PACECCS

Design and Operation of CCS Networks with Shipping: A Full-Chain View

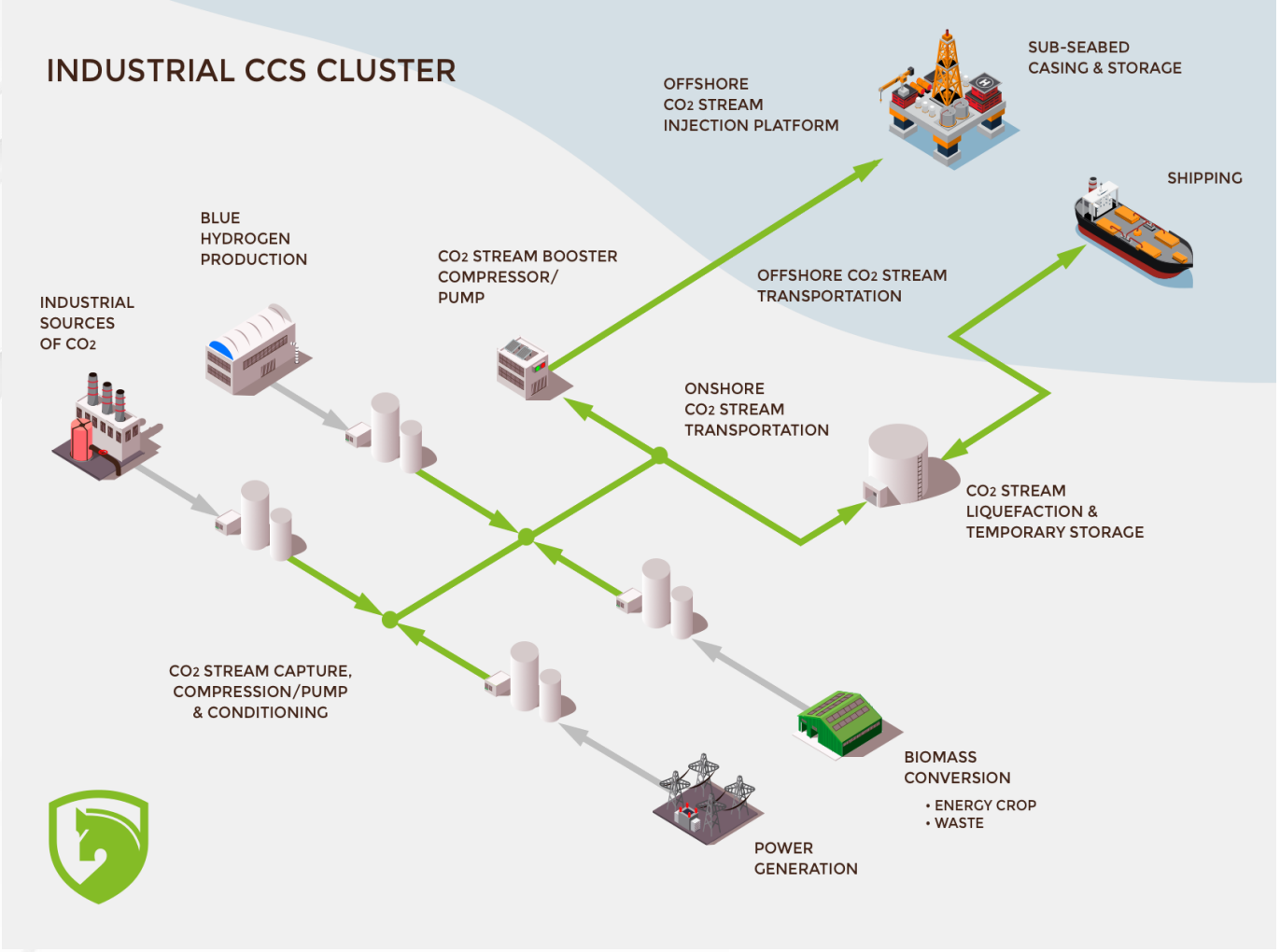
March 2024

CCS: full-chain design and operation

The CCS industrial hub:

- Shared transport & storage infrastructure for CO_2 disposal
- CO_2 sourced from industrial emitters and hydrogen producers
- Transport via a combination of pipelines and shipping

How does shipping operate in combination with capture, pipeline and disposal infrastructure?



CCS is a new industry

There are about 30 CCS projects in operation (data from the GCCSI).

All of them are either:

- EOR (which isn't CCS);
- a pilot or small-scale project;
- Gorgon LNG CCS (a historically troubled project), or;
- Qatar LNG CCS (which we don't know much about).

None of them are shipping projects.

We are still learning.

FACILITY	COUNTRY	FACILITY STATUS	OPERATIONAL DATE	FACILITY INDUSTRY	CAPTURE CAPACITY Mtpa CO_2	FACILITY STORAGE CODE
TERRELL NATURAL GAS PROCESSING PLANT (FORMERLY VAL VERDE NATURAL GAS PLANTS)	USA	Operational	1972	Natural Gas Processing	0.5	Enhanced Oil Recovery
ENID FERTILIZER	USA	Operational	1982	Fertiliser Production	0.2	Enhanced Oil Recovery
SHUTE CREEK GAS PROCESSING PLANT	USA	Operational	1986	Natural Gas Processing	7	Enhanced Oil Recovery
MOL SZANK FIELD CO_2 EOR	Hungary	Operational	1992	Natural Gas Processing	0.16	Enhanced Oil Recovery
SLEIPNER CO_2 STORAGE	Norway	Operational	1996	Natural Gas Processing	1	Dedicated Geological Storage
GREAT PLAINS SYNFUELS PLANT AND WEYBURN-MIDALE	USA	Operational	2000	Synthetic Natural Gas	3	Enhanced Oil Recovery
CORE ENERGY CO_2-EOR	USA	Operational	2003	Natural Gas Processing	0.35	Enhanced Oil Recovery
SNOHVIT CO_2 STORAGE	Norway	Operational	2008	Natural Gas Processing	0.7	Dedicated Geological Storage
ARKALON CO_2 COMPRESSION FACILITY	USA	Operational	2009	Ethanol Production	0.29	Enhanced Oil Recovery
CENTURY PLANT	USA	Operational	2010	Natural Gas Processing	5	Enhanced Oil Recovery
PETROBRAS SANTOS BASIN PRE-SALT OIL FIELD CCS**	Brazil	Operational	2011	Natural Gas Processing	7	Enhanced Oil Recovery
BONANZA BIOENERGY CCUS EOR	USA	Operational	2012	Ethanol Production	0.1	Enhanced Oil Recovery
AIR PRODUCTS STEAM METHANE REFORMER	USA	Operational	2013	Hydrogen Production	1	Enhanced Oil Recovery
COFFEYVILLE GASIFICATION PLANT	USA	Operational	2013	Fertiliser Production	0.9	Enhanced Oil Recovery
PCS NITROGEN	USA	Operational	2013	Fertiliser Production	0.3	Enhanced Oil Recovery
BOUNDARY DAM 3 CARBON CAPTURE AND STORAGE FACILITY	Canada	Operational	2014	Power Generation	1	Various
KARAMAY DUNHUA OIL TECHNOLOGY CCUS EOR	China	Operational	2015	Methanol Production	0.1	Enhanced Oil Recovery
QUEST	Canada	Operational	2015	Hydrogen Production	1.3	Dedicated Geological Storage
UTHMANIYAH CO_2-EOR DEMONSTRATION	Saudi Arabia	Operational	2015	Natural Gas Processing	0.8	Enhanced Oil Recovery
ABU DHABI CCS (PHASE 1 BEING EMIRATES STEEL INDUSTRIES)	United Arab Emirates	Operational	2016	Iron and Steel Production	0.8	Enhanced Oil Recovery
ILLINOIS INDUSTRIAL CARBON CAPTURE AND STORAGE	USA	Operational	2017	Ethanol Production	1	Dedicated Geological Storage
CNPC JILIN OIL FIELD CO_2 EOR	China	Operational	2018	Natural Gas Processing	0.6	Enhanced Oil Recovery
GORGON CARBON DIOXIDE INJECTION	Australia	Operational	2019	Natural Gas Processing	4	Dedicated Geological Storage
QATAR LNG CCS	Qatar	Operational	2019	Natural Gas Processing	2.2	Dedicated Geological Storage
ALBERTA CARBON TRUNK LINE (ACTL) WITH NORTH WEST REDWATER PARTNERSHIP'S STURGEON REFINERY CO_2 STREAM	Canada	Operational	2020	Oil Refining	1.6	Enhanced Oil Recovery
ALBERTA CARBON TRUNK LINE (ACTL) WITH NUTRIEN CO_2 STREAM	Canada	Operational	2020	Fertiliser Production	0.3	Enhanced Oil Recovery
ORCA	Iceland	Operational	2021	Direct Air Capture	0.004	Dedicated Geological Storage
GLACIER GAS PLANT MCCS	Canada	Operational	2022	Natural Gas Processing	0.2	Dedicated Geological Storage
SINOPEC QILU-SHENGLI CCUS	China	Operational	2022	Chemical Production	1	Enhanced Oil Recovery
RED TRAIL ENERGY CCS	USA	Operational	2022	Ethanol Production	0.18	Dedicated Geological Storage

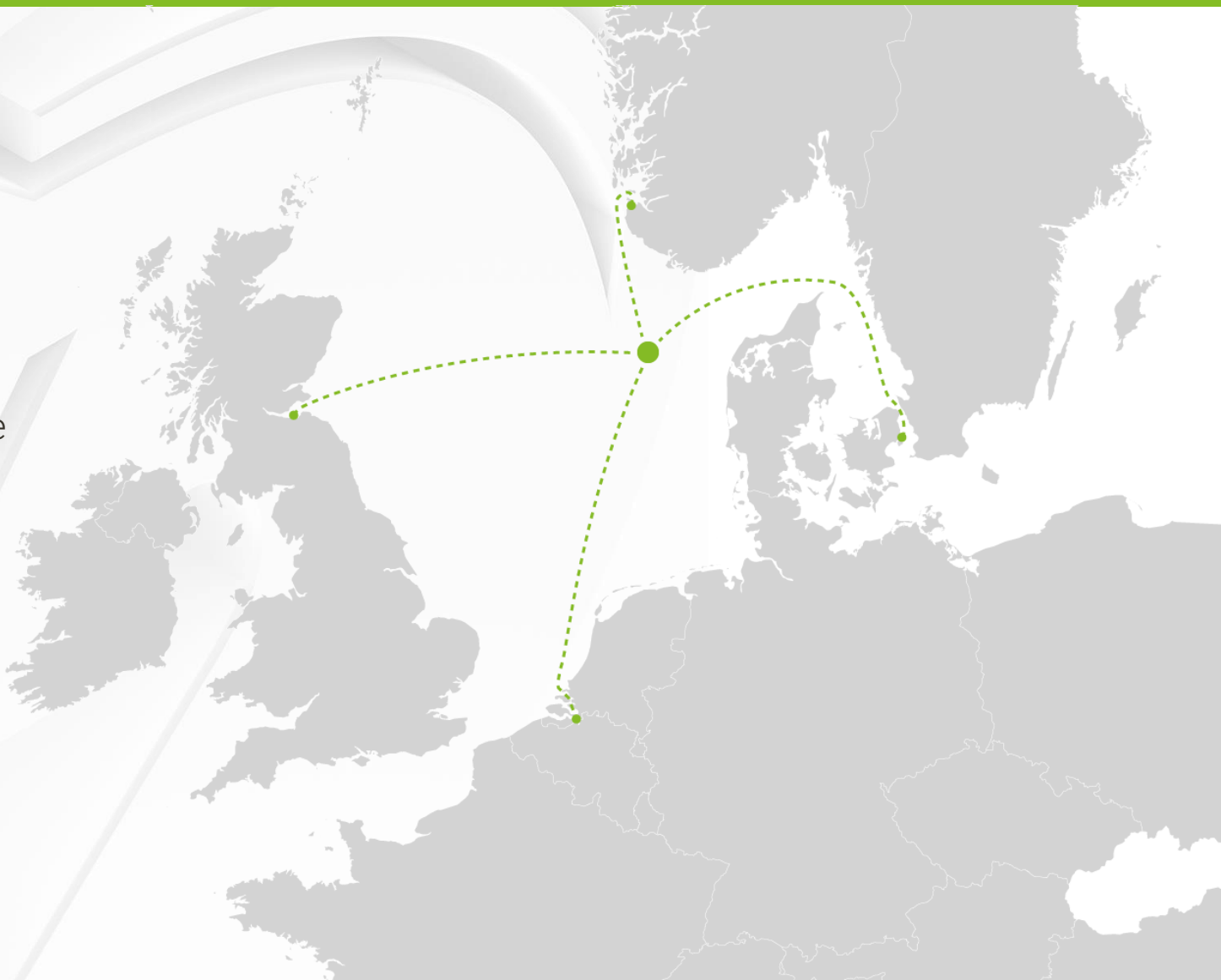
Integrating shipping into CCS

Project drivers

- Cost
- Safety
- Operability

A simple project is an operable project.

Some early assumptions around shipping don’t always hold true.



Case Study 1: Blue hydrogen to offshore storage

This case study is “based on a true story”.

The map is fake – I’m showing blue hydrogen being produced at the Pace CCS London office.

- A new blue hydrogen plant, producing H_2 from gas, with CO_2 capture.
- Dedicated shipping shuttles to offshore disposal, with minimum infrastructure floating buoy at the point of injection.

Project assumption: MP shipping (for minimum ship cost and alignment with Northern Lights)

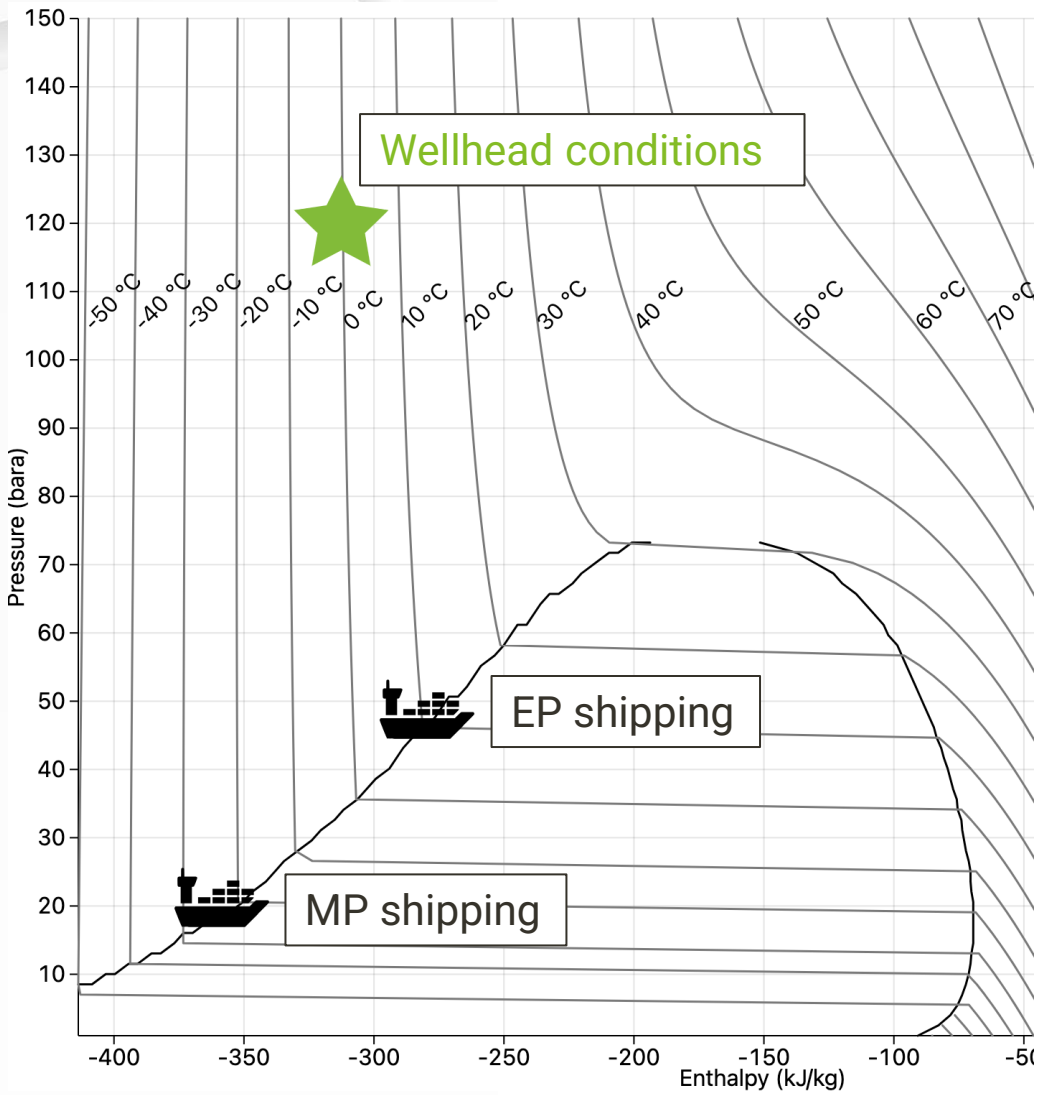
Case Study 1: Blue hydrogen to offshore storage

This a *pressure-enthalpy* chart, for Northern Lights CO_2 (February 2024 updated specification).

- Pressure is on the y-axis
- Enthalpy – heat – is on the x-axis

The green star shows the minimum temperature (0 °C), or minimum enthalpy, at the injection wellhead.

- MP shipping has lower enthalpy than needed. Heating at the point of injection is required.
- EP shipping has higher enthalpy than needed. Heating is not required.



Case Study 1: Blue hydrogen to offshore storage

What have we learned:

- About *100 MW* of heating is required for the MP shipping case (based on the planned injection rate).
- The cost and practicality of providing this heat is a showstopper.
- The true cost of the project required review of full-chain operability and design.

Project status: MP shipping dropped. Project returned to concept stage.

Case Study 2: CCGT with CO_2 export by ship

This case study is also “based on a true story”.

The map is also fake – I’m showing CO_2 capture from a gas turbine at the Pace CCS London office, with export to Scotland.

- An existing large CCGT, with retrofitted CO_2 capture, with export via shipping to a third-party project.
- Interim CO_2 storage required at a busy harbour.
- No local pipeline or disposal infrastructure.

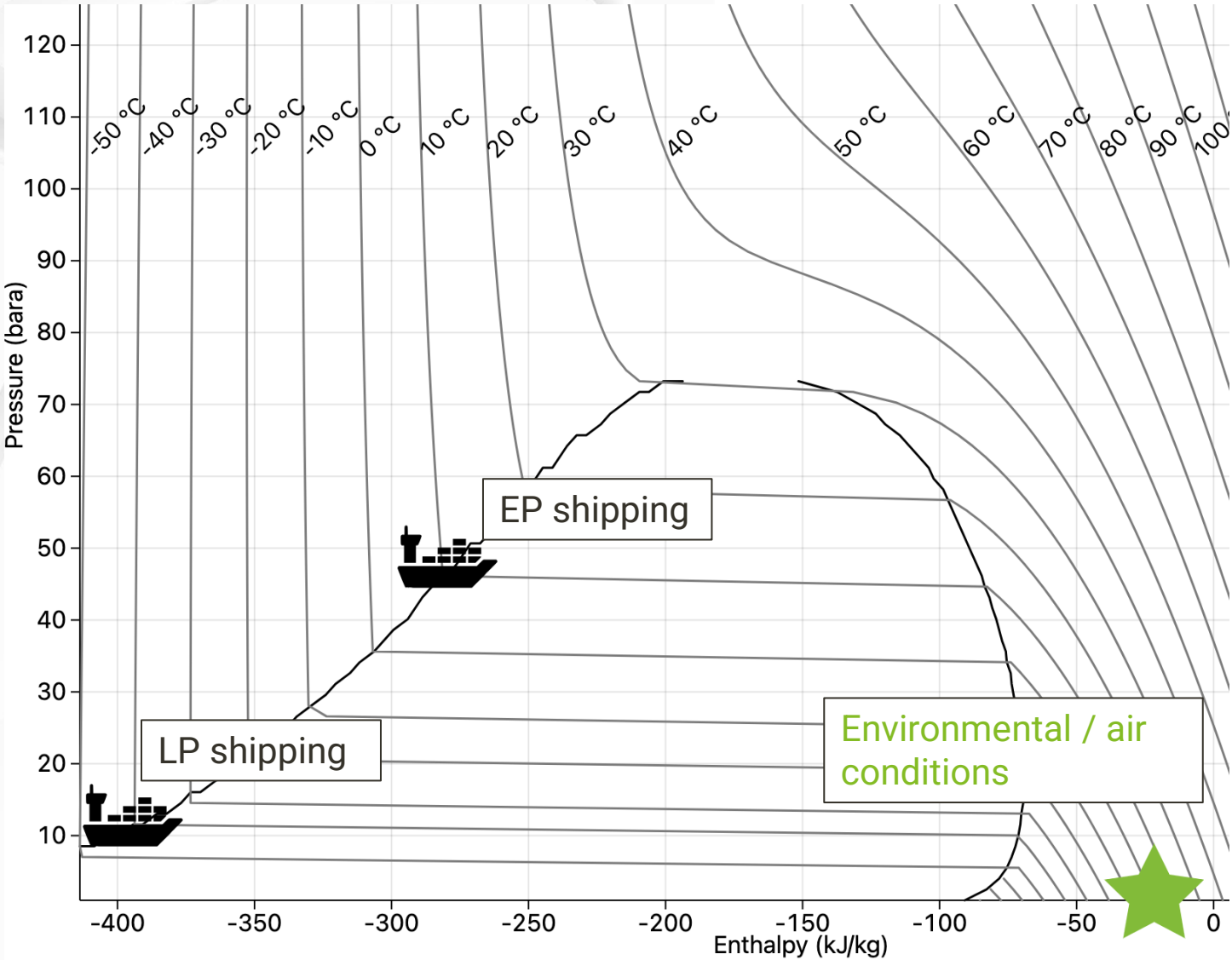
Project assumption: LP shipping (for maximum ship size and economies of scale)

Case Study 2: CCGT with CO_2 export by ship

This the pressure-enthalpy chart.

The green star shows the ambient air conditions. This is the enthalpy where the CO_2 will disperse in the event of a release.

- A release from LP shipping storage requires about 50% more heat before it will disperse.
- EP shipping storage containers are much smaller.



Case Study 2: CCGT with CO_2 export by ship

This a CO_2 MP release event, in Mainz Germany in 2015.

Released CO_2 from low enthalpy conditions is very cold. It forms cold CO_2 fog and dry ice.

- A release from EP storage containers is lower volume.
- A released from EP shipping storage disperses more quickly, because less environmental heat is required.

Case Study 2: CCGT with CO_2 export by ship

Captured CO_2 always comes with impurities.

For brownfield CCS, the CO_2 capture unit is usually the most expensive item in the full-chain design.

Non-polar impurities are more soluble at EP conditions compared with MP or LP conditions.

- EP shipping allows for less pure CO_2.
- Less pure CO_2 allows for cheaper, simpler capture technologies, with no liquefaction process needed.

Specification	EP Conditions	LP or MP
CO_2 content (minimum)	95%	99.81%
N_2 (maximum)	2.2%	0.19%
H_2 (maximum)	0.8%	
CH_4 (maximum)	4.7%	

Major and common non-polar shown only.
LP/MP specification as per Northern Lights (February 2024.)

Case Study 2: CCGT with CO_2 export by ship

What have we learned:

- EP shipping is safer than other options due to the higher enthalpy of the harbour storage conditions, and the smaller size of the storage vessels.
- EP shipping enables lower cost capture.
- The true cost of the project required review of full-chain operability and design.

Project status: LP shipping assumption under review.

Summary

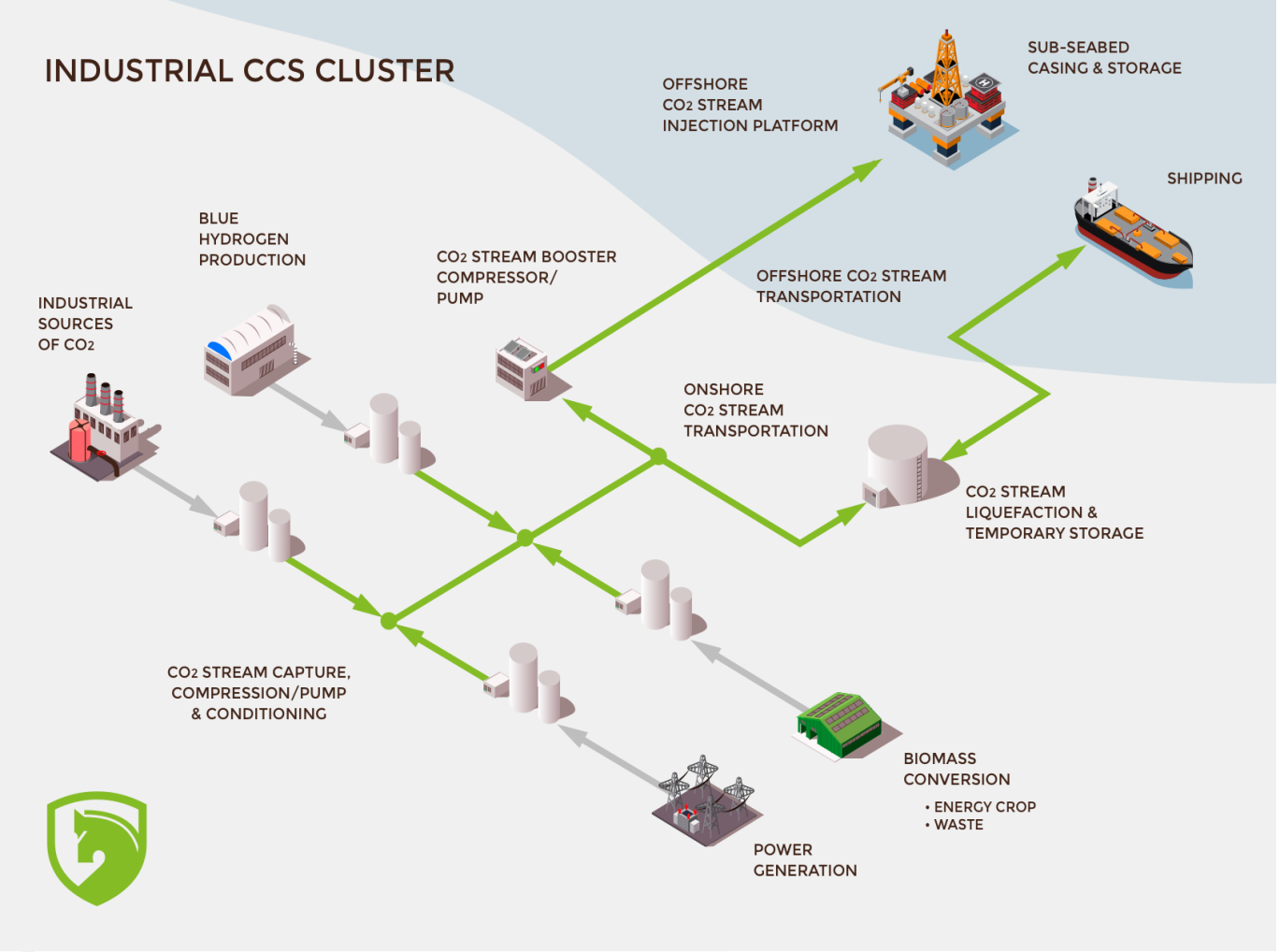
CCS is a new industry.

We are still learning.

Pace CCS have been asked to independently review shipping conditions on about 15 CCS projects in Europe & Asia.

- When we started, none of those projects were considering EP shipping.
- Now, all those projects consider EP shipping as an option, or as their base case design.

Our lesson: consider the full chain.



Thank You

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