Technical Concepts and Costs of CCS (in the German North Sea)

Dr. Sven Hoog, Fichtner GmbH & Co. KG

Beiratssitzung, Hamburg, 26.09.2023

GEOSTOR

Status of current activities at Fichtner

GEOMAR

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

CAU Kiel University Christian-Albrechts-Universität zu Kiel

Deutsches Meeresmuseum Stralsund

Universität Hamburg
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GEOSTOR – finding a feasible Solution to store CO_2 effectively in the German North Sea

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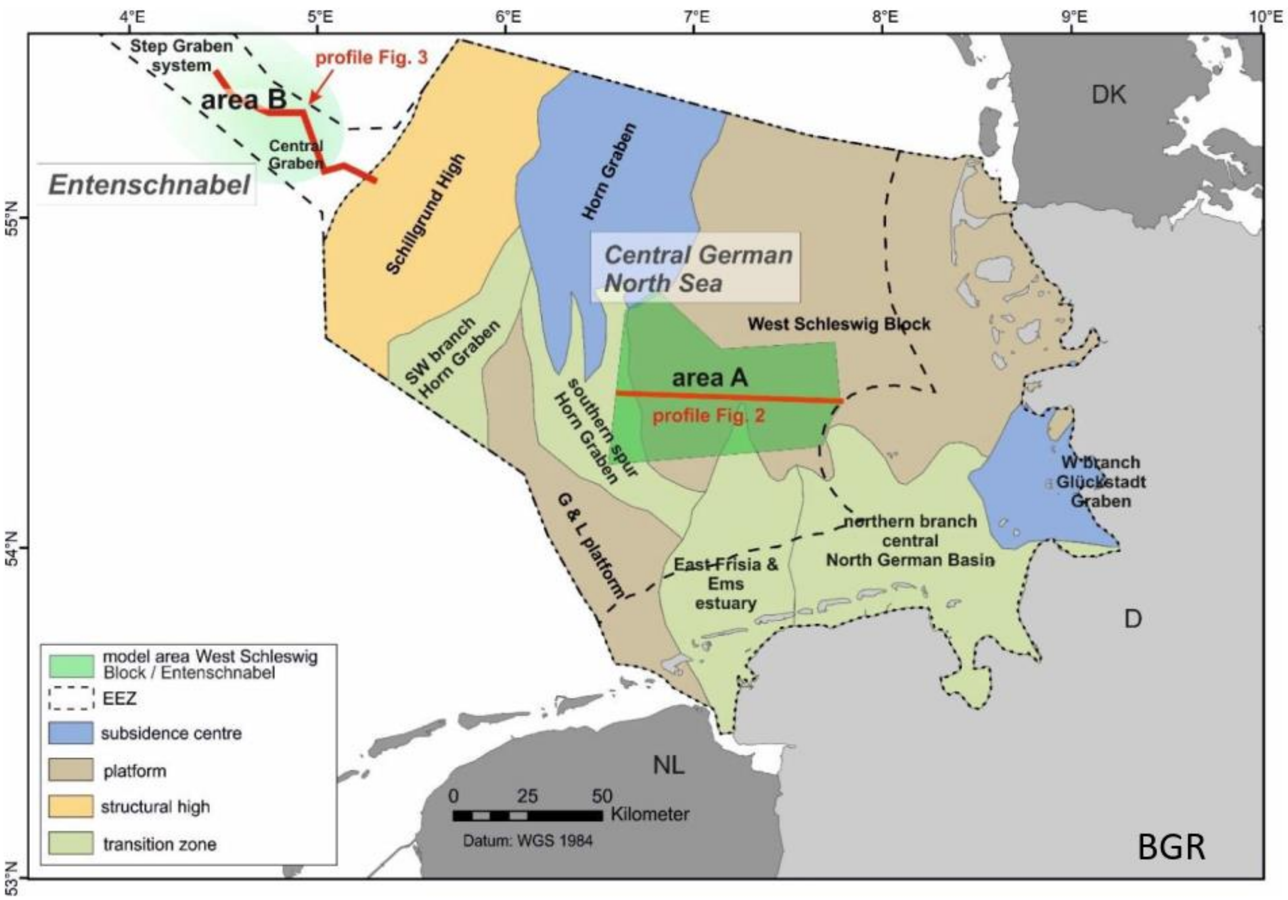
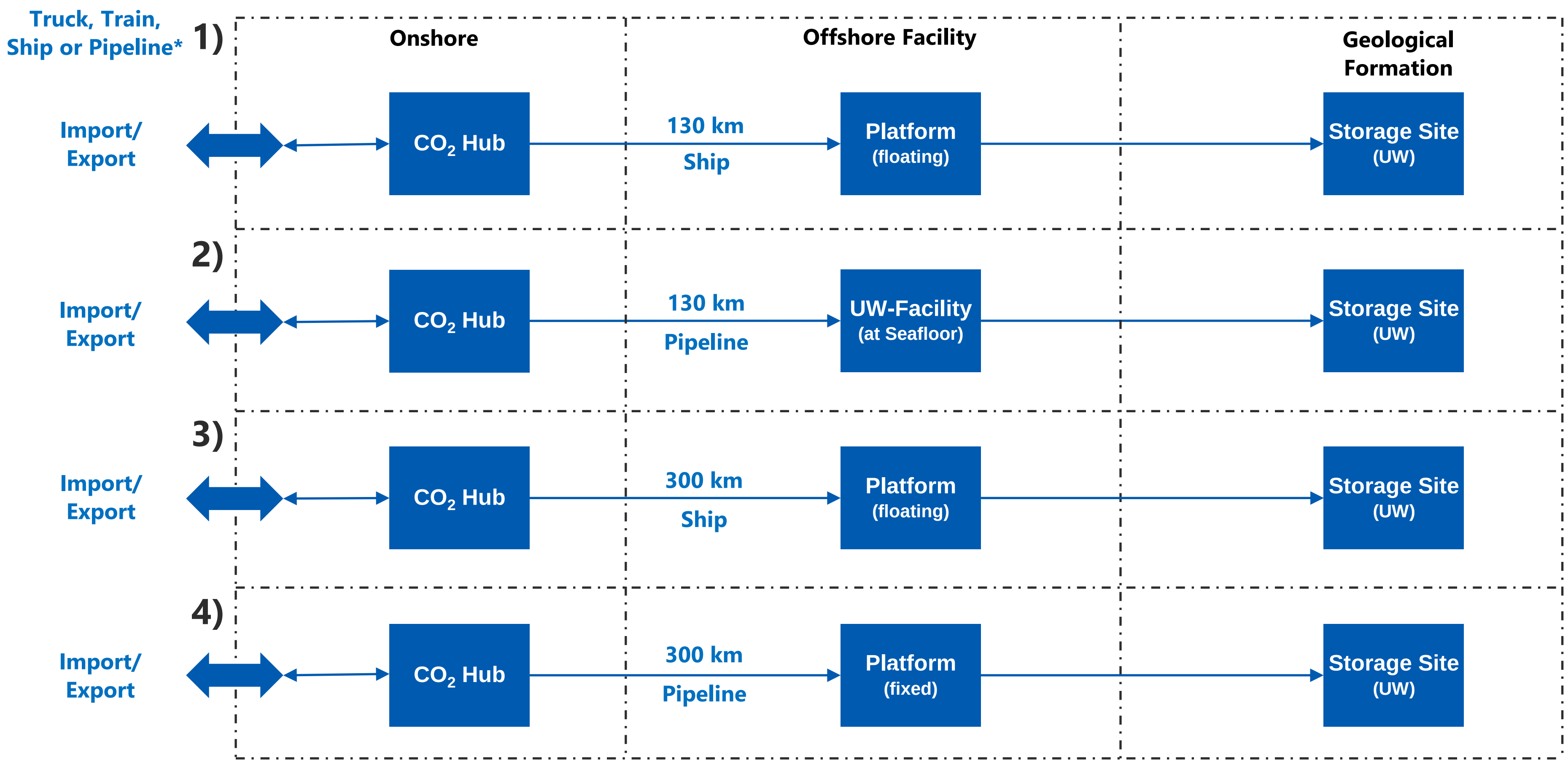
Governing aspects for designing CCS Logistics Chains:

- Storage Site location(s) - Hub location
- Storage capacity / storage volume per year
- Distances (Sources->Hub, Hub->Offshore Site)
- Transport means (low/no GHG emissions?!)
- Metocean data (water depth at site, bathymetry, wind, waves, current, soil condition)
- Sources of CO_2 (physical, chemical, process implications)
- Materials / components selection and availability
- Legal aspects, Contracts, HSE
- Costs (UXO, drilling, transportation, platforms, processing, temp. storage, main components, monitoring)
- Risks for all links of the Logistics Chain
- <u>Note</u>: CCU is also gaining Momentum (syn. Methanol, Diesel, Kerosene, LPG, LNG)



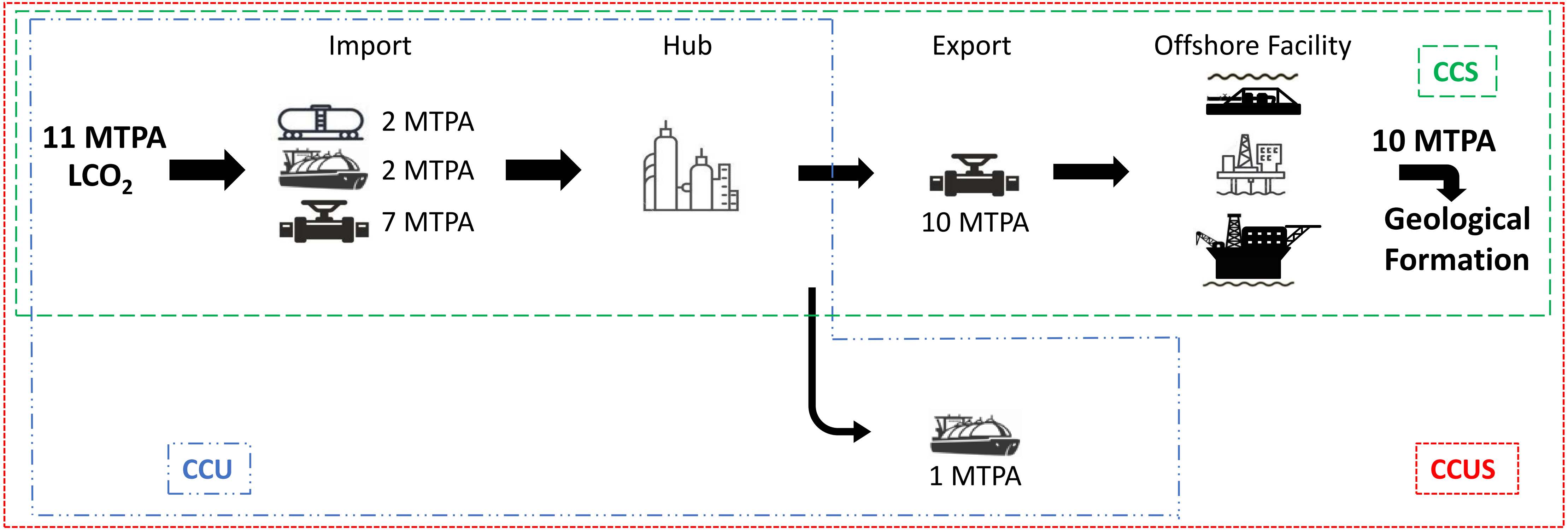
German Offshore CCS Sites under investigation in GEOSTOR

Block Flow Diagram (BFD) for 4 Scenarios



* Import only

Base Case for Hub process simulation

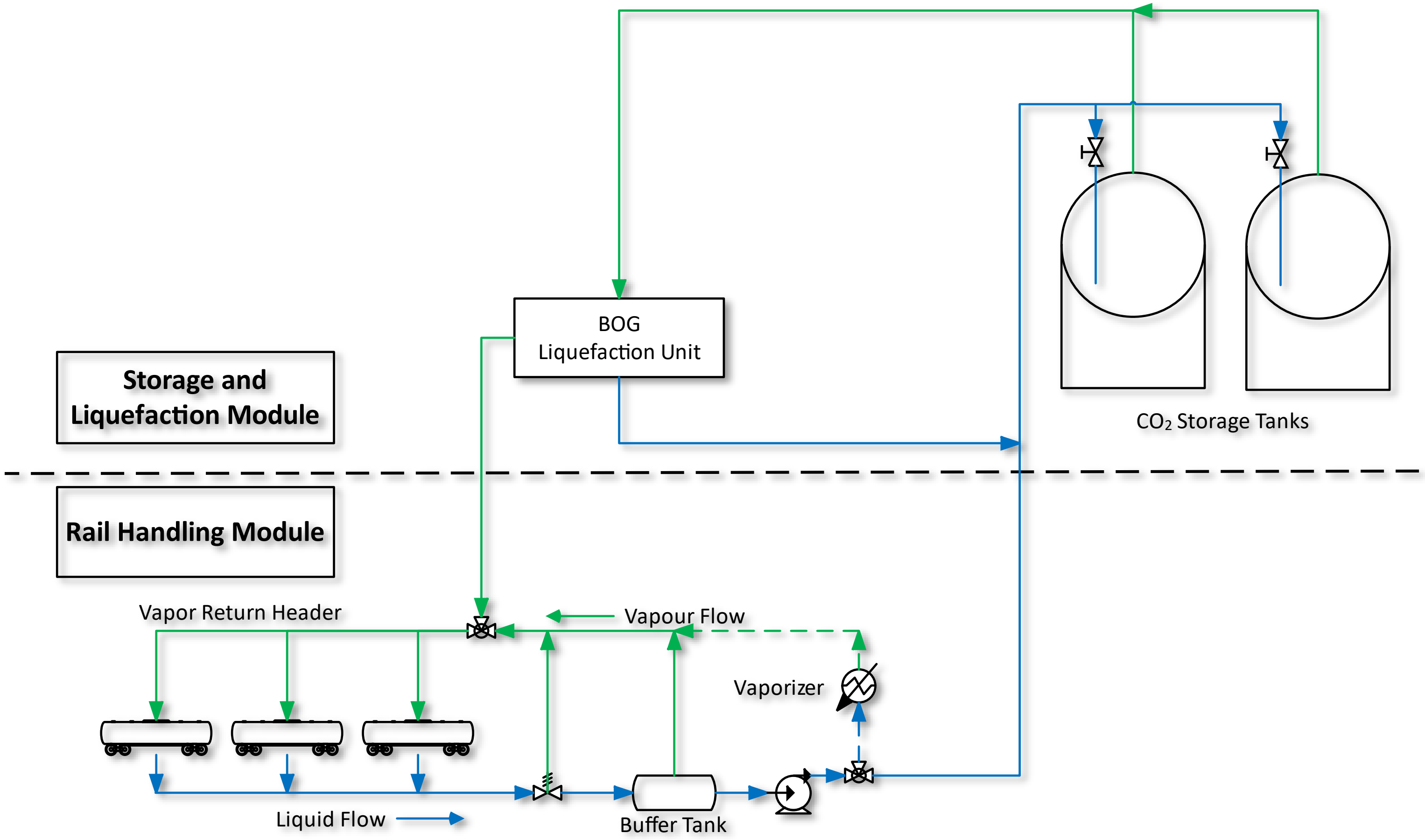


CCS: Carbon Capture and Storage CCU: Carbon Capture and Utilisation CCUS: Carbon Capture, Utilisation and Storage

Definition of Base Case for Cost Estimation:

- Import of 2 MTPA liquid CO_2 via small ships (7 700 m^3) → Requires unloading of 258 ships per year (ca. five ships per week)
- Import of 2 MTPA liquid CO_2 via 32x RTCs (62 m^3) → Requires unloading of 960 trains per year (ca. three trains per day)
- Export of 1 MPTA liquid CO_2 via Ship (23 000 m^3) → Requires loading of 43 ships per year (ca. one ship per week)

PFD* – Rail Handling Module

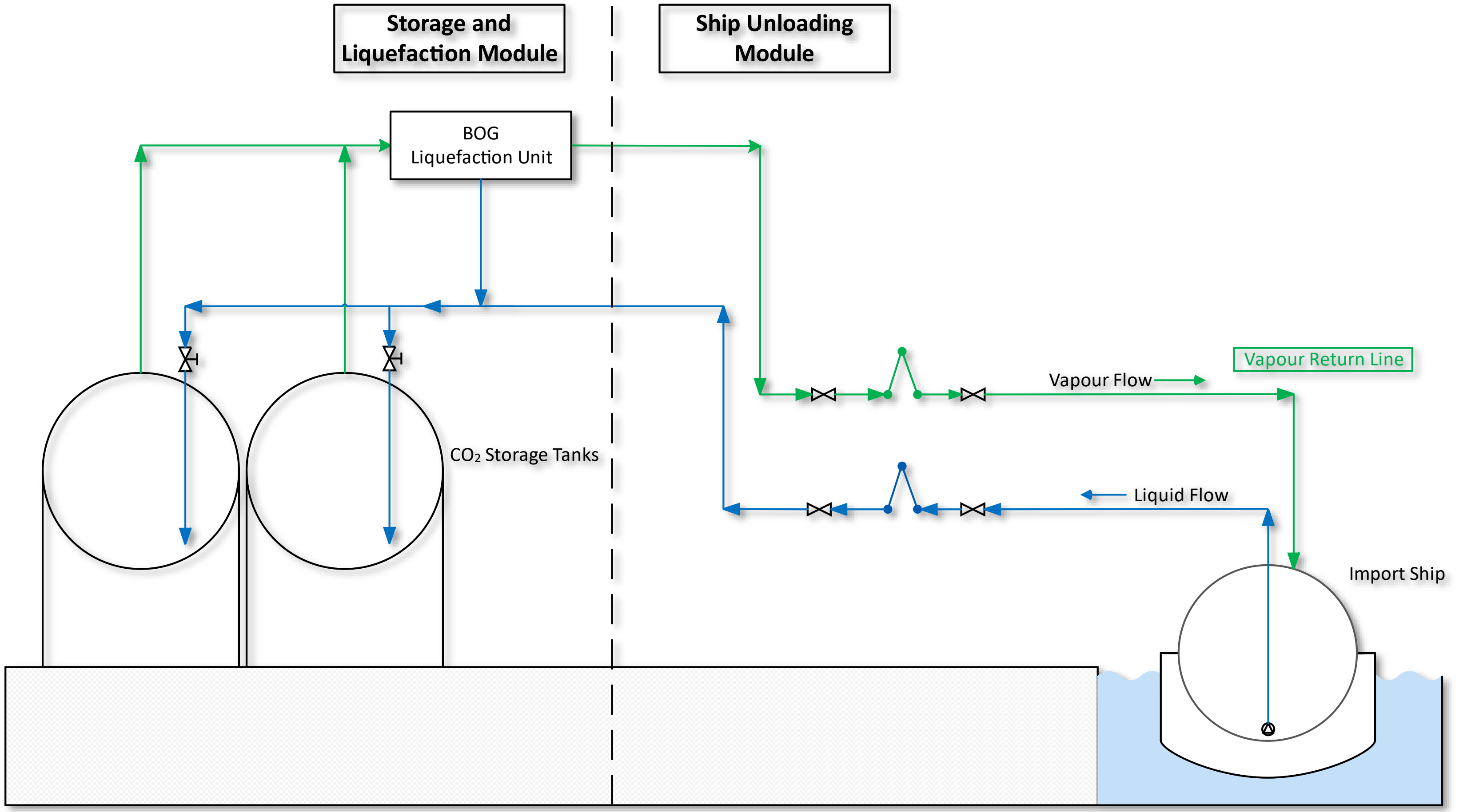


Rail Handling Module:

- Liquid CO_2 is unloaded from RTCs and transferred to storage tanks
    - 32 loading arms are foreseen for unloading of liquid CO_2
- Gaseous CO_2 (displaced BOG from storage tanks) is directed to RTCs to replace liquid CO_2 volume with gaseous CO_2
    - Vaporizer is forseen for temporary operation if amount of BOG is not sufficient for unloading
- Buffer Tank is required to ensure that pump is primed
- Expected excess BOG production during unloading: ca. 4.84 wt.% of liquid CO_2 from all RTCs
    - BOG is liquefied in Storage and Liquefaction Module

*Process Flow Diagram

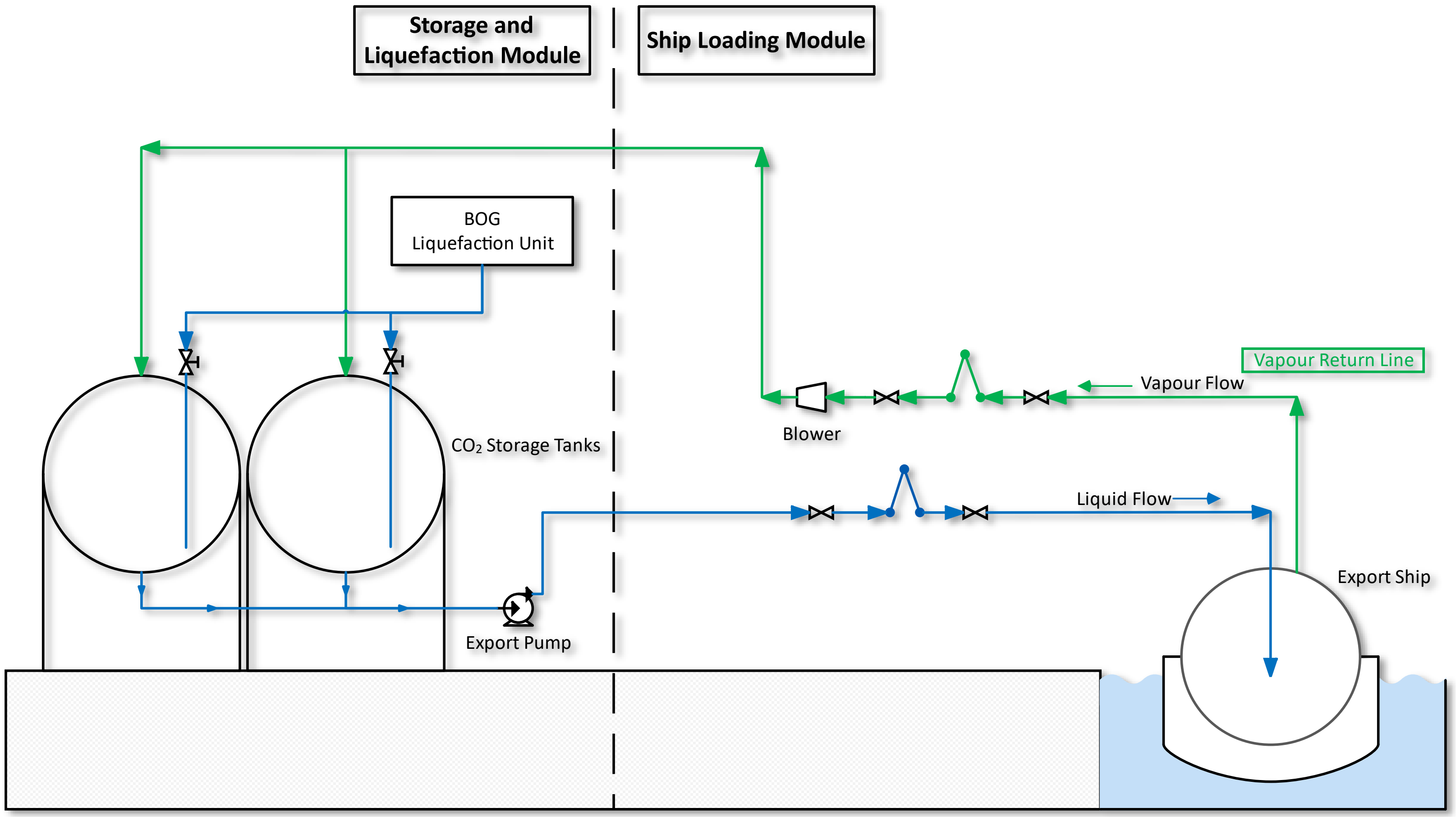
PFD – Ship Handling Module: Unloading of Import Ships



Unloading of Import Ships:

- Liquid CO_2 is pumped with in-tank pumps of import ship (capacity of 7 700 m^3) to storage tanks
- Gaseous CO_2 (displaced BOG from storage tank) is directed to import ship to replace liquid CO_2 volume with gaseous CO_2
  - Vapor return line forseen for gaseous CO_2 transfer
- Expected excess BOG production during unloading: ca. 4.78 wt.% of liquid CO_2 from import ship
  - BOG is liquefied in Storage and Liquefaction Module

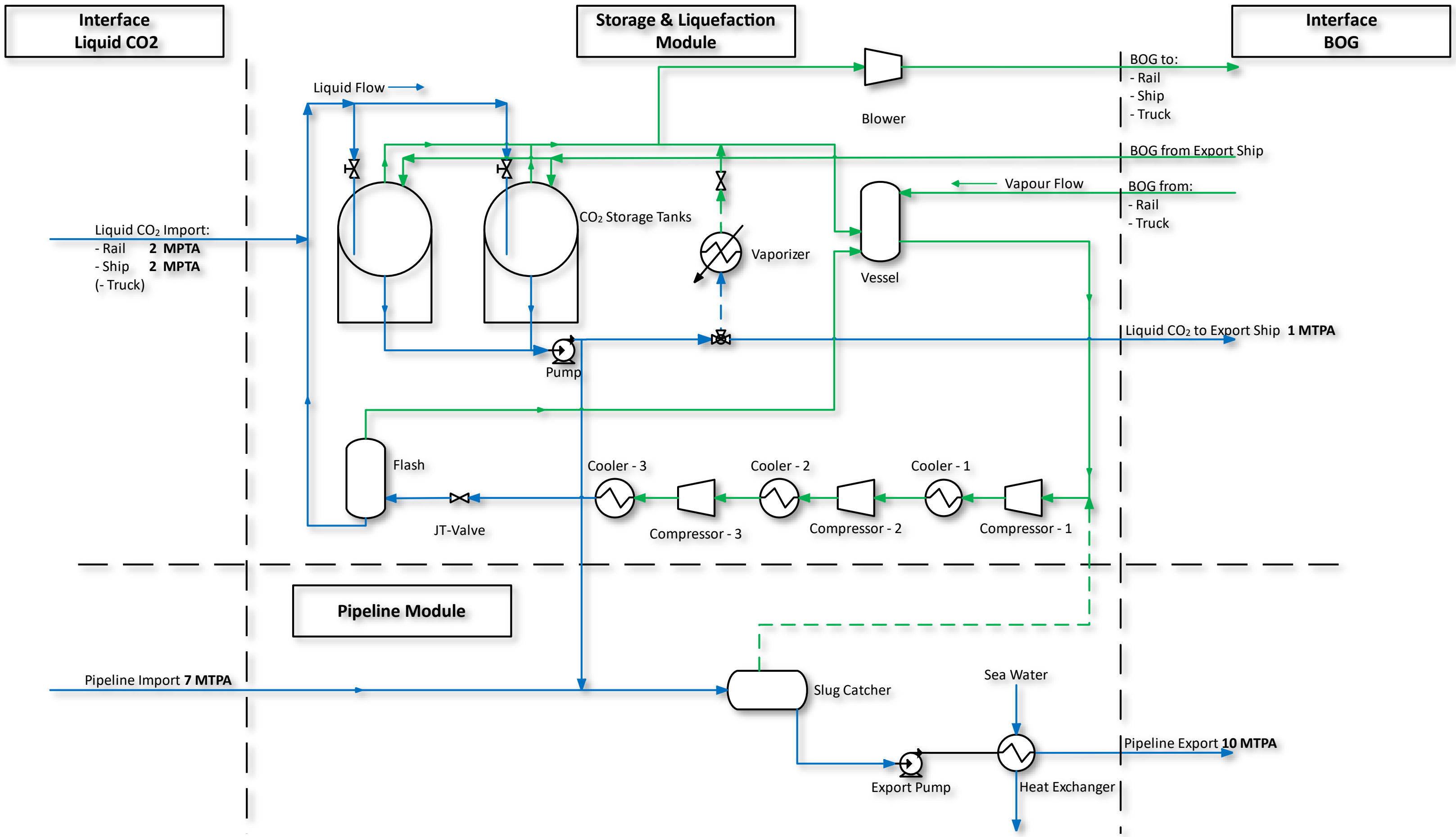
PFD – Ship Handling Module: Loading of Export Ships



<u>Loading to Export Ships</u>

- Liquid CO_2 from storage tanks is transferred via export pump to export ship (capacity of 23 000 m^3)
- Gaseous CO_2 (displaced BOG from export ship) is transferred to storage tanks due to high volume flow, which is connected to the Storage and Liquefaction Module
  - Vapor return line forseen for gaseous CO_2 transfer
  - Blower forseen to overcome pressure losses of vapor return line
- Expected excess BOG production during loading: ca. 4.85 wt.% of liquid CO_2 from export ship

PFD – Storage & Liquefaction Module // Pipeline Module



<u>Storage and Liquefaction Module:</u>

- Imported liquid CO_2 from rail, ship and truck is transferred to storage tanks
  - Two spherical tanks with capacity of 25 000 m^3 are foreseen
  - Displaced BOG in storage tank is transferred to the individual modules to replace the liquid CO_2 in the carrier
  - Excess BOG is directed to liquefaction unit
  - Liquefaction is performed by multi-stage compression with intercooling

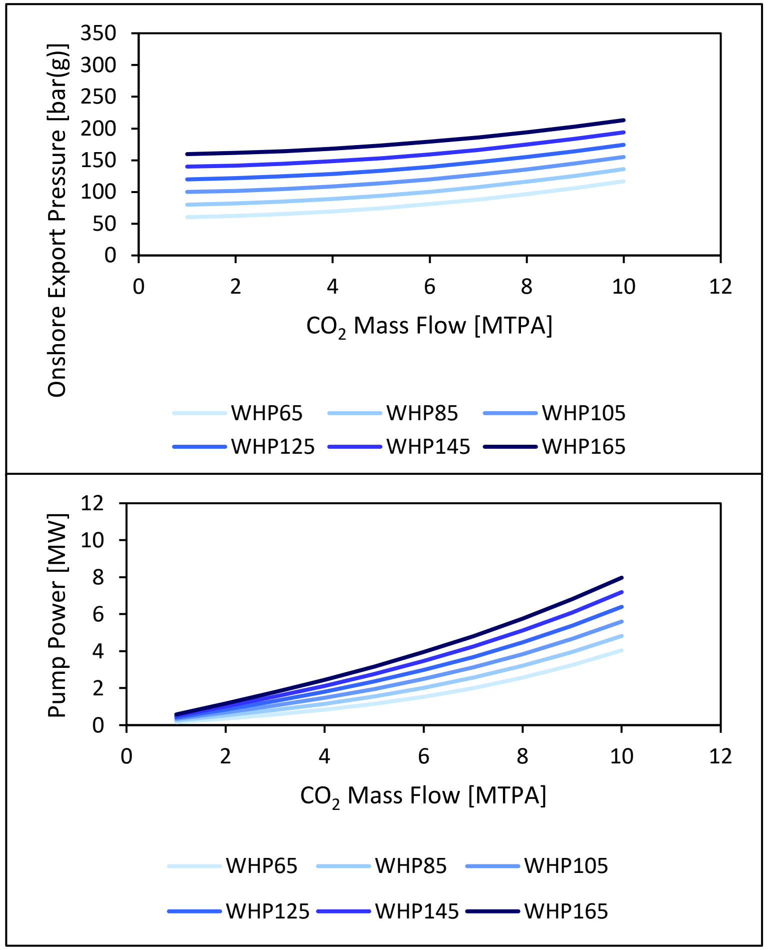
<u>Pipeline Module:</u>

- Imported CO_2 from pipeline and CO_2 from storage tanks is combined in a slug catcher to meet specified export rate
- Heat exchanger necessary for liquid CO_2 export to meet minimum temperature for sequestration (in order to prevent formation of permafrost zone)
  - Heat integration with liquefaction unit under development

Analysis of Scenario 2 & Scenario 4

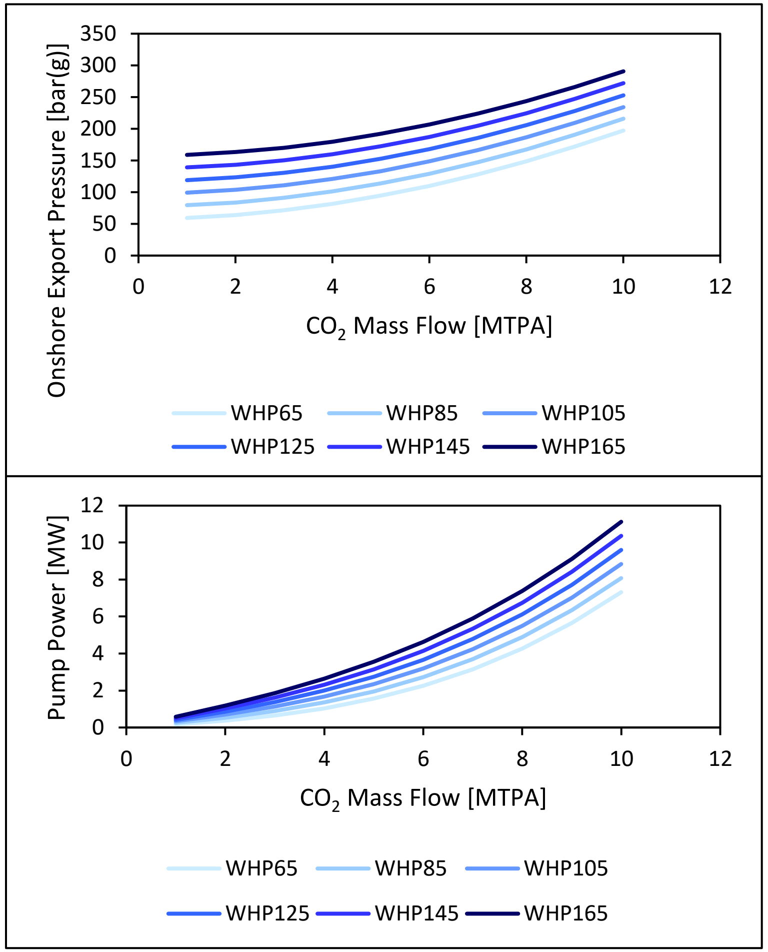
Pipeline from Hub to UW-Facility

Case Study: 130 km Pipeline, DN500



Pipeline from Hub to Platform (fixed)

Case Study: 300 km Pipeline, DN500

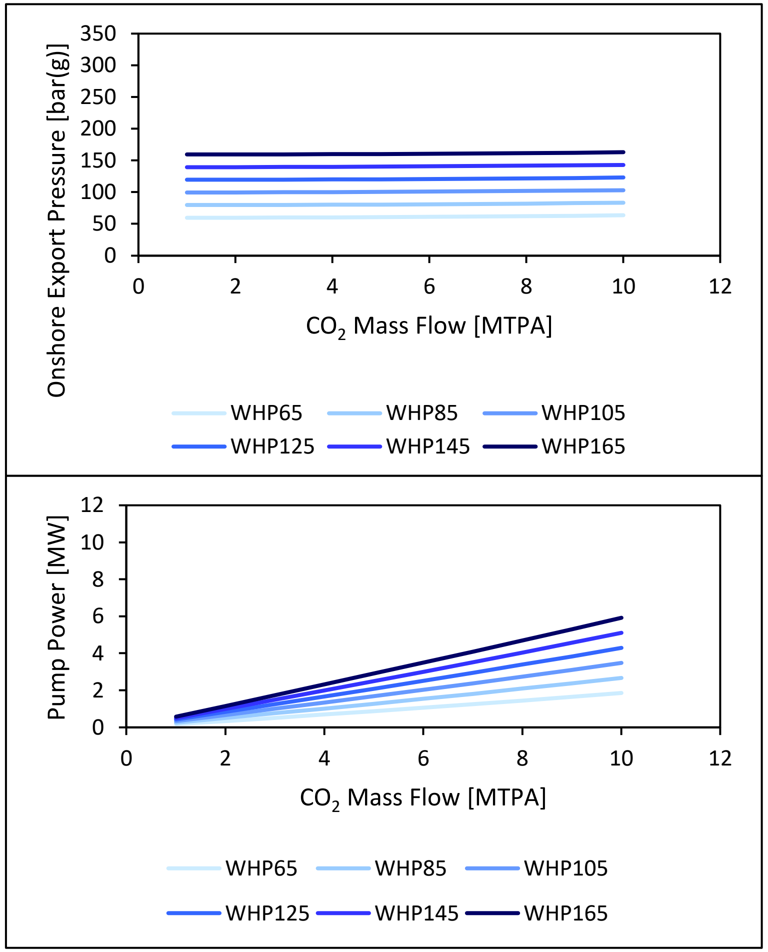


WHP=Well Head Pressure

Analysis of Scenario 2 & Scenario 4

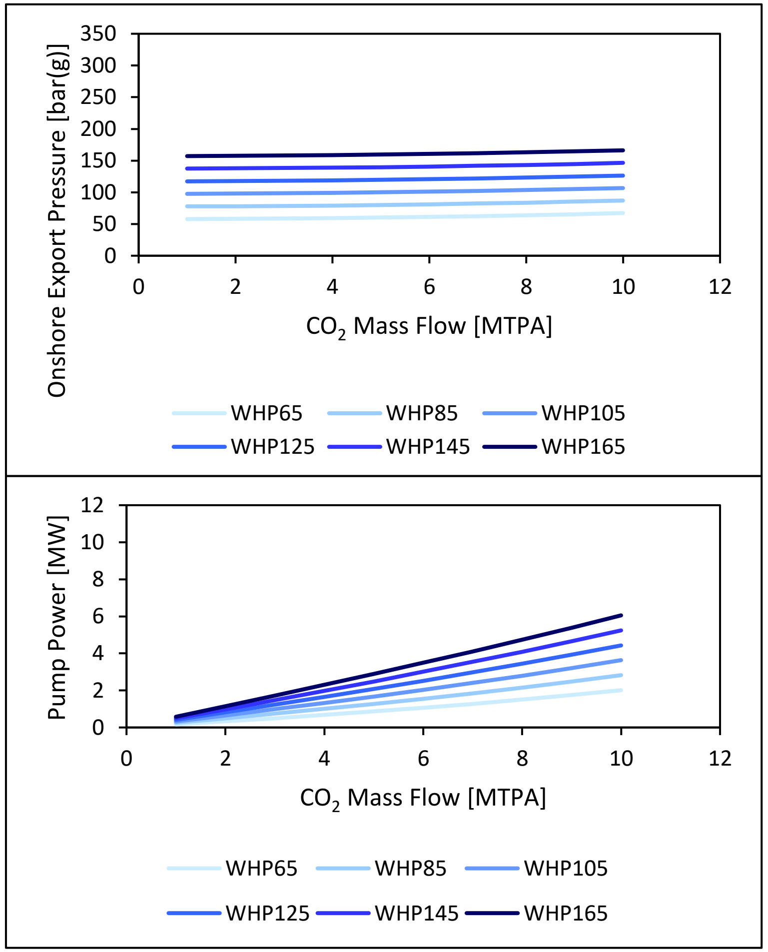
Pipeline from Hub to UW-Facility

Case Study: 130 km Pipeline, DN800



Pipeline from Hub to Platform (fixed)

Case Study: 300 km Pipeline, DN800



Equipment List

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ID	Rev.	DESCRIPTION				DESIGN DATA														DIMENSIONS AND WEIGHT			MATERIAL				NOTES
		GEOSTOR CCS Modules	Description	Amount	Fluid	Design Temperature		Operating Temp. [°C]			Design Press. [barg]		Operating Press. [barg]			Flow [m³/h]	Head @ max. flow [bar]	(Pump) Power [kW]	Electric Power [kW]	Volume [m³]	Diameter/ Width / Length [m]	Height [m]	Internals	Shell	Insulation		
						Min	Max	Min	Norm	Max	Min	Max	Min	Norm	Max										Type	Thickness [mm]	
1		Hub	Main Storage Tanks	3	LCO_2	-46	50	-	-30	-	0	22	13	15	18	-	-	-	-	25000	20,40	-		LTCS			Storage shall consist of 3 spheres tanks,eachwith approx 25000m³ of storage capacity. In total there is 75 000 m³ of storage capacity which should provide storage of 40 000 m³ carrier with parallel injection at max rate for 36 hours. Selected material is low temperature carbon steel. Tanks shall be insulated in order to minimize
2		Processing	Pressure compensation evaporator (electric)	TBD	LCO_2/ GCO_2	-46	50	-	-30	-		H		H		TBD	-	-	TBD	-	H	H					Evaporator shall generate sufficient ammount of GCO_2 to maintain the pressure in storage tanks within the plant, ship and truck trailers.
3		Processing	Booster Pumps	2	LCO_2	-46	50	-	-30	-		30		25		1060	TBD	TBD	-	-							Booster pumps should provide sufficent suction pressure for the export pumps and protect them from cavitation. N+1 arragement is envisaged.
4		Transportation	Export Pumps	TBD	LCO_2	-46	50	-	-30	-		H		H		1060	H	bis 11 MW	-	-							Pumps shall be in n+1 arragement. Pump output power and head is dependent of pipeline and well head pressure. As such pump power and pressure can be defined once above mentioned
5		Harbour/Jetty	Marine Loading Arms (LVL-configuration), Large Ships up to 23 000 m³	3	LCO_2/ GCO_2	-46	50	-	-30	-						LCO_2 1418 per loading arm					0,3238 / 80						Total capacity of loading arms is defined based on assumption that 40 000 m³ can be unloaded in approx. 12 hours. Two loading arms are needed with a loading of 2831 m3/h or 2890 t/h per 23000 m3 ship with 80 m L, 0,323 m OD, 0,304 m ID.
22		Harbour/Jetty	Marine Loading Arms, Medium Ships up to 7 700 m³	2	LCO_2/ GCO_2											LCO_2 1252 per loading arm					0,406 / 80						For a loading rate of 1280 t/h the loading arm(s) was calculated to be 80 m L, 0,406 m OD, 0,387 m ID. One arm is sufficient per ship.
																											Pipeline diameter and rating is still pending. See

The Equipment List (selected view) summarizes main Components of the overall facility as Basis for the Cost estimate

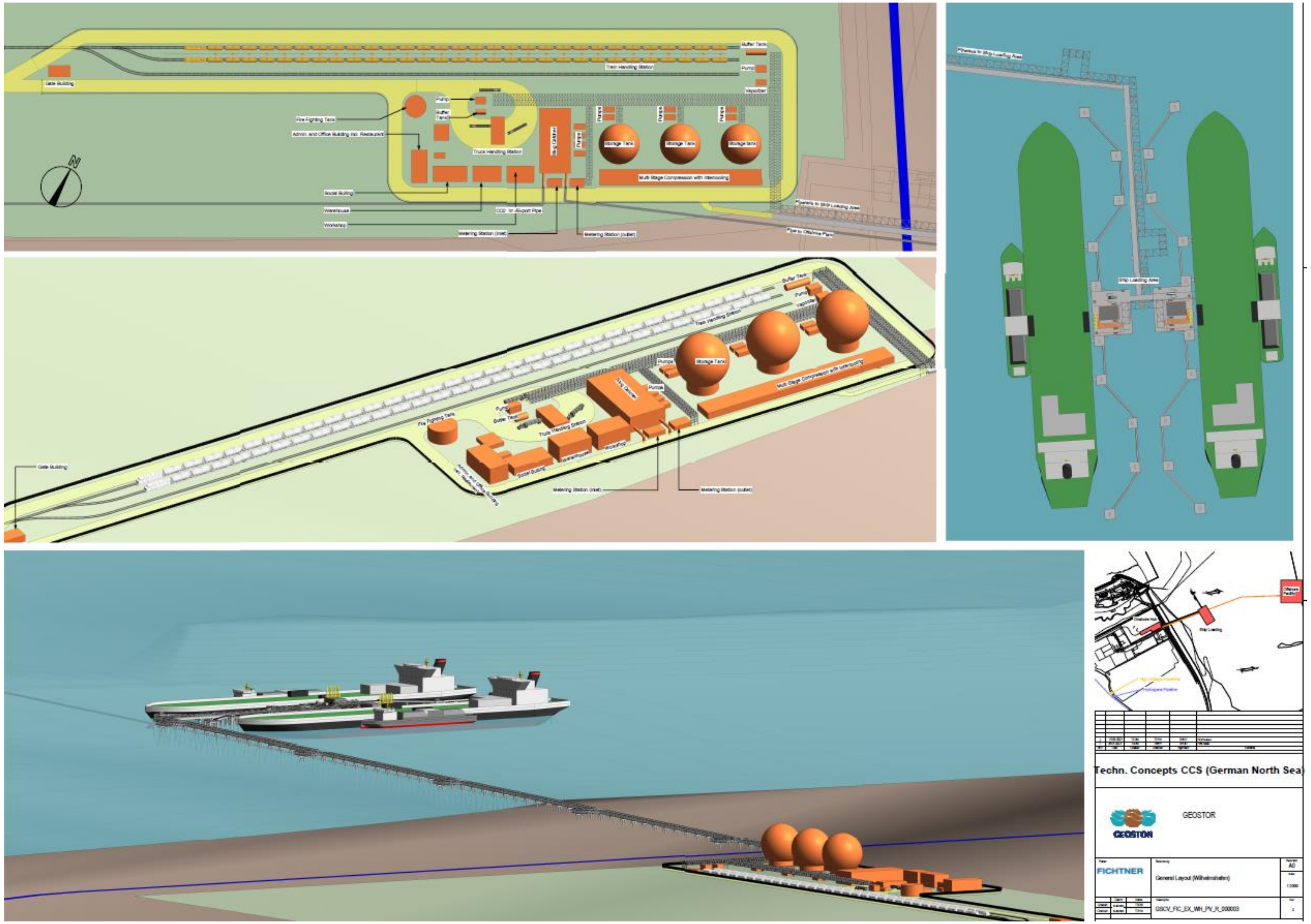
Layout planning (updated)

Main Building Blocks

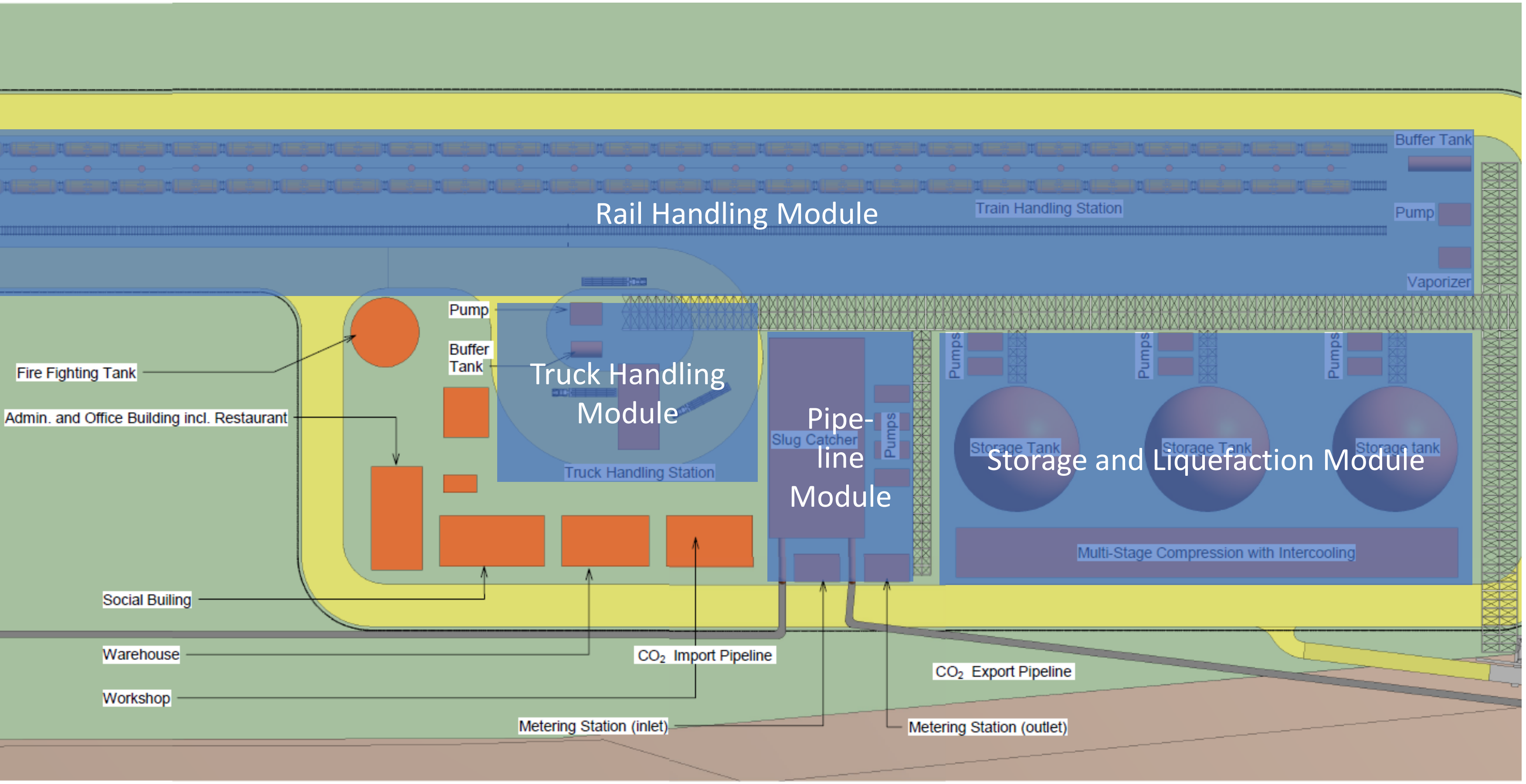
- A Jetty or Berth Quay
- Storage in (spherical) storage Tanks
- Process Plant incl.
  - Entrance with roads to the plant
  - Workshop, laboratory and admin. building
  - Gas conditioning trains
  - Compressor, chiller and pump trains
- Pipeline connecting Jetty and Tanks
- Truck loading/unloading Station
- Train loading/unloading Station
- Import Pipeline to the Hub
- Export Pipeline to the subsea storage Site

Aim is

- to evaluate the overall feasibility
- to define an effective footprint, small area is preferred
- to define the base for the cost estimation



Layout planning (modular approach)



CO_2 handling is organized in five Main Modules:

1. Rail Handling Module
2. Truck Handling Module
3. Pipeline Module
4. Storage and Liquefaction Module
5. Ship Handling Module (not shown here)

The Storage and Liquefaction Module is interfacing with all other Modules

- All produced Boil-Off Gas (due to heat ingress and pressure losses in pipes and vessels) is handled centralized at the Storage and Liquefaction Module
- Excess BOG is liquefied to minimize CO_2 losses

Risk Assessment (HAZID)

Risk Assessment/ Risikoanalyse GEOSTOR Section Nr./ Sektion Nr.	Keyword / Schlagwort	Applicable for/ Anwendbar auf	Cause / Comment Ursache / Kommentar	Consequence / Konsequenzen	Probability/ Wahrschein-lichkeit		Safety/ Sicherheit		Health/ Gesundheit		Environment / Umwelt		Reputation / Ansehen		Economy / Wirtschaftlichkeit		Risk/ Risiko	Existing safeguards/ existierende Sicherheitsregel	Mitigation measure / Minderungsmaßnahme	Action / Maßnahme
Section 1: Legislative and normative Risks / Gesetzgeberische und normative Risiken																				
Laws, Rules and Regulations / Gesetze, Vorschriften und Regelungen	TA Lärm	All	Zahlreiche regelmässige Transporte per Landfahrzeuge oder Schiff zu Tage und in der Nacht.	Lärmbelastungen hängen von Frequenz und Typ der Fahrzeuge ab. Möglicher Show-Stopper bei Überschreitung zulässiger Grenzwerte.	Unlikely	2	Minor	0	Serious	2	Serious	2	Serious	2	Serious	2	4		Nutzung von mögl. geräuscharmen Transportfahrzeugen. Auch ein Pipeline-Netzwerk ist vorgesehen.	Gutachten ist zu erstellen.
		Hub	Arbeit rotierender Maschinen (Kühler, Kompressoren, Pumpen).	Lärmbelastung übersteigt geltende Grenzwerte. Maschinen müssen ggf. eingehaust werden.		0		0		0		0		0		0	0			
	TA Luft	All	Zahlreiche regelmässige Transporte per Landfahrzeuge oder Schiff zu Tage und in der Nacht.	Luftschadstoffbelastung hängen von Frequenz und Typ der Fahrzeuge ab. Möglicher Show-Stopper bei Überschreitung zulässiger Grenzwerte.	Most likely	16	Minor	0	Serious	2	Serious	2	Serious	2	Catastrophic	16	256		Nutzung von mögl. Abgasarmen Transportfahrzeugen. Auch ein Pipeline-Netzwerk ist vorgesehen.	Gutachten ist zu erstellen.
		Hub	Arbeit rotierender Maschinen (Kühler, Kompressoren, Pumpen).	Luftschadstoffbelastung übersteigt geltende Grenzwerte. Maschinen müssen ggf. abgasnachbehandelt werden.		0		0		0		0		0		0	0			
	Einhaltung des Standards und Normen, (TRGS, TRBS, TRAS, TRWS,...)	All	Arbeit mit Gefahrenstoffen (CO2)			0		0		0		0		0		0	0			
	BImSchG	All	Lagerung / Hantierung von Gefahrstoffen in Größenordnung unterliegt dem BImSchG	Erstellung zahlreicher Dokumentationen zu Sicherheit, Brandschutz, Ex-Schutz werden benötigt und liegen nicht geeignet vor. Behörden werden nicht früh genug kontaktiert. Gutachten liegen nicht geeignet vor. Projektzeitplan kann gefärdet werden.	Probable	8	Minor	0	Minor	0	Minor	0	Very serious	4	Very serious	4	32		Ein erfahrener Planer sollte dringend beauftragt werden. Kenntnis der Materie, der zuständigen Behörden und ein Netzwerk von benötigten Gutachtern sind vorteilhaft.	Frühzeitge Ausschreibung und Beauftragung des Planungsbüros. Frühzeitige Identifikation und Information der zuständigen Behörden (Scoping Termin)
	BetrSichV	Staff	Der verantwortliche Umgang bei Transport und Hantierung ist sicherzustellen	Bei Missachtung wird keine Betriebsgenehmigung erteilt		0		0		0		0		0		0	0			
	Bauordnung	Hub	Einhaltung benötigter Gebäudeabstandsflächen,	Verfügbare Baufläche nicht ausreichend		0		0		0		0		0		0	0			
	Brandschutz	All	Arbeiten mit brennbaren und explosiven Stoffen			0		0		0		0		0		0	0			
	AwSV	All	Bestandteil des BImSchG-Verfahrens. Leckage von grundwassergefährdenden Stoffen.	Verunreinigung des Bodens und des Grundwassers		0		0		0		0		0		0	0		Einplanung von Auffangwannen unter mögl. Leckageorten (Flanschen, Leitungskupplungen, Schmiermittelbereichen)	

Risk Register (selected view of initial assessment)

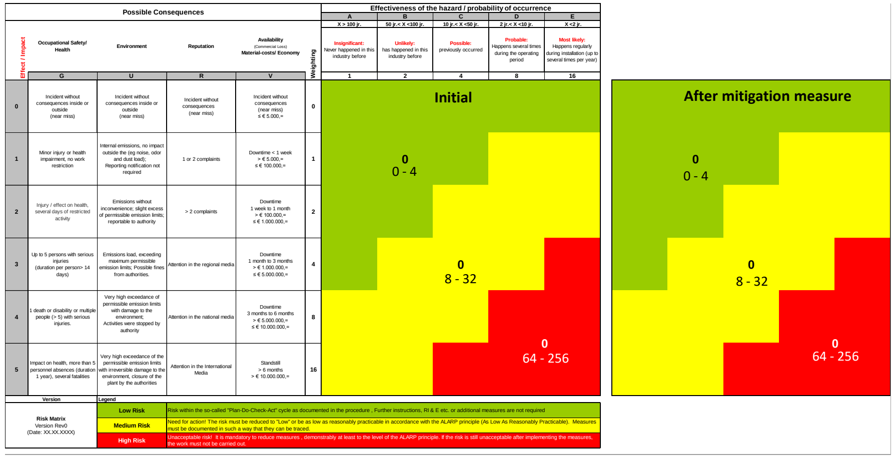
Risk Categories

The Risk Register lists identified Causes and Effects as Basis for a HAZID. The initial status is answered by a mitigation round.

The Risks result from multiplying

Risk = Probability of occurance x Severity (here: for 5 fields)

In a later stage an HAZOP also allows consideration of operational Risks



Resulting Risk Matrix (initial and after mitigation measures, example)

Next Steps

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Technology

- Communication with AP 2 for required Flow Regimes to reach injection goals – yet to come
- Fine tuning of HYSYS Simulations to get the correct inputs for the Heat and Material Balances - ongoing
- Fine tuning of Block Flow Diagrams (BFD, for considered Options) - OK
- Preparation of simplified Process Flow Diagrams (PFD) - OK
- Finalization of Equipment Lists - ongoing
- Preparation of Electrical Load Lists - ongoing

Costs

- Started, based on equipment list
- Development of a cost model
- Implementation of selected technology into the cost model
- Goal: Cost per stored ton of CO_2 for each considered Scenario

Many thanks for your attention!

Contact: Sven.Hoog@fichtner.de; Achim.Stuible@fichtner.de

https://geostor.cdrmare.de