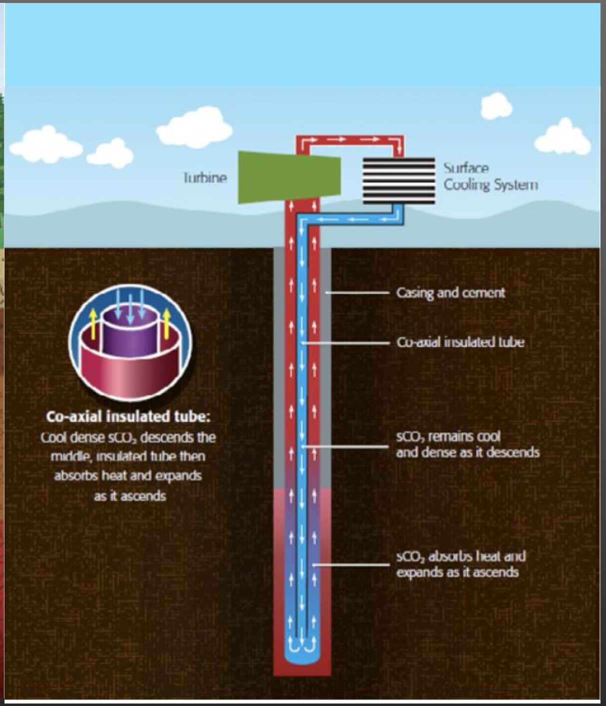
OPEN LOOP SYSTEM
(NATURALLY OR ARIFICIALLY CONNECTED)

DUAL WELL CLOSED LOOP SYSTEM
(SINGLE OR MULTI-LATERALS)

SINGLE WELL CLOSED LOOP SYSTEM
(COAXIAL)







Meckel, after Muir (2020)

Increasing surface footprint

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COMPARISON

Open Loop

- Proven technology
- Suitable for projects of all scales
- Requires porous and permeable aquifer
- Water rights may be an issue
- 2 wells (injector and producer)
- Loop involves flow through aquifer
- Fracking required to establish connectivity
- Microseismicity
- Produced fluid may generate scale at surface
- Large surface footprint with regular maintenance required

Closed Loop

- More speculative technology
- Suitable for smaller-scale projects
- Requires only heat (no porosity necessary)
- No injection or production from aquifer
- 1 or 2 wells (Co-axial or U-tube)
- Loop is contained in well(s)
- No fracking
- No microseismicity
- Produced fluid is contained within well – no scale
- Small surface footprint with minimum maintenance

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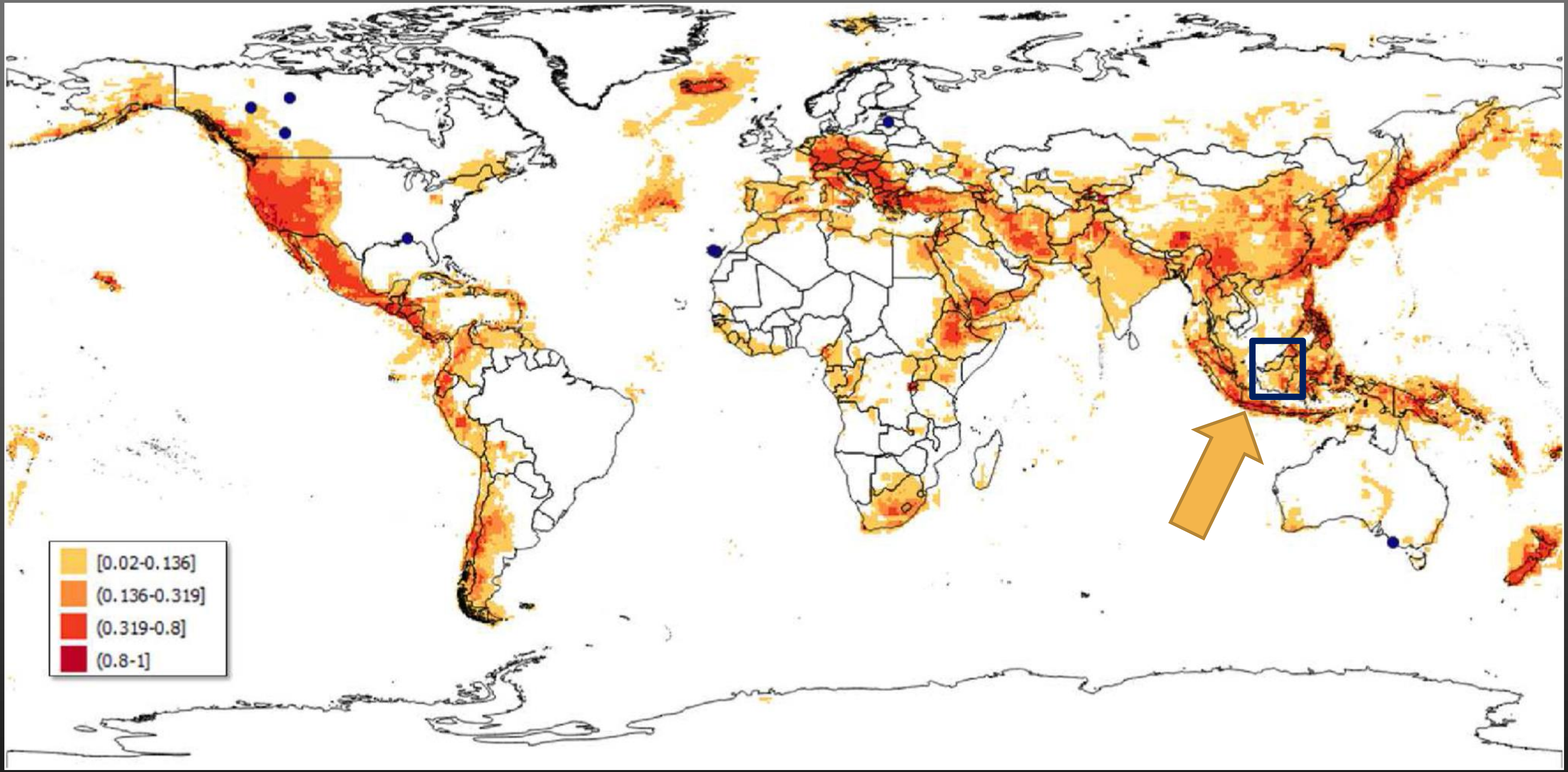
SUITABILITY FOR GEOTHERMAL POWER PLANTS



From Coro & Trumpy (2020)

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GENERATE SOLAR ENERGY AND EXPORT MORE GAS

Peder Elfving

Renewable Energy Consultant | MSc Industrial Engineering

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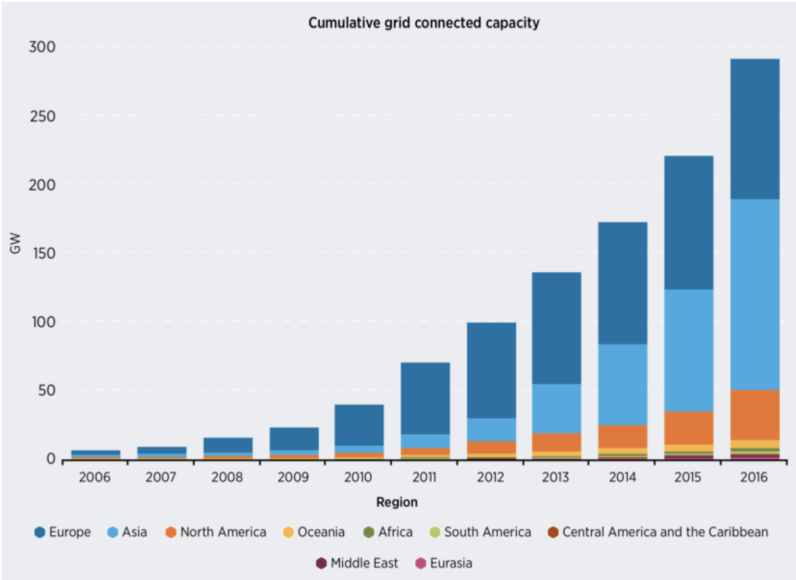
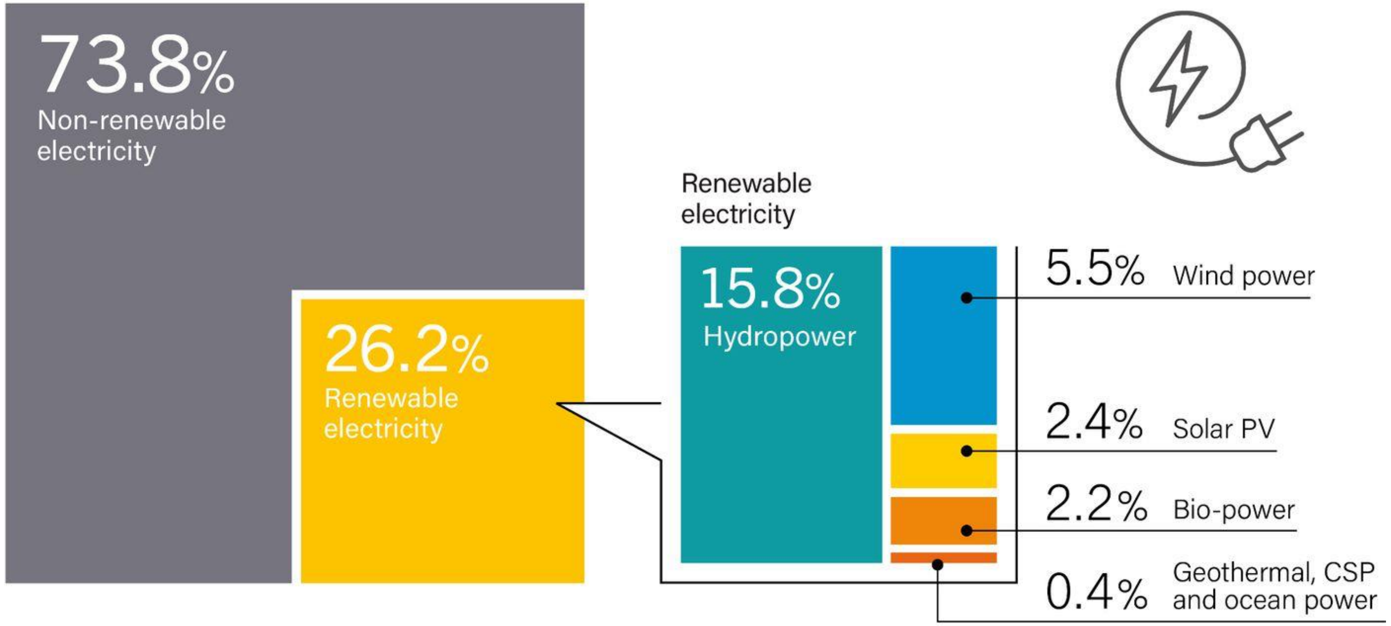
RENEWABLES MARKET PENETRATION

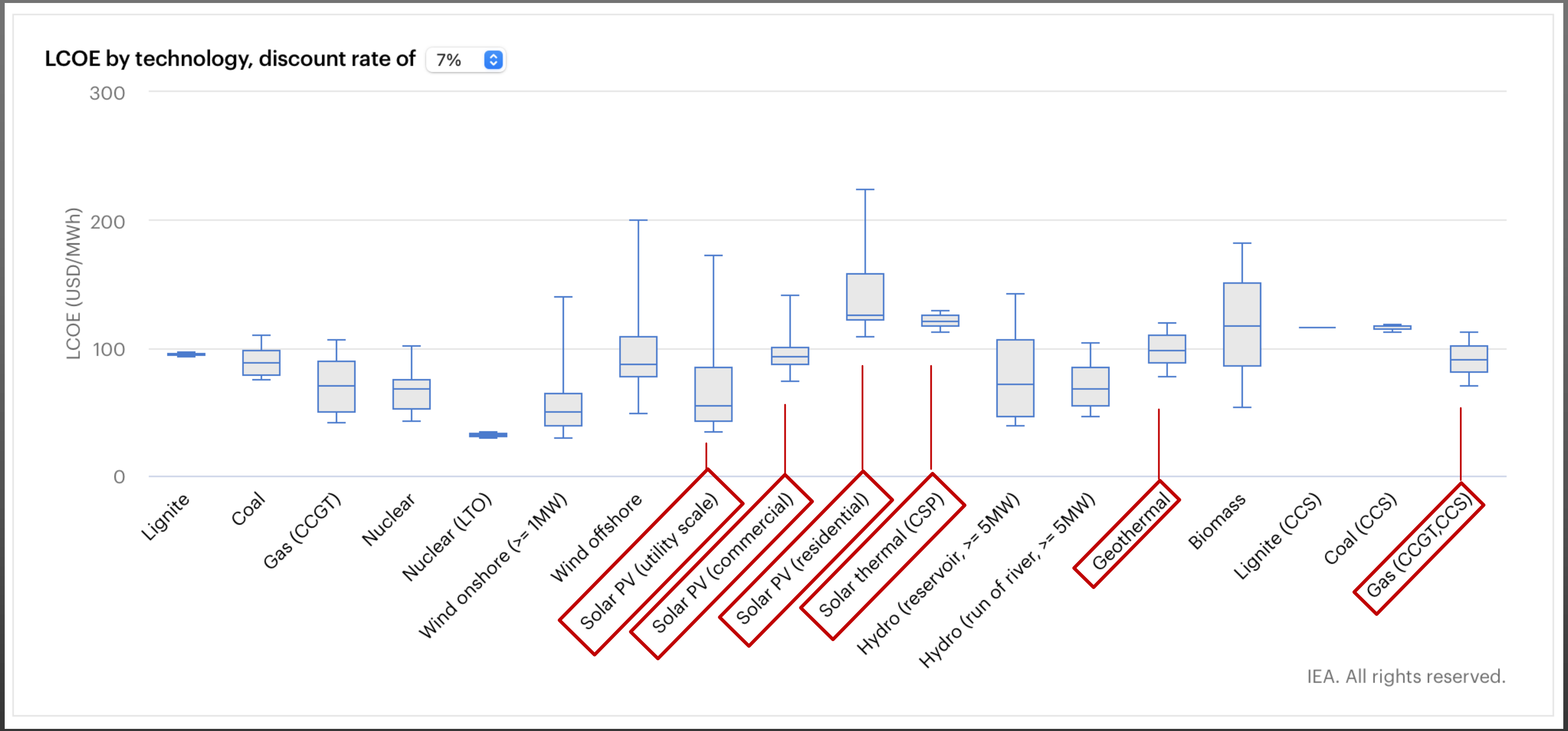


Estimated Renewable Energy Share of Global Electricity Production, End-2018



GROWING FAST …

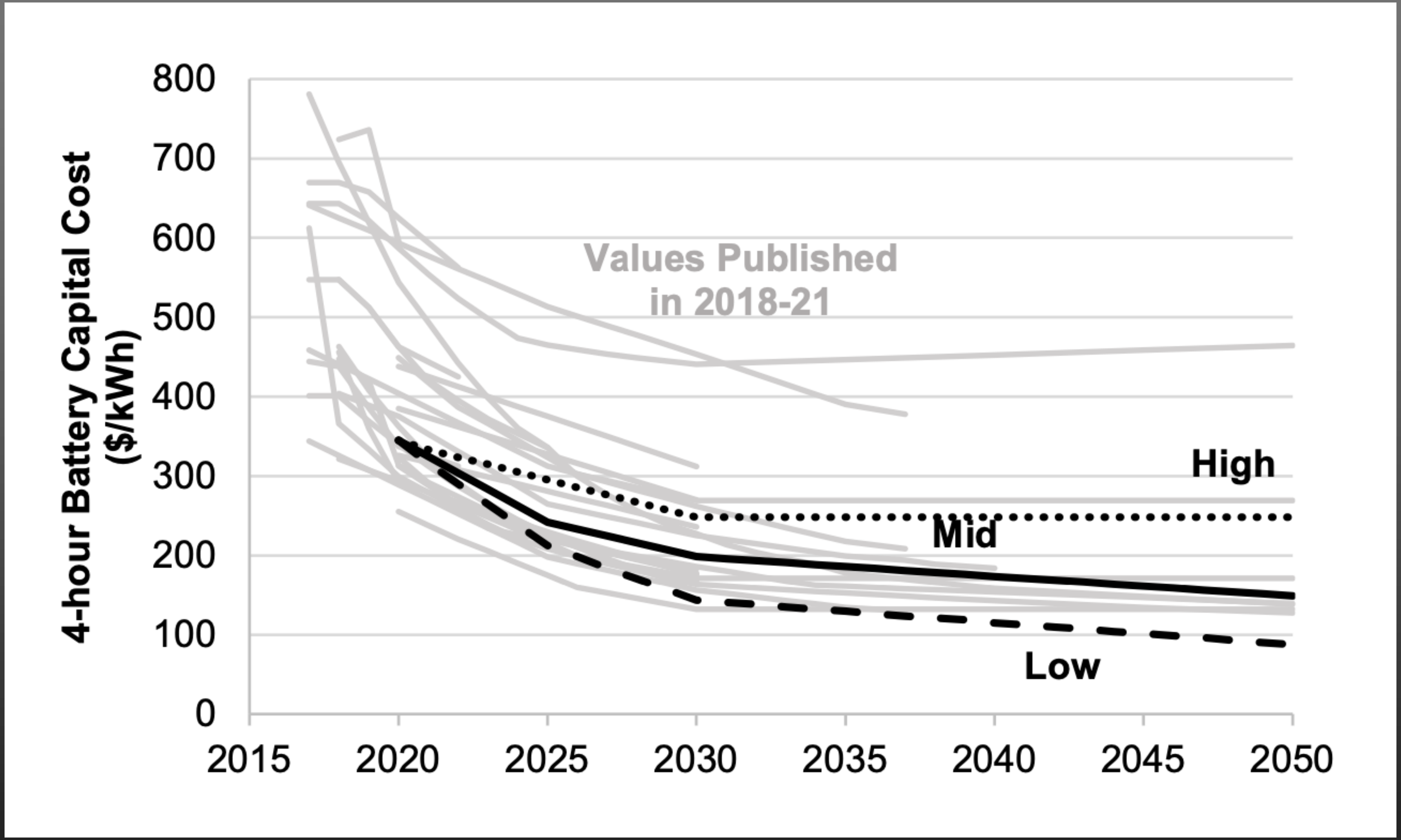
… BUT STILL SMALL



RENEWABLE UTILITY SCALE PRICING IS LOWER THAN CONVENTIONAL ENERGY

In 2021 Malaysia received Large Scale Solar received tenders in the ranges MYR 0.1768 - 0.2481/kWh (without storage)

ENERGY STORAGE COSTS ARE DECREASING RAPIDLY



UTILITY SCALE ENERGY STORAGE IS MORE ACCESSIBLE THAN EVER

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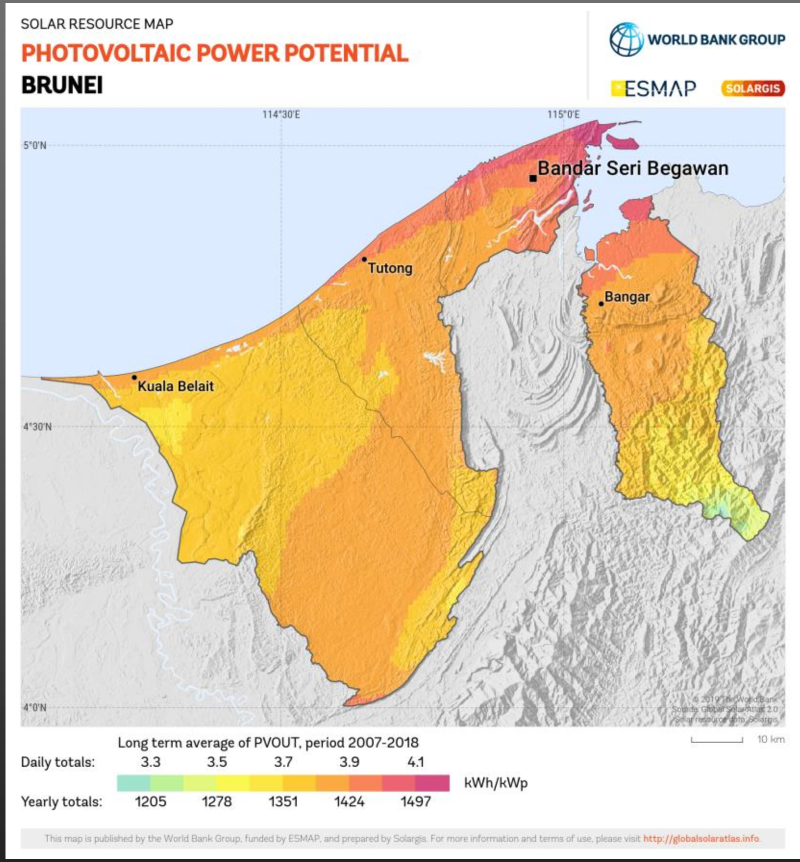
SOLAR + STORAGE

- Utility scale solar power has the possibility of providing emissions free energy over a 25+ years horizon
- Low maintenance requirements
- Energy storage complements solar by:
  - Providing grid stability by evening out excess or lack of energy, millisecond reaction times
  - Time-shifting energy availability to when needed
  - Frequency regulation
  - Backup Generation – allowing time for diesel/gas generators to cold start as needed
- Offset fuel is available for export



Being close to the equator Brunei has high solar irradiance securing high output from solar power.

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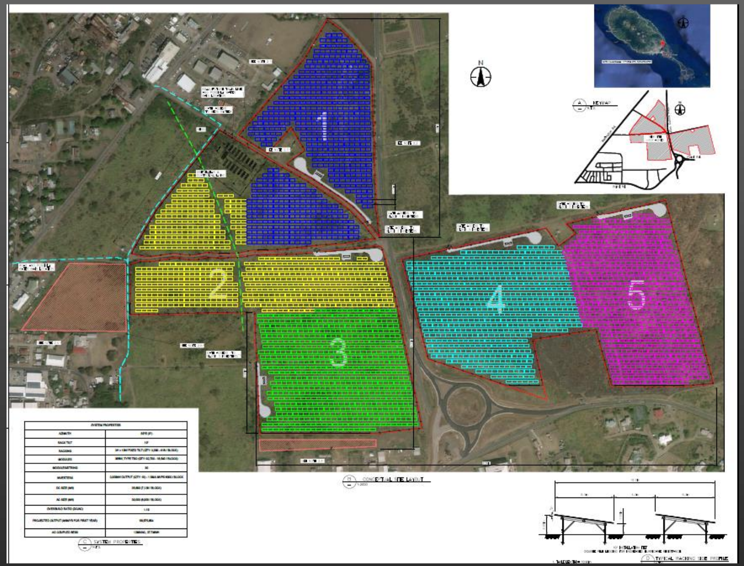
SUMMARY

- With the high solar irradiance in Brunei Darussalam there is unused potential in a free and sustainable natural resource
- Solar + Storage provides a fantastic emissions-free opportunity to participate in the electrification transition
- Solar + Storage increases the grid stability, storing excess capacity for later use
- Using less conventional fuel for local electricity generation allows for more export opportunities, in addition to CCS



Solar + storage example: St.Kitts 34MWp solar plant with 48MWh battery storage will provide the islands primary power with traditional diesel generators providing back-up.

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