CCUS and Low Carbon Fuels

11 – 12 March 2025 | Tokyo, Japan

Regional CCS Enabler? - Direct Injection of CO2 from Vessels into Offshore Reservoirs

Stephen Stokes

Wood plc

Presenter

- Energy transition manager, global head of CO2 transport and storage
- 24+ years' of experience - North Sea and WA based
- Background in field development, flow assurance and subsea systems
- Author and presenter of several CO2 transport industry papers
- Member of SA committee EE-002, Working Group 2 (CO2 ISO/TC265 standards)
- Drives excellence in the execution and delivery of CCS projects world-wide
- Brings insights and best practice from CCS projects being developed globally

wood.

- UK and Europe
- North America
- Middle East
- South East Asia
- **Japan**
- Australia

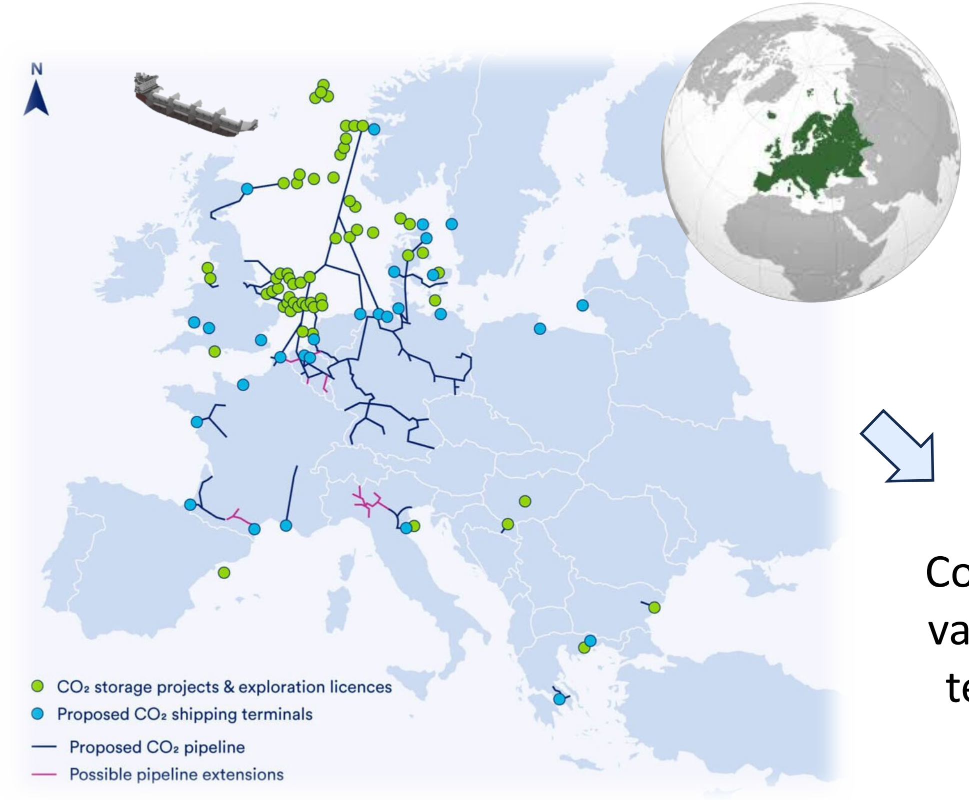
We are supporting live CCS projects in all regions at various stages of development.

- CO2 injection projects
- CCS hub developments
- CO2 gathering networks
- **Liquid CO2 value chains**
- Legacy asset repurposing
- etc

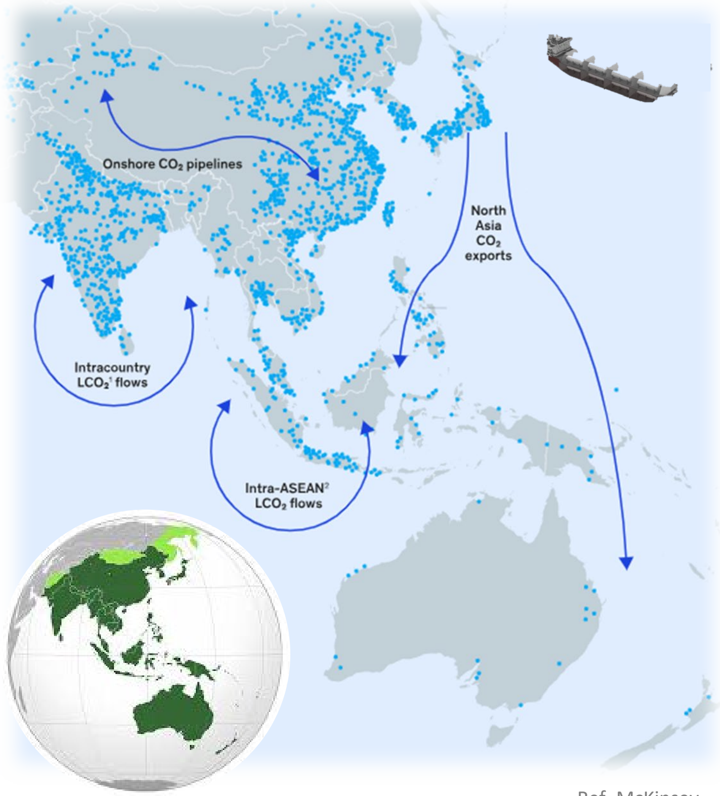
200+ CCS studies
completed across the globe.

40+ years
experience in this space.

Emerging cross-border CO2 networks

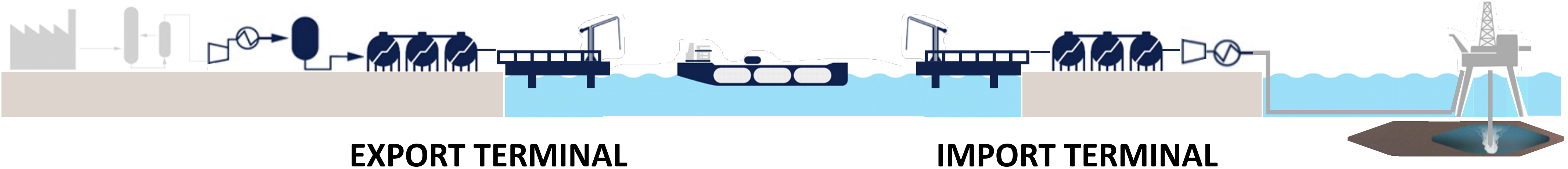


Ref: Clean Air Task Force (CATF)



Ref. McKinsey

Conventional value chains: terminal to terminal



EXPORT TERMINAL **IMPORT TERMINAL**

Alternative strategy – ‘direct’ injection

✓ drivers

- **Reduce threshold ($/tCO2)** - bypass import ‘buffer’ storage and offshore pipelines
- **Open new markets** - significantly reduce value chain cost
- **Decentralisation** - align emitters (sources) to storage
- **Versatility** - emitters can potentially access multiple reservoirs
- **Flexibility** - prove up storage and then scale

? considerations

- **Batch (stop / start) injection** - operation without onshore intermediate ‘buffer’ storage and constant CO2 supply
- **Offshore offloading** – marine operations, floating systems, water depth, metocean, no jetty / port infrastructure

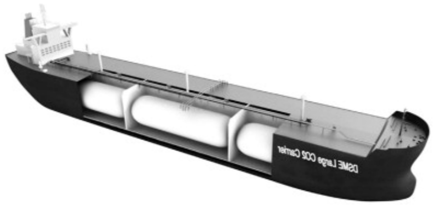
Ref. ineos

Case Study

- Japan emitter(s) – export to Australia (3,600 nautical miles)
  - *Port to port, existing jetties, access to power etc.*
- 0.95 MTPA CO2
- Low Pressure (LP) LCO2 ships (7 bar, -46°C), CO2 density 1,150 kg/m^3
  - *LP selected for scale, MP and EP can be considered also*
  - *40,000 m^3 capacity, 14 knots*
- Offshore storage
  - *Case assumes re-use of existing legacy hydrocarbon facilities*

Ref. Tenet Petrochemical DMCC

#1 - Export



Ref. https://doi.org/10.1016/j.ijggc.2012.11.008

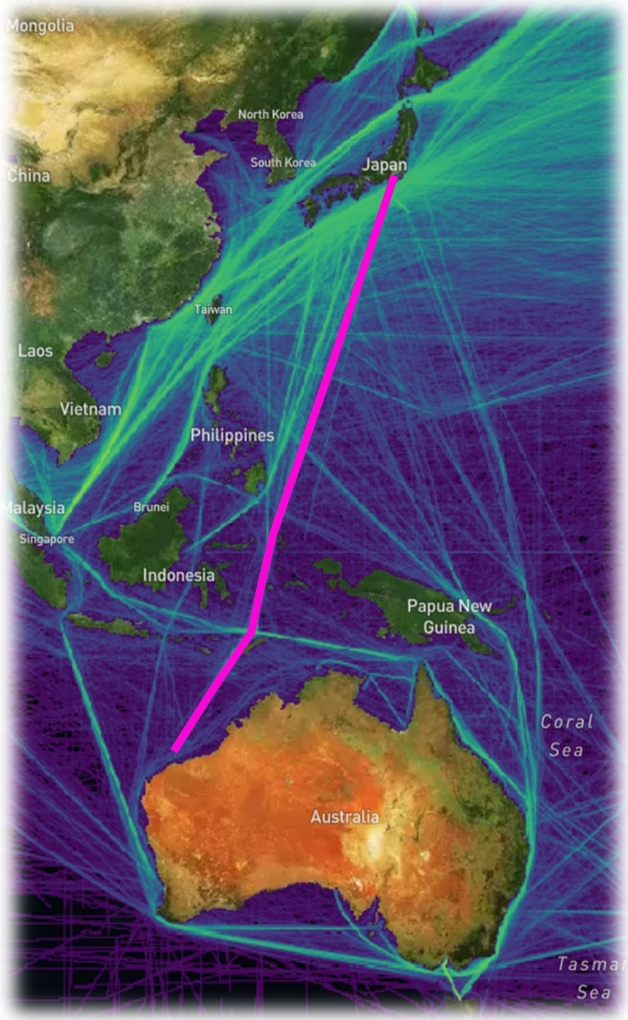
#2 - Shipping

Ref. Upstream Engineering, LLC

#3 - Injection

Building Blocks

$ COST vs. RISK ⚠



Ref. ResourceWatch

Methodology

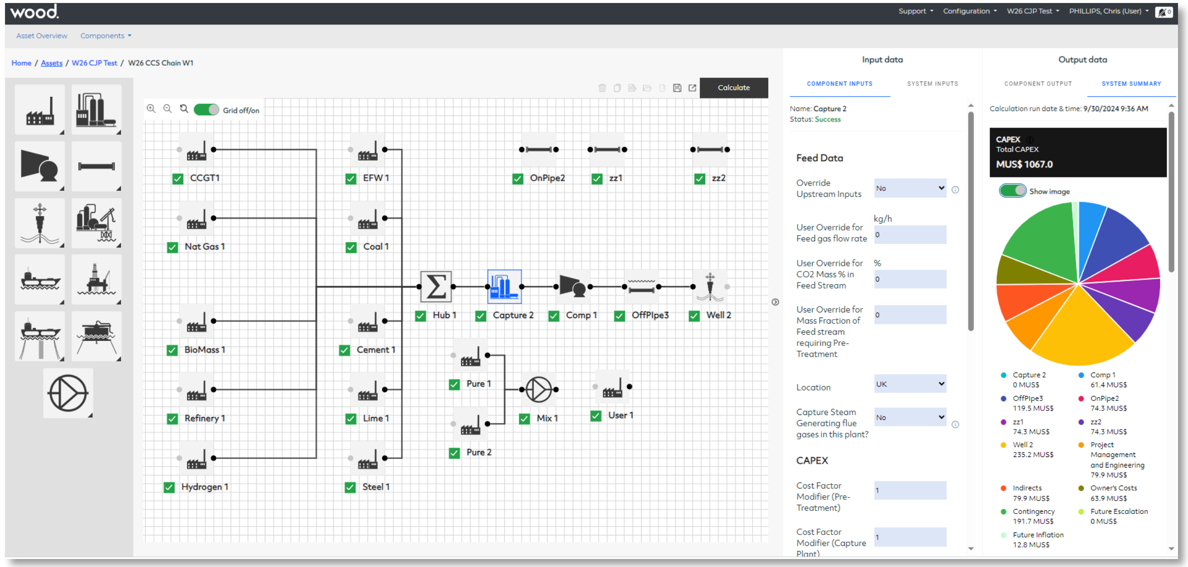
Through the evaluation of multiple configurations, users can quickly highlight the most viable and sustainable solutions for their CCS development.

- Innovative concept analysis tool
- Create bespoke CCS value chains
- Report Class V (screening) level CAPEX & OPEX
- Calculate CO2 footprint for various Hub Development scenarios.

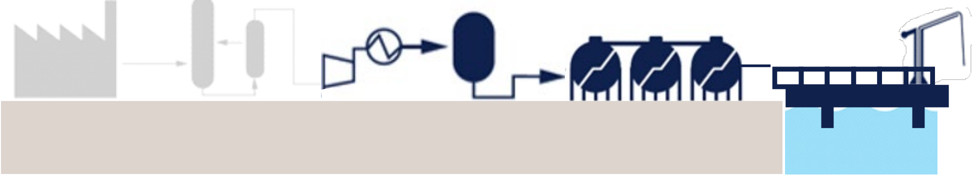
Rapidly assess a wide array of CCUS Hub Development Concepts, producing robust technical definition and costing information for CCUS value chains validated by 40+ years of experience in the CCUS industry.

CCX.

CCXpert™ for evaluating CCUS value chain options

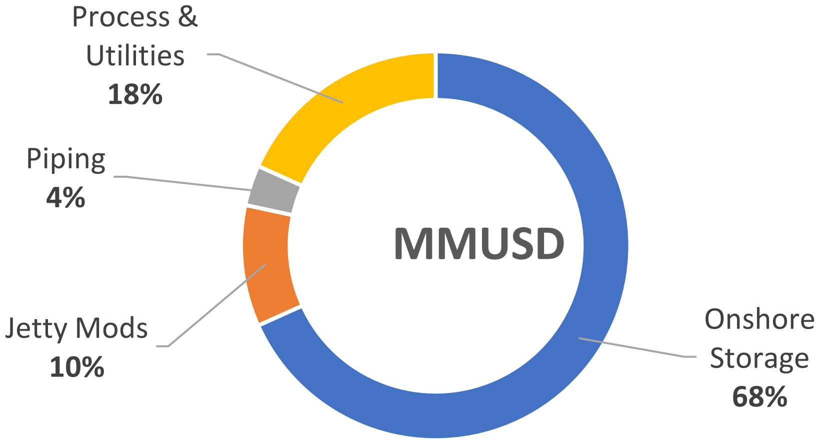


Building Block #1 - Export



3rd party Emitter source and capture	Export Terminal (liquefaction, storage, loading)

Out of scope	• CO_2 gas feed from emitter(s)
	• Closed loop liquefaction process
	
	• 4 x 30m diameter spheres
	  • *SuperElso SA533*
	• 122% buffer
	  • *~3.7 days rundown @ 1 MTPA*
	
	• Loading pumps
	• BOG management system
	• LCO2 and vapour return lines
	• Marine loading arms
	• Jetty modifications
	• Fiscal metering



Component	CAPEX MMUSD
Storage	
Jetty Modifications	
Piping	
Process, Utilities	

MMUSD
(including indirects & contingency)

Building Block #2 - Shipping

Shipping Logistics Assessment

Data [0.95 MPTA, LP SHIPMENT]	Unit	TO IMPORT TERMINAL	DIRECT INJECTION
Input Data			
Ship Storage Capacity (Working)	m^3	36,400	
Ship Availability	-	95%	
Loading Rate (at Export Terminal)	m^3/hr	4,250	
Loading Rate (at Import Location)	m^3/hr	4,250	400
Calculations			
Average CO_2 Transported per day	m3/day	2,382	
Shipment Roundtrip Duration (Sum)	days	21.5	**25.2**
Entry, loading at exit export terminal	*hours*	*(17.4)*	
Transit time to import	*hours*	*(240.0)*	
Entry, Unloading and Exit at Import Location	*hours*	*(17.4)*	(108.0)
Transit time to export	*hours*	*(240.0)*	
Feasible Roundtrips per Vessel	-	16.2	13.7
Required Trips	-	22	
No. of CO_2 Carriers Required	-	2	2
Carrier Utilisation	-	68%	**80%**
Export Loading Occupancy	-	4%	
Import Unloading Occupancy	-	4%	**30%**

Carrier(s)

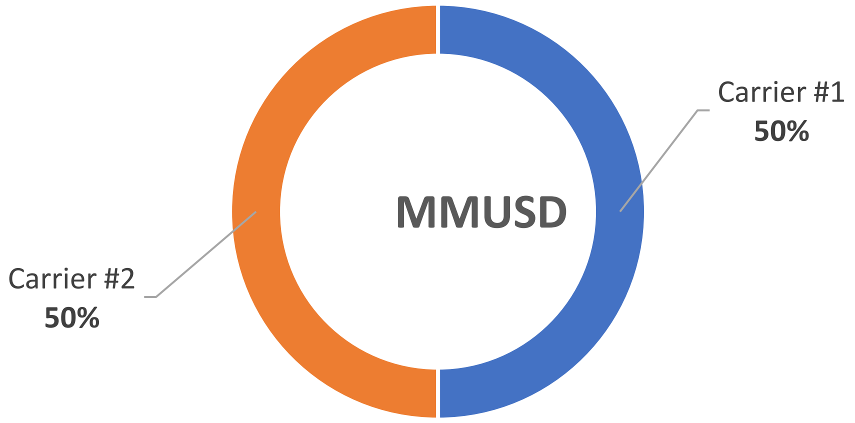
- **2 x 40,000 m^3 LCO2 Carriers**
- **Type-C storage (LP)**

Logistics (to terminal):

- 0.7 days load/unload
- 21 days roundtrip
- 68% utilization

Logistics (direct to well):

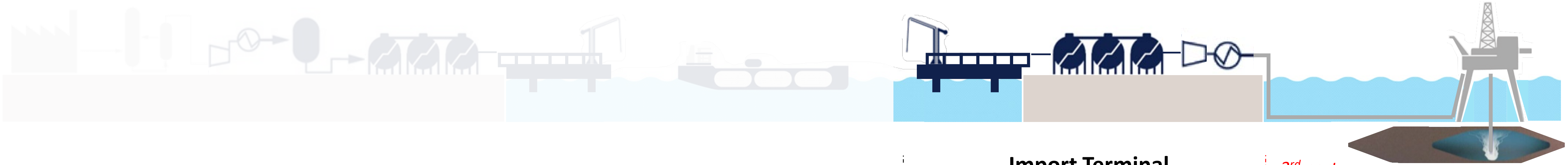
- 4.5 days unload
- 25 days roundtrip
- 80% utilization



Component	CAPEX MMUSD
Carrier #1	
Carrier #2	

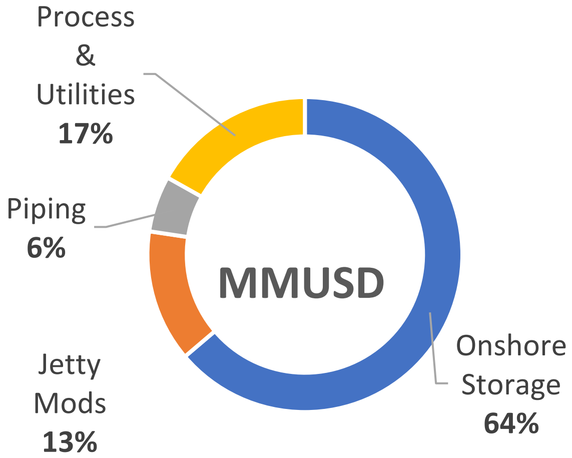
MMUSD
(including indirects, insurance & owner's costs)

Building Block #3A
Import (Conventional)



Ref. spectra.mhi.com

Component	CAPEX MMUSD
Storage	
Jetty Modifications	
Piping	
Process, Utilities	

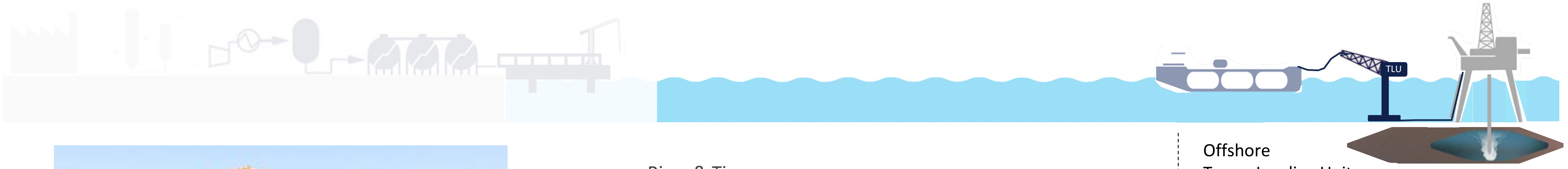


MMUSD
(including indirects & contingency)

Import Terminal (offloading, storage, compression, heating)	3rd party Offshore pipeline and injection facility

• Unloading pumps
• BOG management system
• LCO2 and vapour return lines
• Marine loading arms
• Jetty modifications
 	
• 6 x 26m diameter spheres
  • SuperElso SA533
• 121% buffer
  • ~3.6 days rundown
 	
• Pump (to pipeline pressure)
• Heater (to pipeline inlet)
• Fiscal metering
	Out of scope

Building Block 3B – Direct Injection

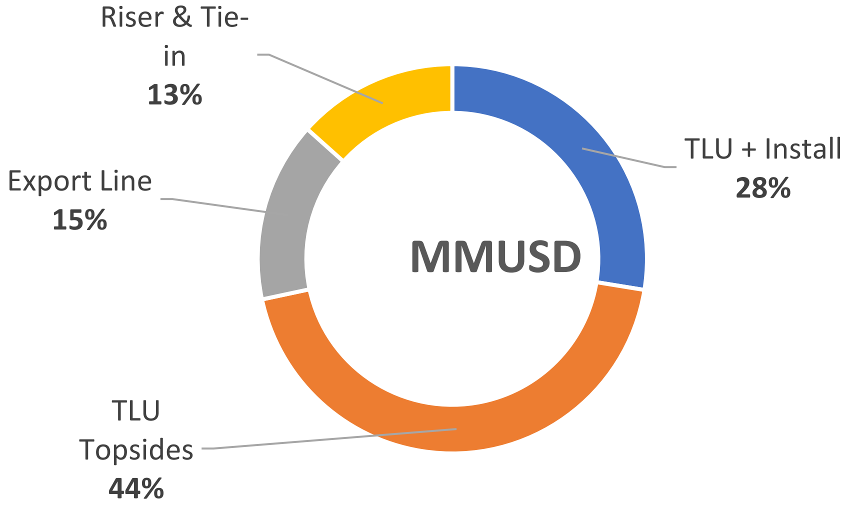


Offshore
Tower Loading Unit
(offloading only)

3rd party
Injection facility

Ref. turbosquid.com

Component	CAPEX MMUSD
TLU + Installation	
TLU Topsides	
Piping	
Riser & Tie-in	

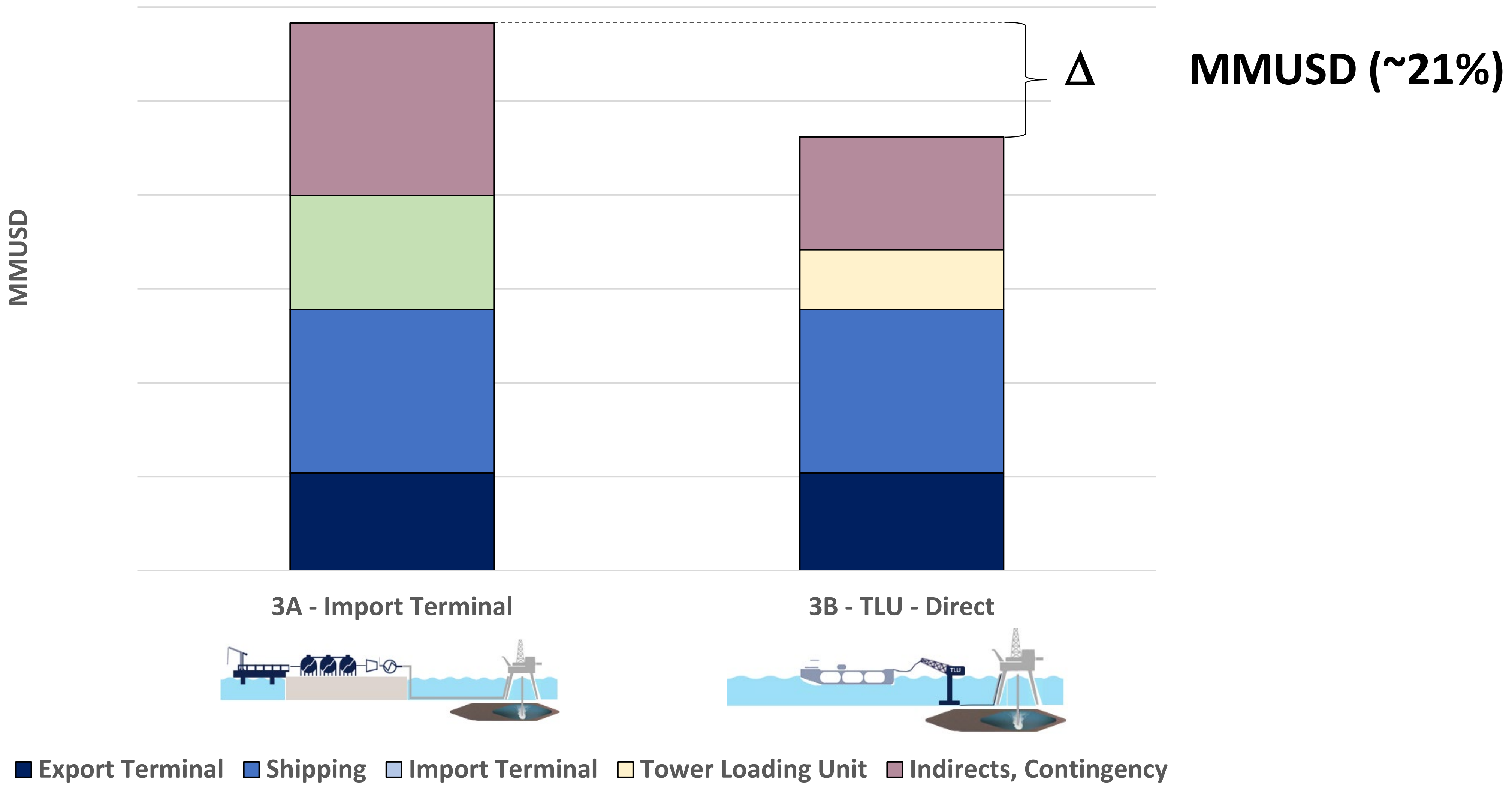


MMUSD
(including indirects & contingency)
[40% of conventional terminal]

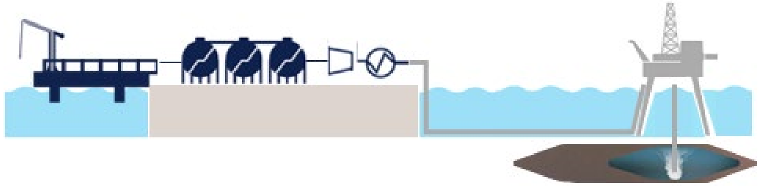
- **Transfer hoses**
- **TLU jacket & piles**
- **TLU process skid (topsides)**
  - *Pump (to pipeline pressure)*
  - *Heater (to pipeline inlet)*
  - *Metering*
  - *Diesel gen.*
- **Export line (subsea)**
- **Riser and tie-in**

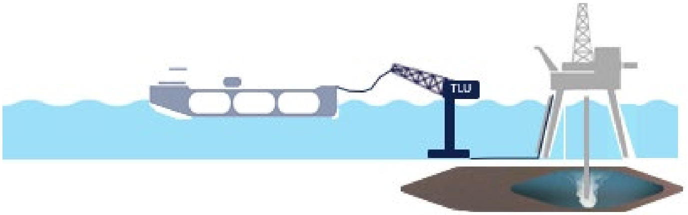
Out of scope

$ Value Summary



Risk





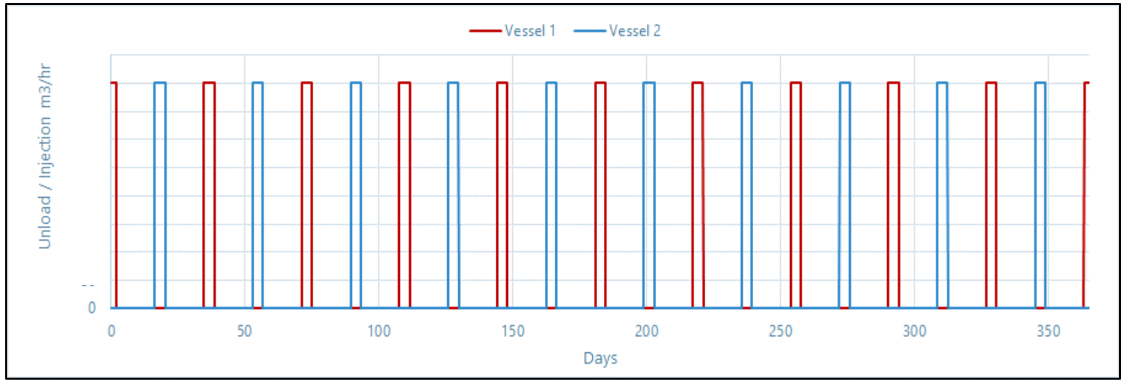
Conventional Import Terminal

- Case study excludes new pipeline ($$$)
- Pipeline qualification for re-use (hidden costs)
- Schedule – storage on critical path
- Access to 3rd party pipeline – capacity constraints, reliance on other emitter agreements for commercial approval
- Pipeline access tarriffs
- Terminal land planning / title / approvals
- Jetty use / port congestion
  - *shipping channels, dredging, demurrage*
  - *Berth occupancy – sim. ops (LNG etc)*

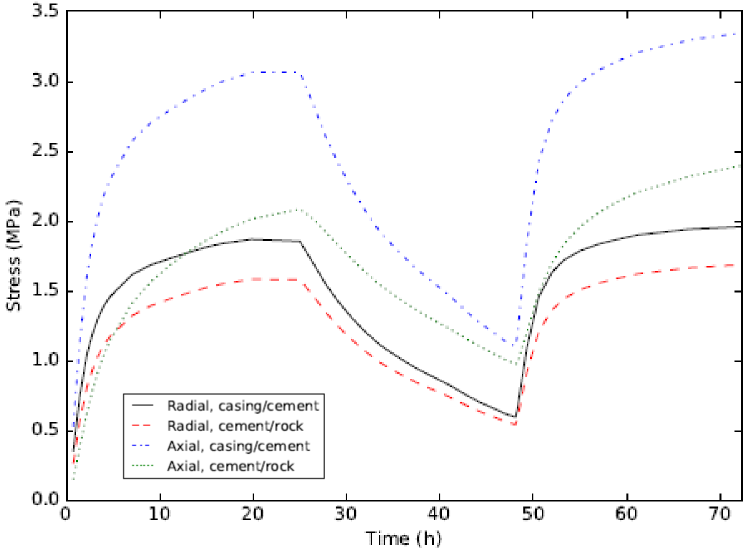
Direct Offshore Injection

- **Batch (intermittent) injection** – pressure / thermal cycling on wells – integrity issue
- Marine operations, weather, metocean - disconnect philosophy
- High ship utilization (80%)
  - *Long offload – constrained by well injection rate (4.5 days to well vs. 17 hrs to storage)*
  - *May need +1 well*
  - *May need +1 ship (show-stopper!)*

Risk Focus - Batch Operation



Wood: batch Injection schedule, 2 Carriers



DOI: 10.1016/j.ijggc.2017.04.007

Wood: coupled Ledaflow / GEM model using (CO2LINK)

- Thermal recovery between injection cycles - expansion or contraction of casings and well barrier materials, which can cause them to crack or de-bond at interfaces

- Pressure cycling of the injection well, with a risk of formation back-flow in the lower part of the well (corrosion / hydrates risk)

- Integrated transient well <-> near well modelling is critical
  - *A surface/well simulation model fully coupled with a reservoir simulation*

- Critical factor = the pause between intermittent injection operations. The formation slowly warms the well.
  - *Heating CO2 helps, but doesn't mitigate*
  - *Lower risk scheme is to have minimal pause between offloads*

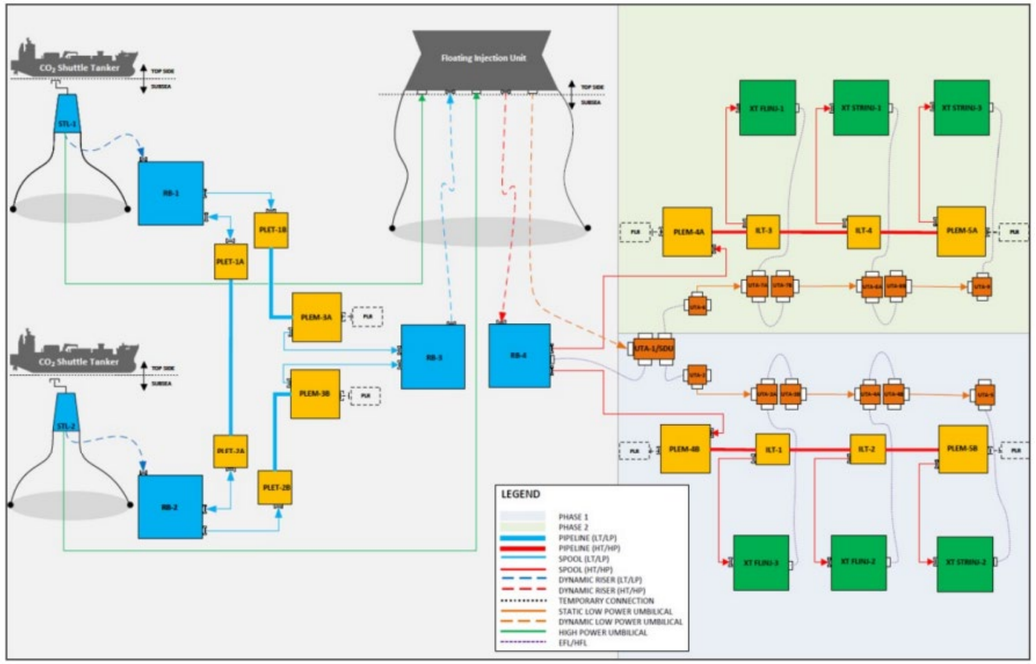
Solutions

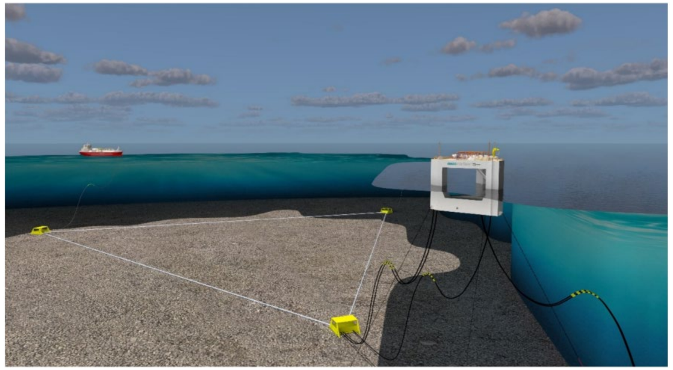
<u>How to achieve value and reduce risk?</u>

- Many direct injection ship concepts under consideration:
  - *Greensand CO2 vessel*
  - *Breeze Ship Design / Equinor*
  - *NEMO Maritime*
  - *Stella Maris (now Yinsin)*
  - *etc*

- EP transport under assessment as enabler (ambient temperature shipment) – injection, KNCC solution (the next presentation!)

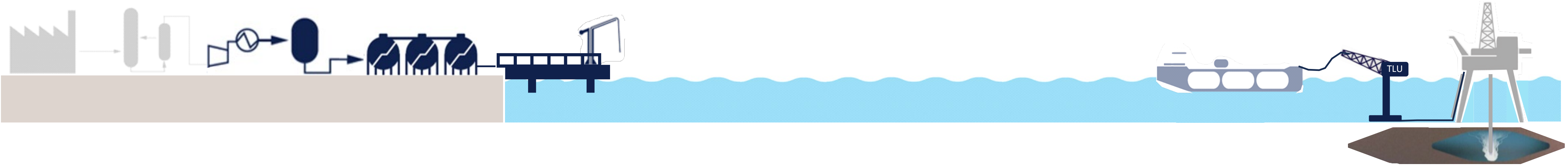
- STARFISH (Europe):
  - *Dual buoy concept to floating injection unit*
  - *For continuous injection, the inbound vessel connects before the outbound vessel disconnects (CO2 and power)*





https://www.nito.no/contentassets/6e7ba31ea5d9421dbf00b3e9c2f08374/horing---konsekvensutredning-havstjerne-horingsdokument.pdf

Summary

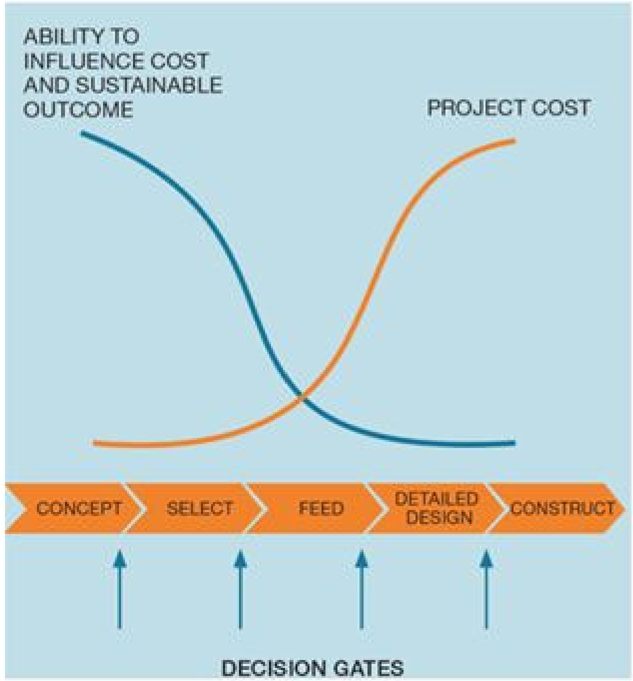


Direct injection – a regional CCS enabler?

- **Business case ($) appears sound…**
- **… but technical risks still need to be reduced to a reasonable level**

- **Front-end loading (FEL) is vitally important; it is where value is added or lost.**
    - *Consider direct injection in the list of early concepts under review*
    - *Carry out economic and technical screening, including non-economic criteria (safety, environment, political, schedule, etc)*

- **Many technology solutions in development….but beware <u>decision bias!</u>**
    - *Time and resources invested in a specific technology can create a bias towards using it, even if a better option exists*
    - ***Engage an independent consultant!***



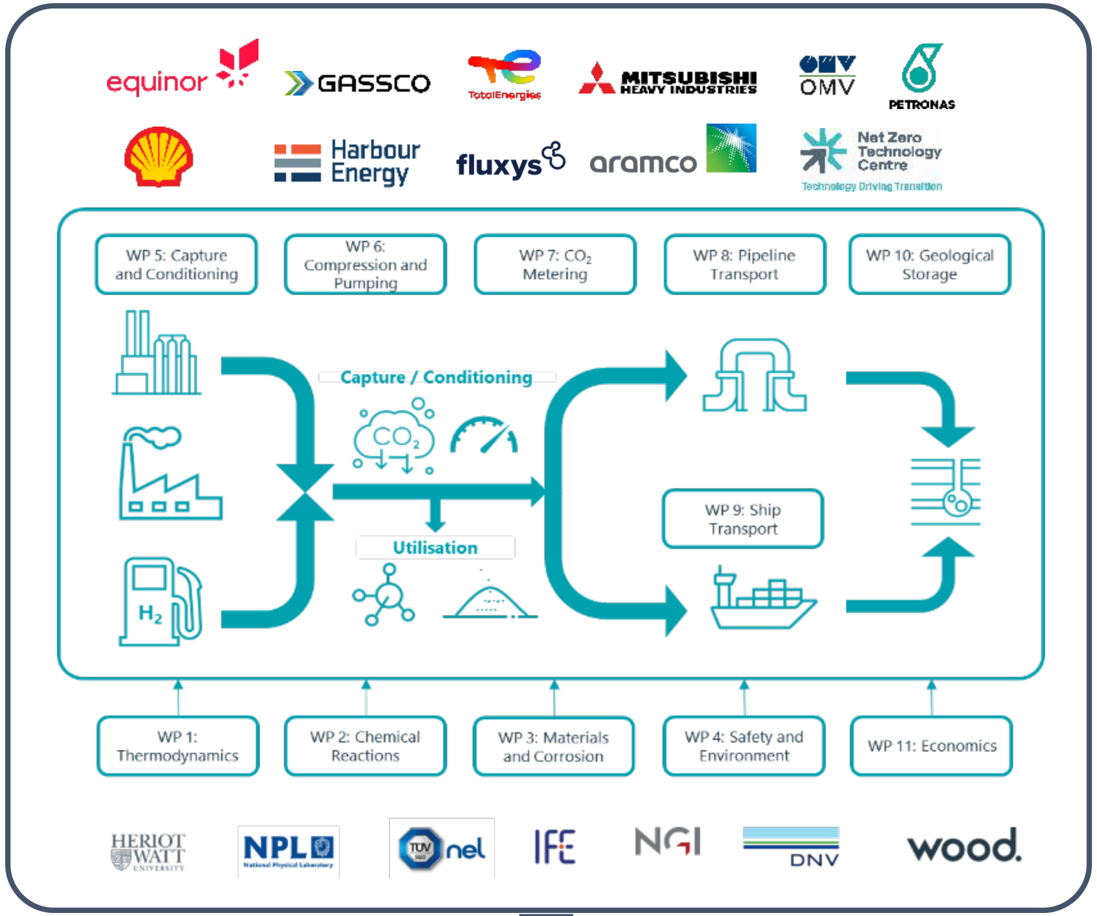
Ref. thechemicalengineer.com

Supporting

Joint industry partnership

Industry guidelines for setting the CO_2 specification for CCUS chains

Internal work packages



External deliverable

Industry guidelines for setting the CO_2 specification for CCUS chains

Thank-you

Arigatou gozaimasu

Q&A

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