Toward the identification of optimal conditions for transport of CO_2 by ship

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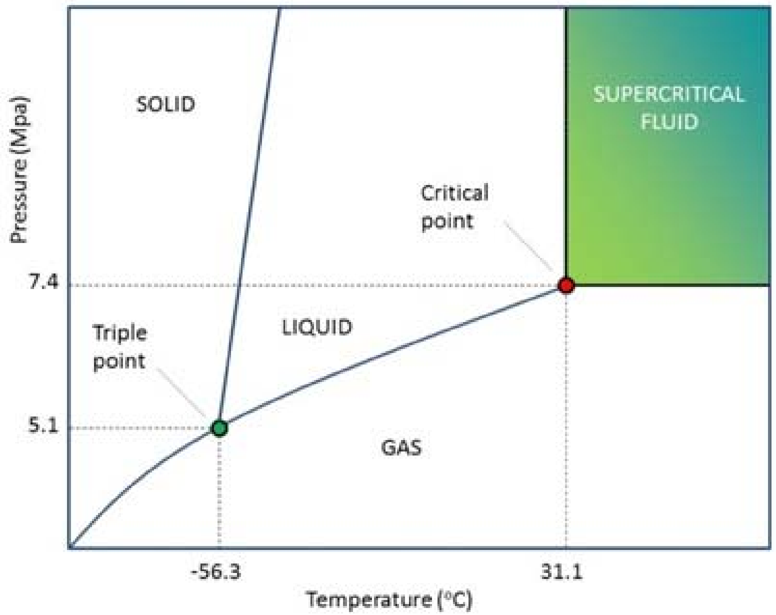
Background

- CO_2 Shipping can be expected to play an important role in early CCS development, for "small" capacities, and/ or long distance transport

- Over the last few years, questions on optimal transport conditions (T and P) have been raised



Background

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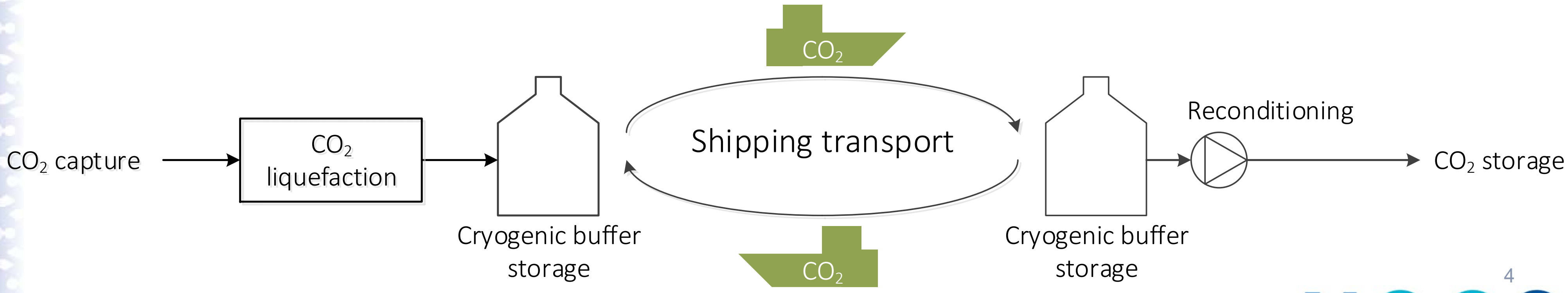
- Over the last few years, questions on optimal transport conditions (T and P) have been raised
  - Most of the recent literature (past 5-10 years) has focused on transport of CO_2 at 6.5 bar and -50ºC
  - Meanwhile transport of food grade CO_2 currently take place at 15 bar

  - Preparatory work for the Norwegian full-scale
    - Initial work pointed at the 15 bar option as the best solution from the cost, safety and maturity perspective
    - Recently, it was indicated that 15 bar is the best option for the full-scale based on maturity and safety but that in the future lower pressure based transport could be a better solution
    - No openly public study has satisfactorily concluded on optimal transport conditions

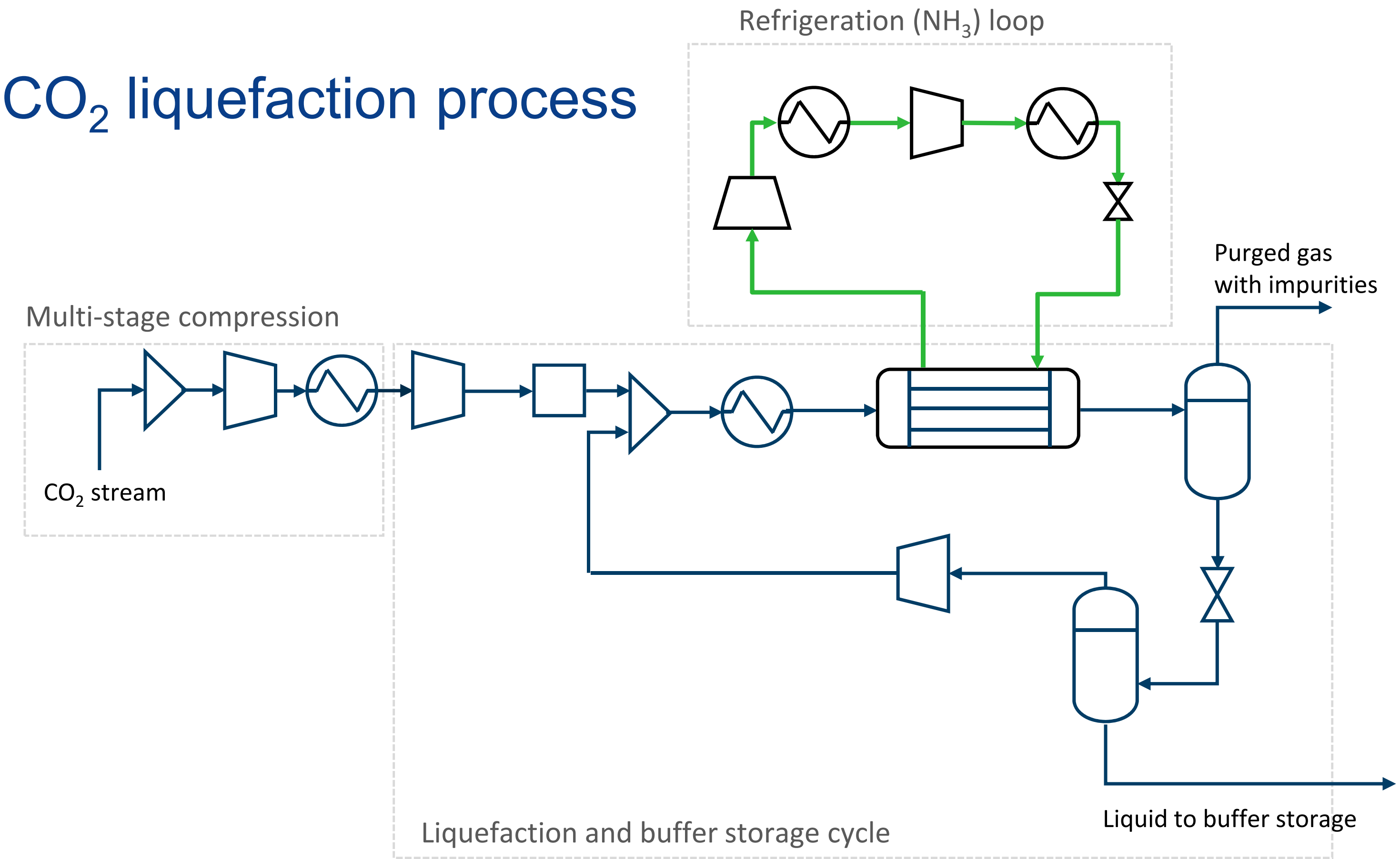
Background

- Objective: Identification of optimal conditions (P,T) for transport of CO_2 by ship taking into account:
  - Impact of potential impurities in the CO_2 stream after capture
  - Transport distance and volume
  - Purity requirements from the storage site



Impact of transport pressure and impurities on the CO_2 liquefaction process

- CO_2 liquefaction process



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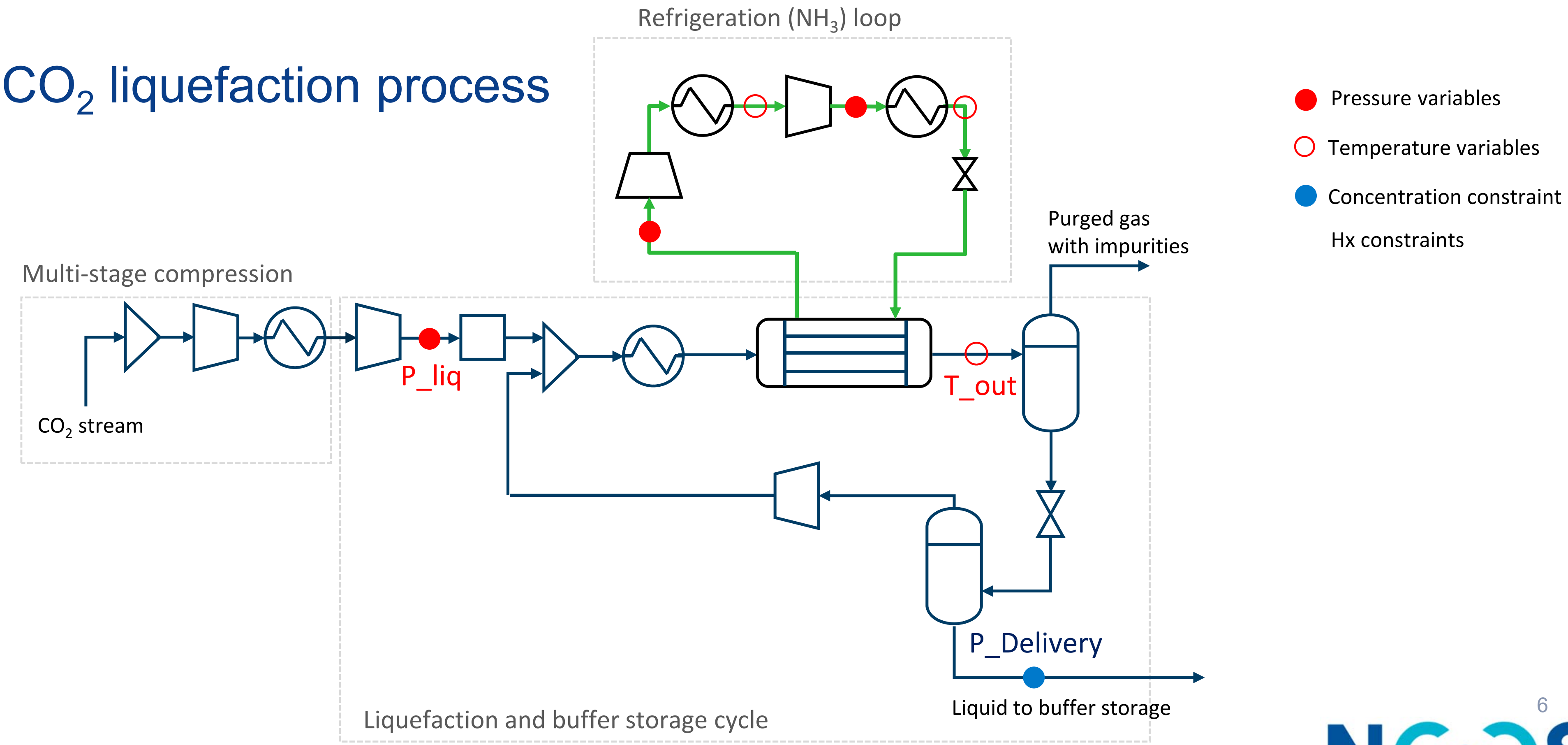
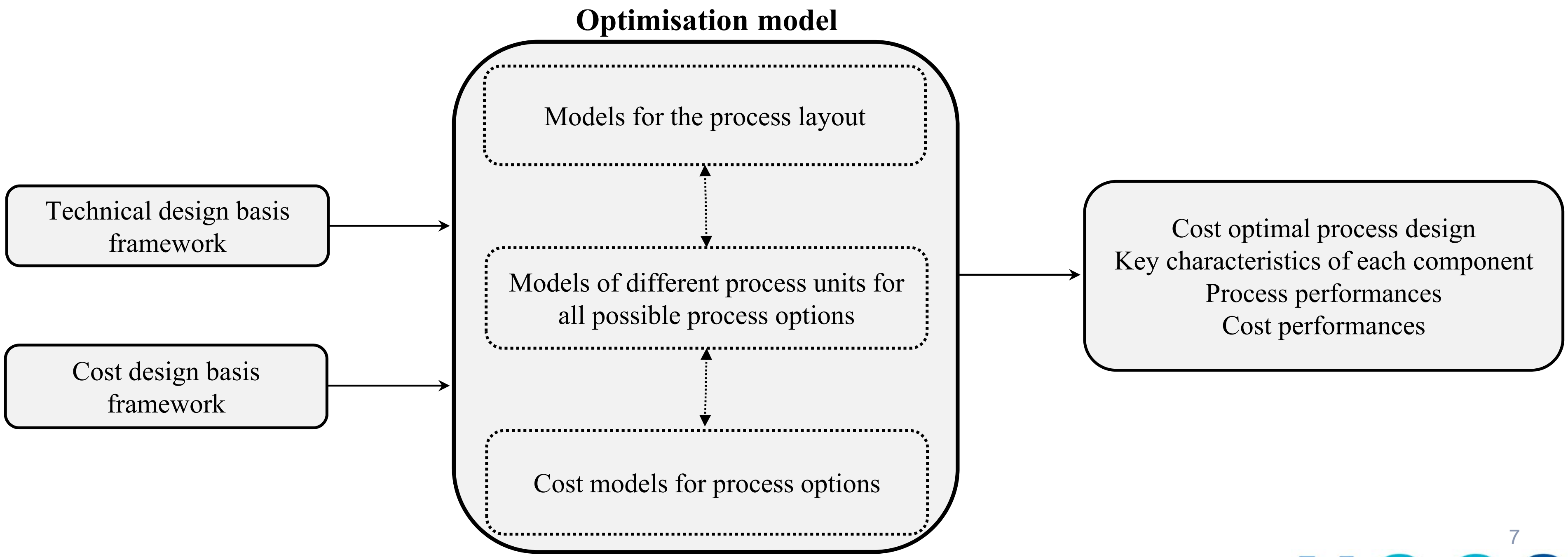


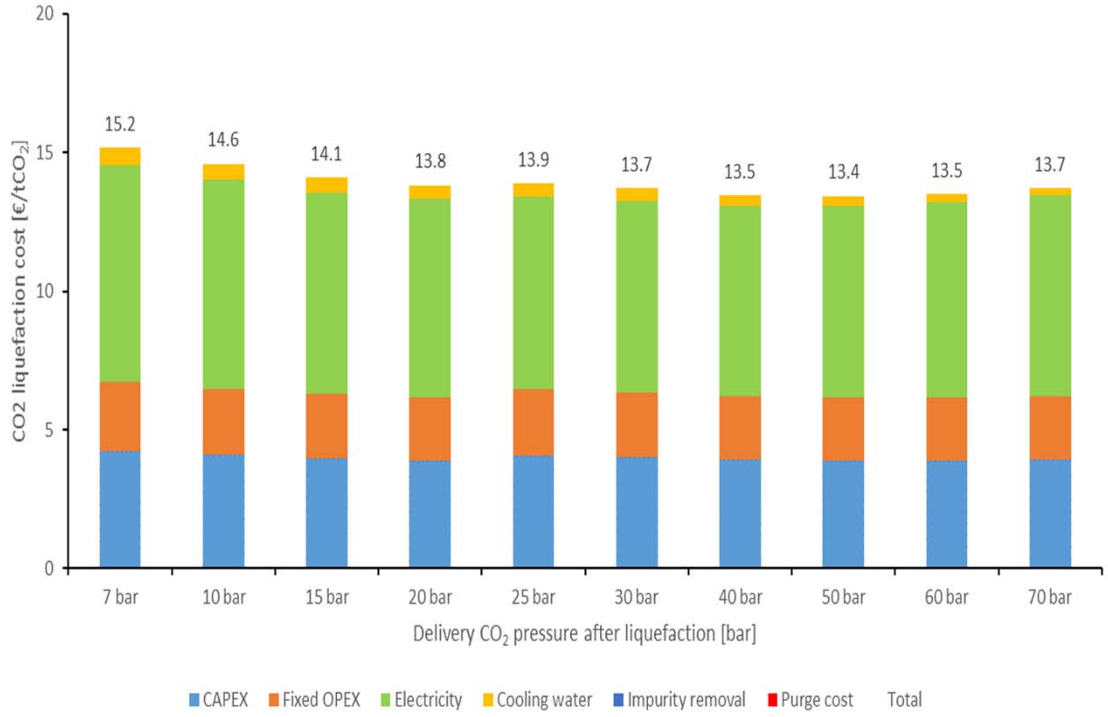
Impact of transport pressure and impurities on the CO_2 liquefaction process

- Optimisation model



Impact of transport pressure and impurities on the CO_2 liquefaction process

- CO_2 liquefaction cost for pure CO_2
  - Trends
    - Highest liquefaction cost at 7 bar
    - Between 7 and 20 bar, cost decrease by 9%
    - Lowest liquefaction cost at 40-50 bar (-13% compared to 7 bar)
    - Small increase beyond 50 bar
- Comparison of 7 v.s. 15 bar
  - 15 bar is 7% cheaper (1.05 €/tCO_2)
- Cost of buffer tanks and ship is not included and will impact the comparison



Impact of transport pressure and impurities on the CO_2 liquefaction process

- 3 impurity scenarios
  - No purity requirement on CO_2 delivered after liquefaction

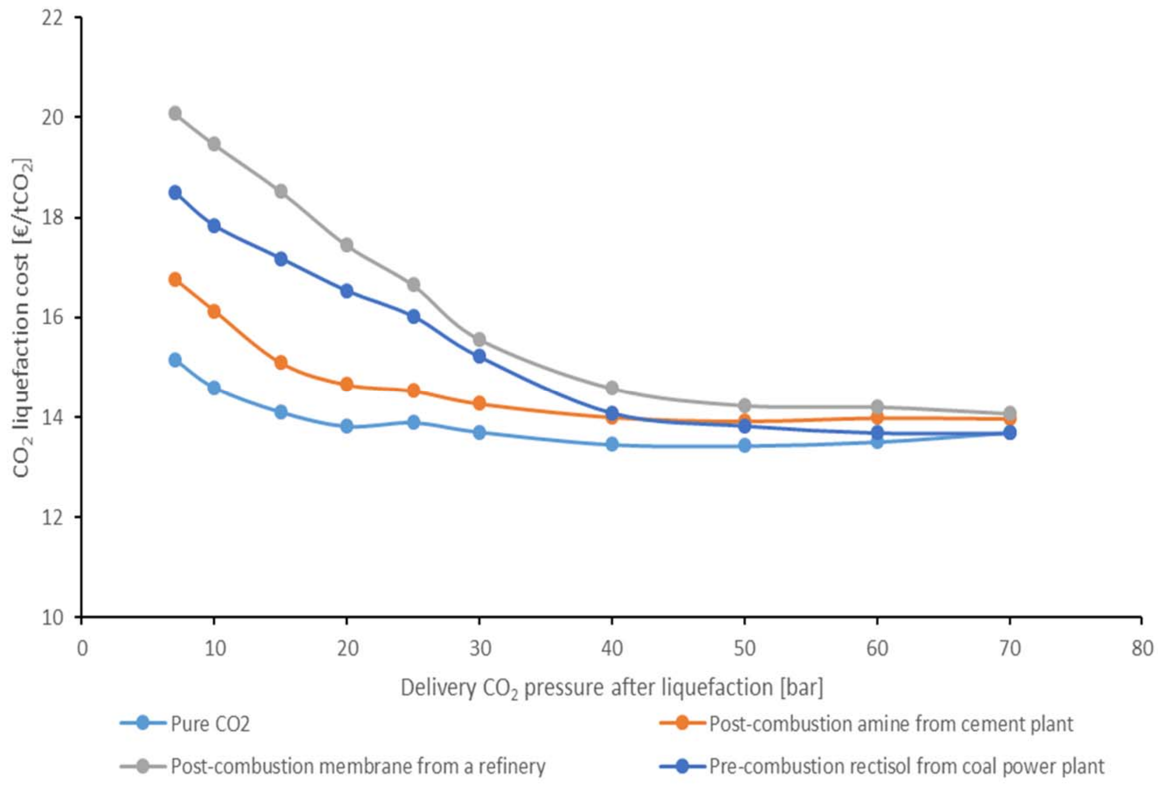
Capture route	Post-combustion	Post-combustion	Pre-combustion
Capture technology	Amine	Membrane	Rectisol
CO_2 source	Cement plant	Refinery	IGCC
CO_2 [%]	96.86	97.0	98.42%
H_2O [%]	3.00	1.0	
N_2 [%]	0.11	2.0	0.44%
O_2 [%]	0.03		
Ar [%]	0.0003		0.09%
MeOH [%]			0.57%
H_2 [%]			0.45%
CO [%]			0.03%
H_2S [%]			0.0005%
Total [%]	**100**	**100**	**100**

Similar level of impurities

Similar level of non-water impurities

Impact of transport pressure and impurities on the CO_2 liquefaction process

- Impact of impurities
  - Impurity can have a significant impact (up to +34%)
  - Impact is the strongest for pressures below 30 bar
  - Both the type and level of impurity matters
  - Impact on the comparison between the 15 and 7 bar
    - Amine (-1.7), membrane (-1.6) and Rectisol (-1.3 €/tCO_2)

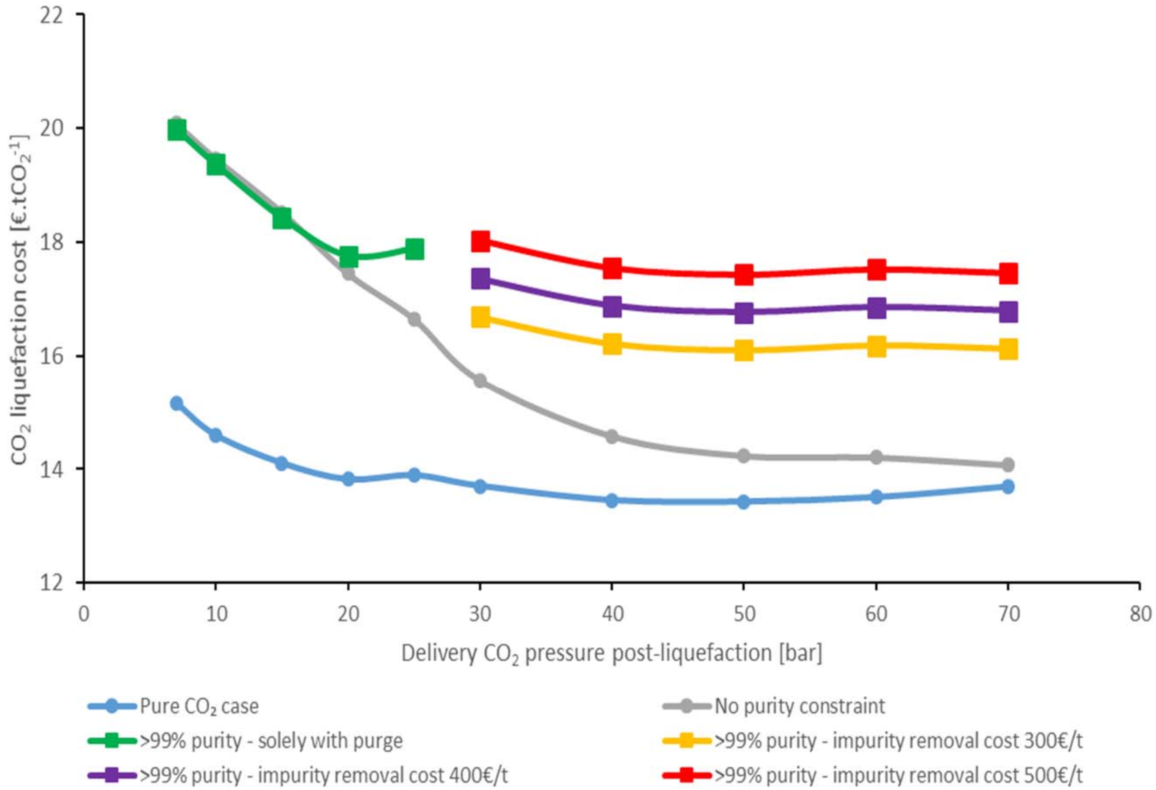


Impact of transport pressure and impurities on the CO_2 liquefaction process

- Purity constraint: 99% (high purity CO_2)
  - 95% CO_2 recovery
  - Post-combustion membrane-based capture from a refinery

  - Impurity removal strategy
    - No purge below 15 bar
    - Purge at 20-25 bar
    - Impurity removal unit above 30 bar

  - Purity constraint significantly reduce the benefit of high pressure delivery



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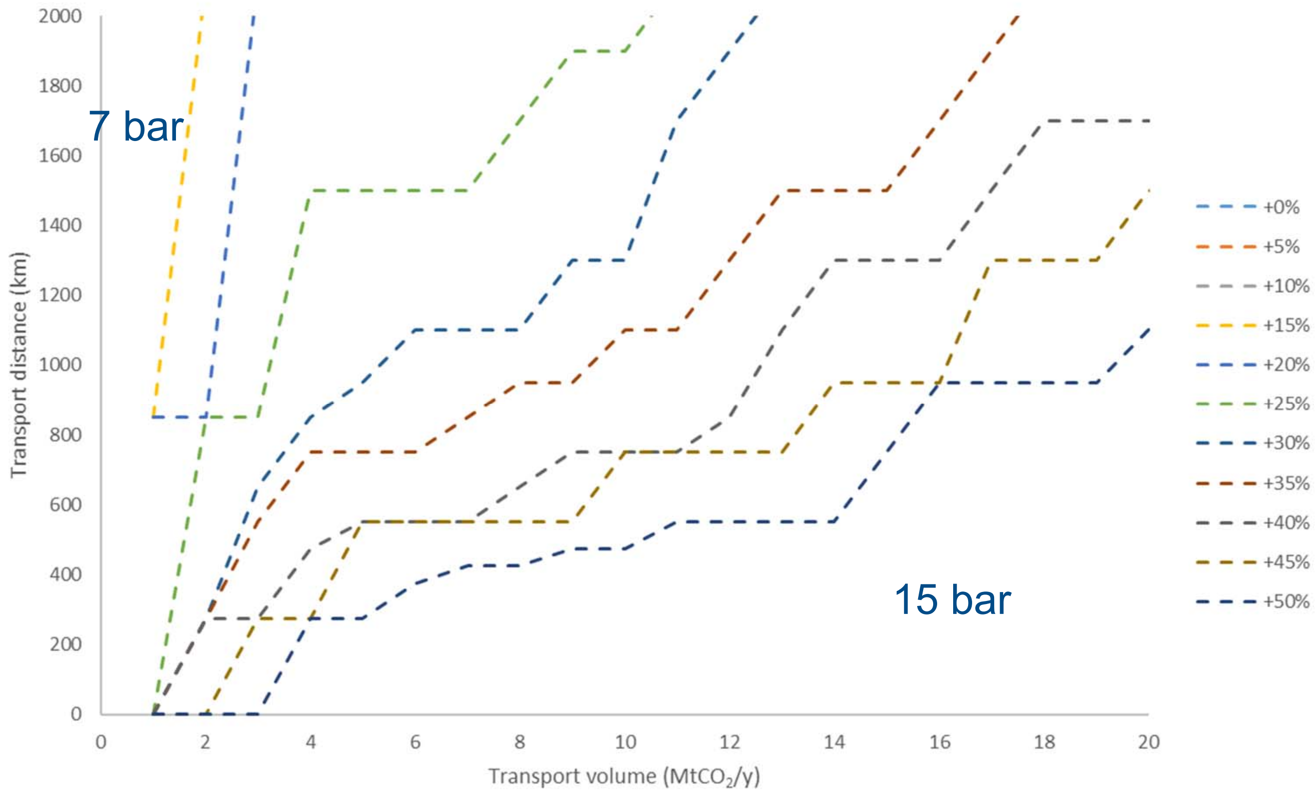
- Integration of the liquefaction results with the shipping supply chain
  - A key element to reach reliable results lies on reliable ship and buffer costs in function of the transport pressure

  - Thus, the first step is to understand the impact of these on the comparison
    - Test case comparing 7bar and 15 bar
      - Varying ratio between buffer storage and ship CAPEX between the 15 and the 7 bar options from on par to +50%

Toward the identification of optimal conditions for transport of CO_2 by ship



Conclusions and future work

- High delivery CO_2 pressure tends to results in lower CO_2 liquefaction costs
  - Strong decrease in cost for pressure from 7 to 30 bar
  - However, overall, the buffer tanks and ship export will become more costly as the transport pressure increase

- The results show that potential impurities can have a significant impact on the cost difference between pressure cases
  - These could have a significant impact the selection of the optimal transport conditions

- At the whole chain level, results show that establishing reliable buffer storage and ship cost estimates depending on the transport pressure is a key to identify the optimal transport conditions

Conclusions and future work

- Future work
  - Establishment of good cost estimates for ship and buffer storage depending on the transport pressure
  - Integrate the liquefaction result with an overall transport evaluations
  - Provide recommendations on optimal transport conditions (T and P) taking into account:
    - Impurity scenarios and purity requirements
    - Transport distance and volume

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