# Post-Combustion Carbon Capture for EU Refineries: Optimal Integration Strategies and Techno-Economics

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Concawe

TNO innovation for life

# TNO OVERVIEW & STRUCTURE

- Mission to create ***impactful innovations*** for the **sustainable wellbeing *and prosperity*** of society.
- Founded by law in 1932
- Not for profit

**TNO NUMBER OF EMPLOYEES**

**4408**

**TNO TURNOVER**
(MLN EURO)

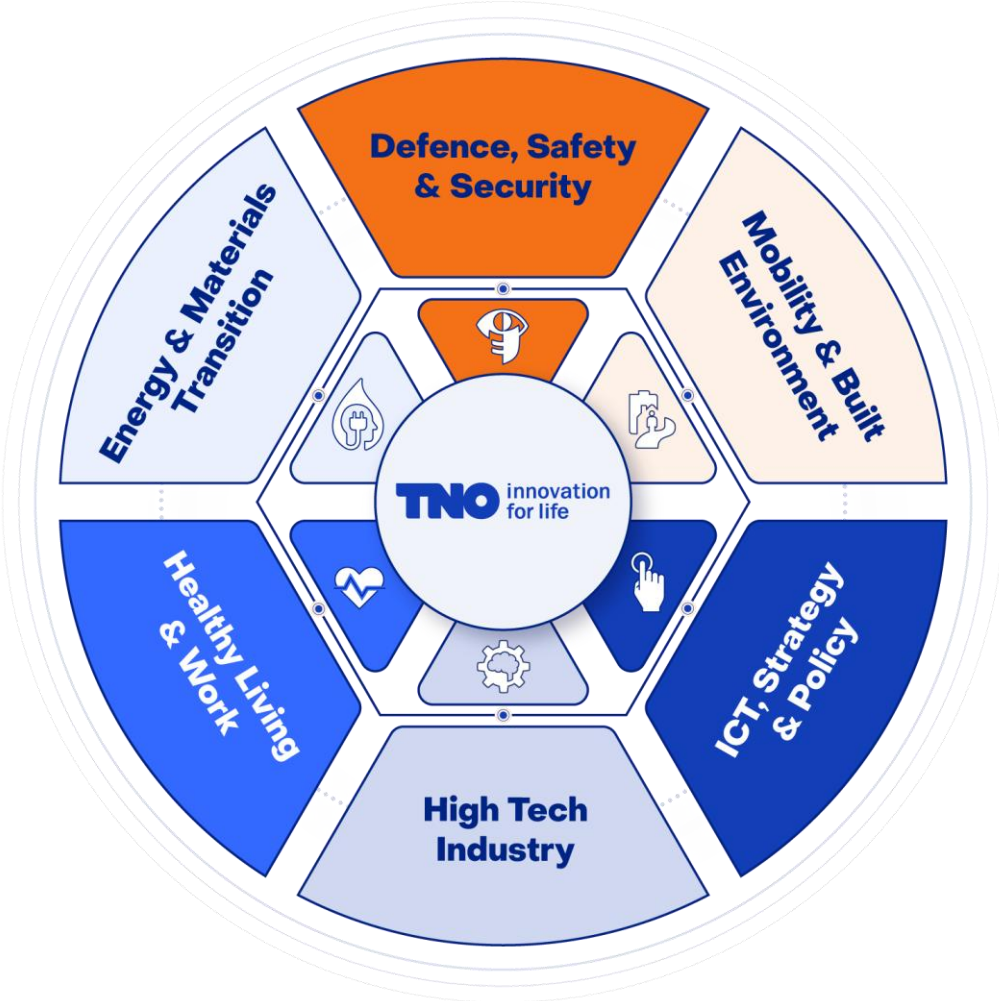
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**CLIENT SATISFACTION**

**4.4 / 5.0**

**PUBLIC-PRIVATE PARTNERSHIPS**

**1,343**



# TNO – Energy & Materials Transition Division

**Feedstock Conversion**



Circular plastics
Sustainable fuels & platform chemicals
Industrial carbon capture

**Power to Industry**



Sustainable industrial heat
Green Hydrogen and Power-2-X (hydrogen, electro- & photochemistry)
Process efficiency & Process flexibility

**Sustainable Materials**



Circularity by design
Energy saving materials
Alternatives for toxic and critical materials

**Molecular Infrastructure**



Safety & integrity of transport infrastructure
New molecular infrastructure
System flexibility

Industrial system analysis
Tecnology evaluation
Tech transfer

# Introduction

Link to part 1 report

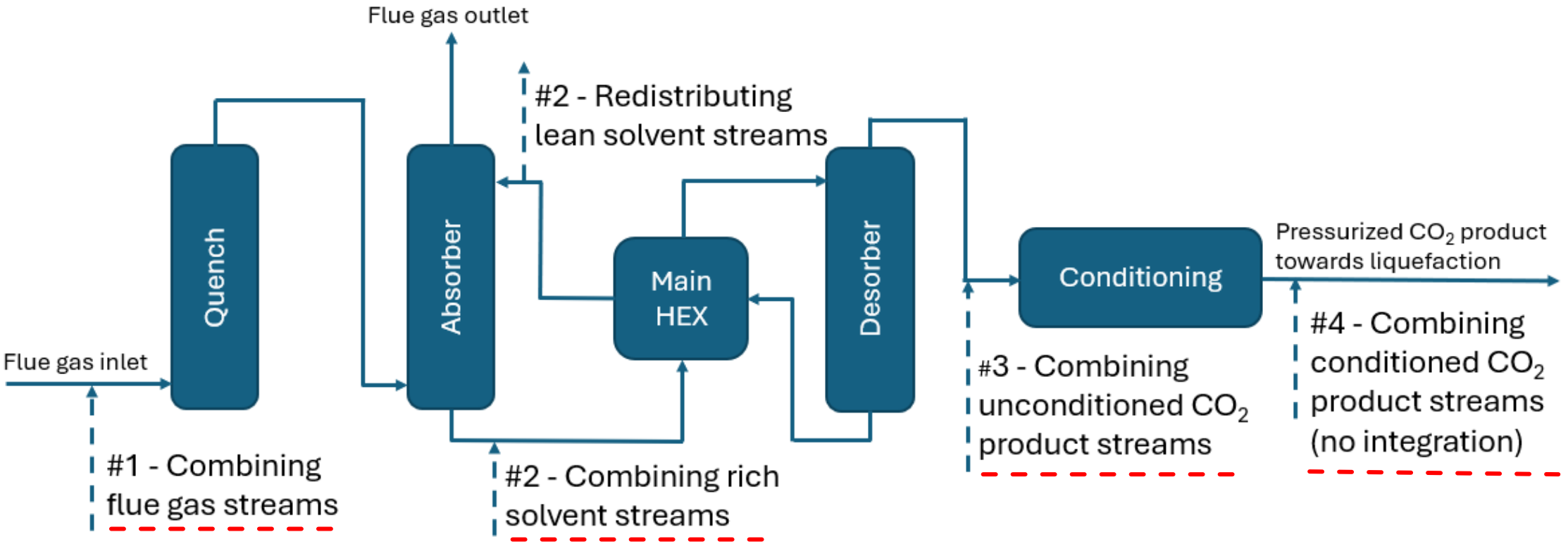
- Concawe has commissioned TNO to conduct a study towards implementation of carbon capture in refineries
- **Part 1:** Review of carbon capture technologies and their commercial implementation (public report available)

Focus of this presentation:

- **Part 2:** Post-Combustion Carbon Capture for EU Refineries: Optimal Integration Strategies and Techno-Economics (public report available in October 2026)
- **Part 3:** Direct Air Capture (DAC) for refineries

  (public report available in October 2026)

# Carbon capture integration options

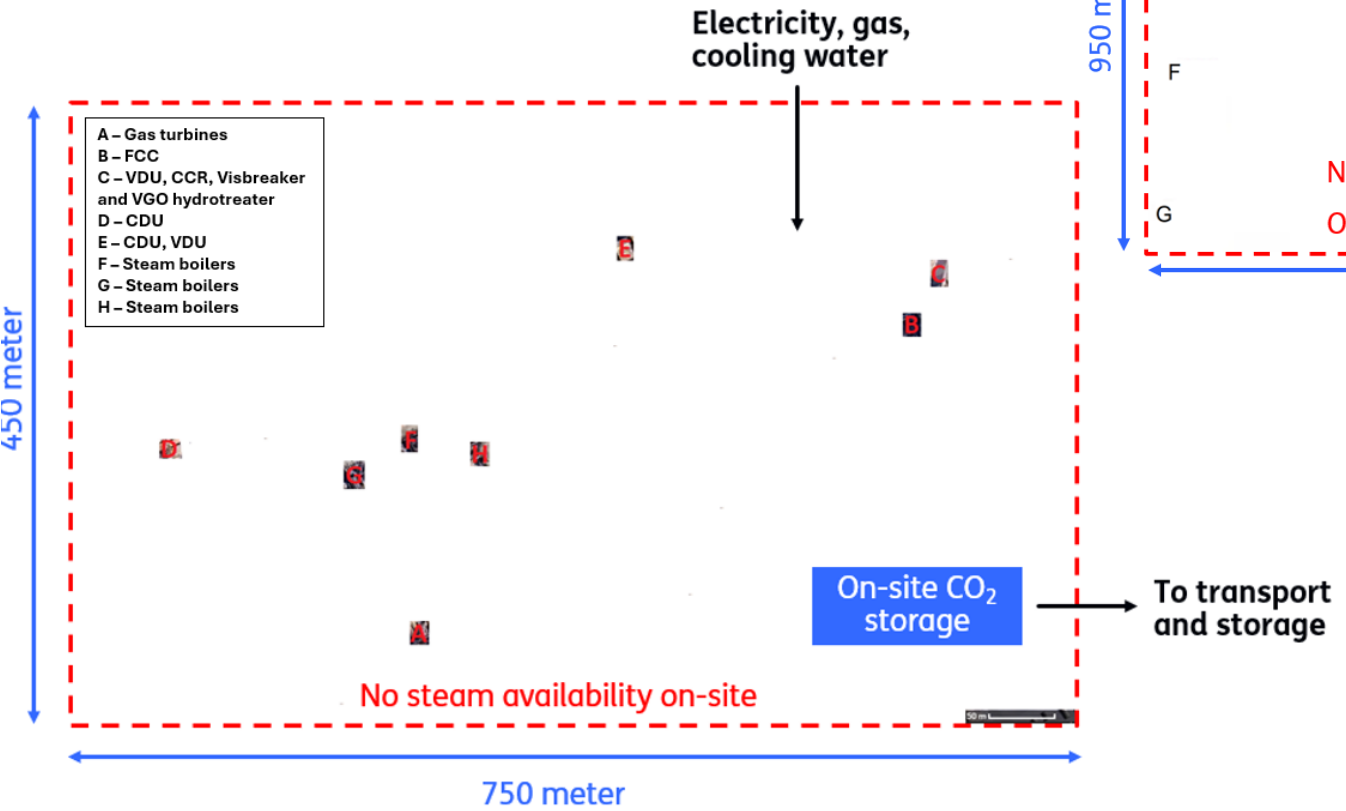




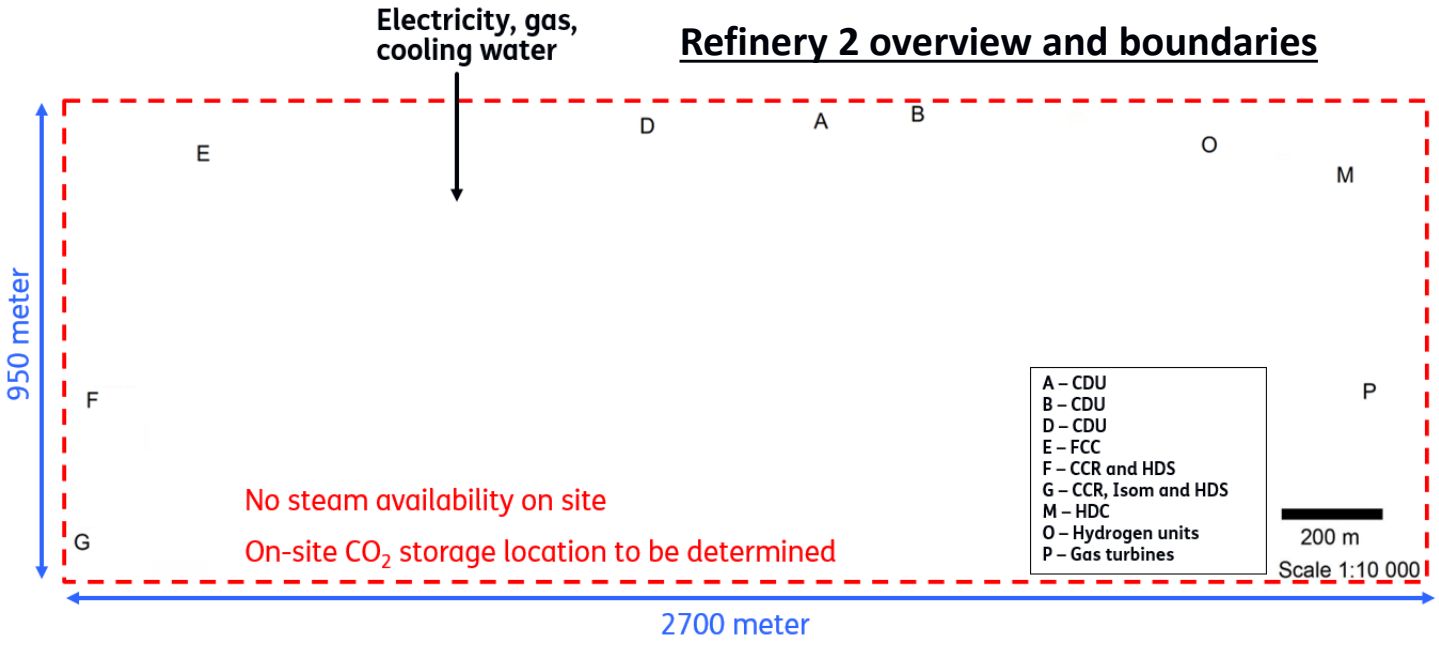

How can a carbon capture process be optimally integrated in a refinery considering all emission points of the site?

# Refinery introduction and boundaries

## Refinery 1 overview and boundaries




## Refinery 2 overview and boundaries




Real EU refineries are used, but their data is anonymized and normalized for EU average refineries:

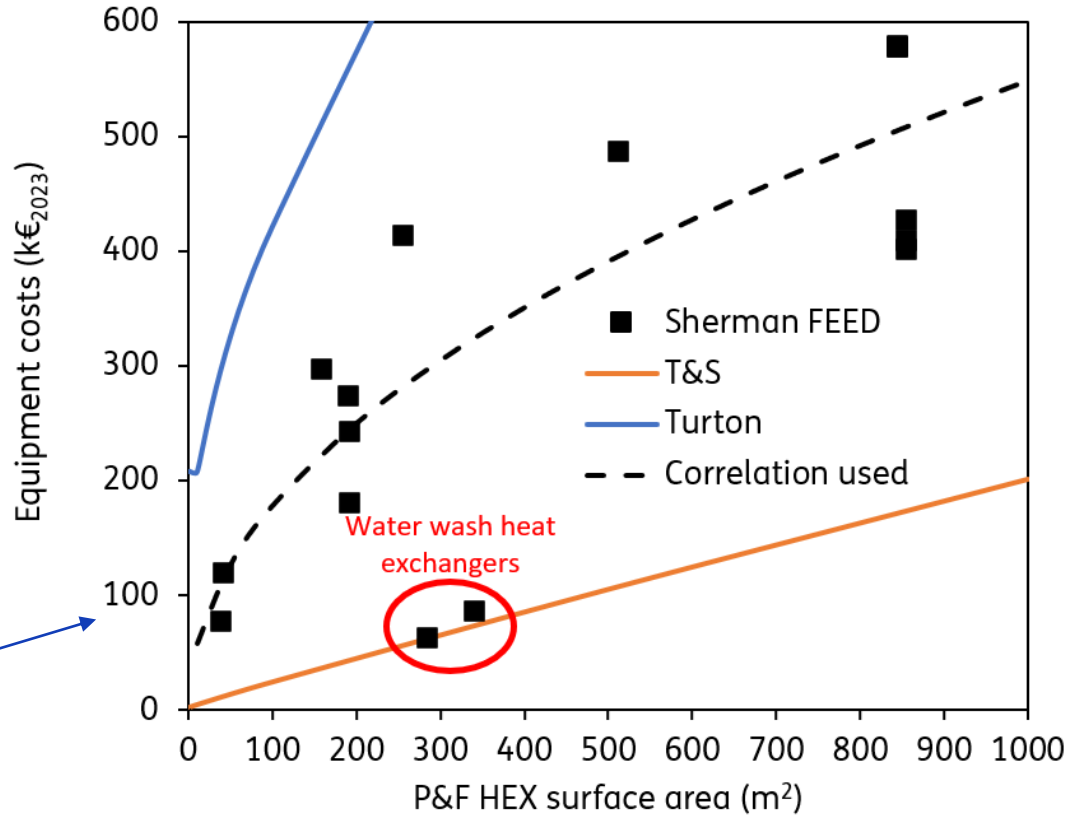
- Refinery 1: Medium conversion refinery
- Refinery 2: Complex refinery

# Information basis for case study

A fully transparent case study is targeted, where all assumptions taken and data used can be tracked:

- **Process simulations** → Gives mass and energy balances
- **Variable OPEX** → Cost of utilities assumed or taken from databases (e.g. Eurostat)
- **Fixed OPEX** → standard literature values (mostly function of CAPEX)
- **CAPEX** → Cost correlations are generated per equipment type based on open literature (books, public FEED studies)

**Example:** Heat exchanger CAPEX



# Screening tool (two-stack model)

A screening tool is developed to evaluate many scenarios for integration of two stacks without the need for detailed process simulations

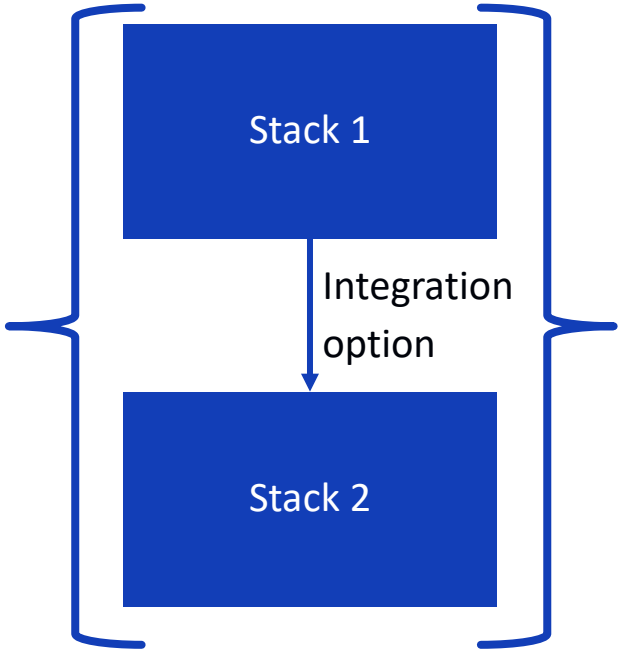
**Input (for both stacks)**

Flue gas flow rate

$CO_2$ concentration

Distance between stacks

Integration type




**Output**

OPEX

CAPEX

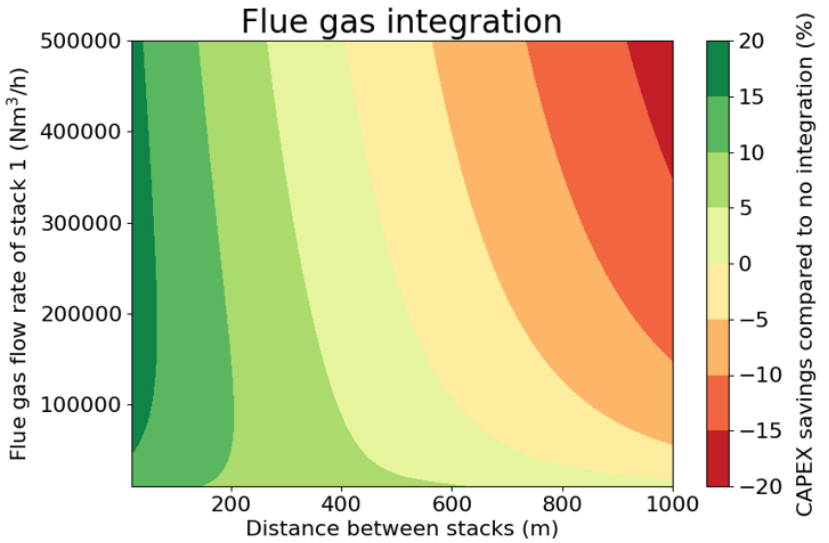
Total cost of capture

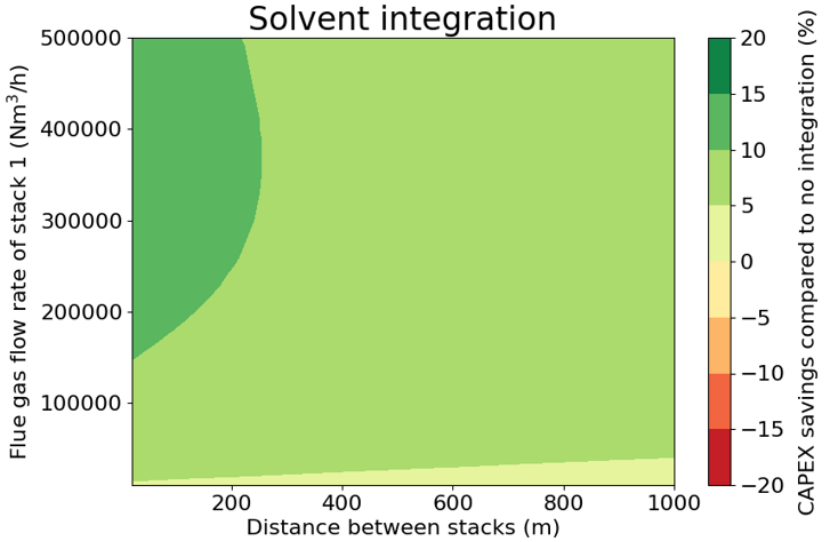
# Results of screening tool

## Main lessons

- Variable OPEX is hardly affected by the different integration options
- Either flue gas or solvent integration is always found as optimal integration option
- CAPEX savings for integration can be up to 20% (flue gas integration at short distances)
- Flue gas integration is preferred at short distances, solvent integration is preferred at longer distances
- The $CO_2$ concentration of a flue gas has a limited effect on the CAPEX savings from integration

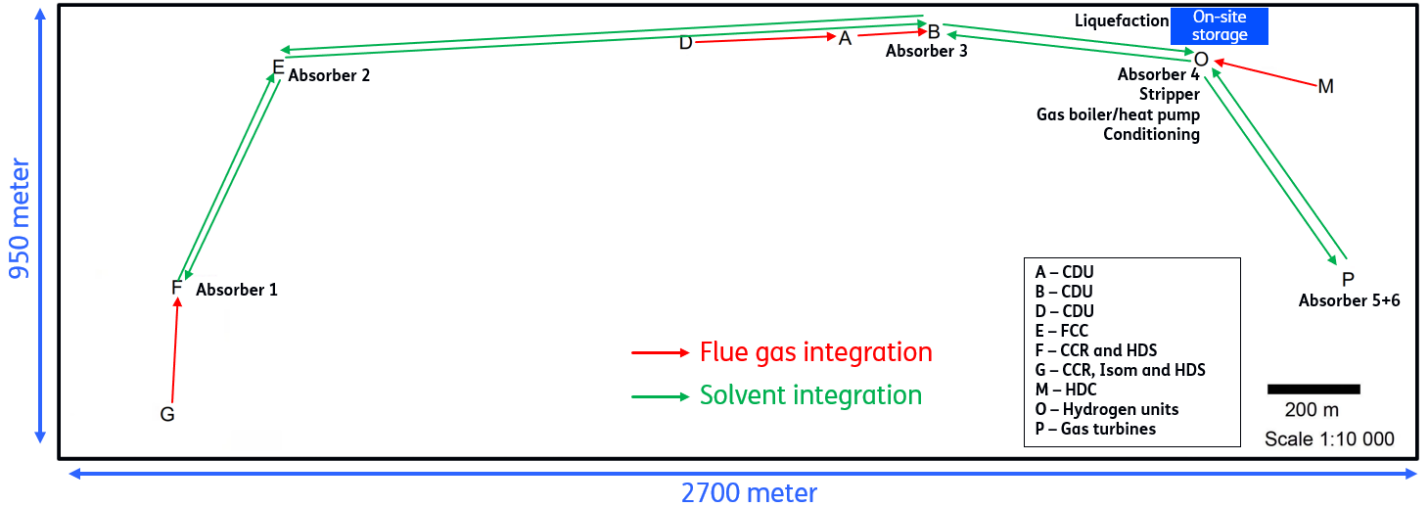
Example results



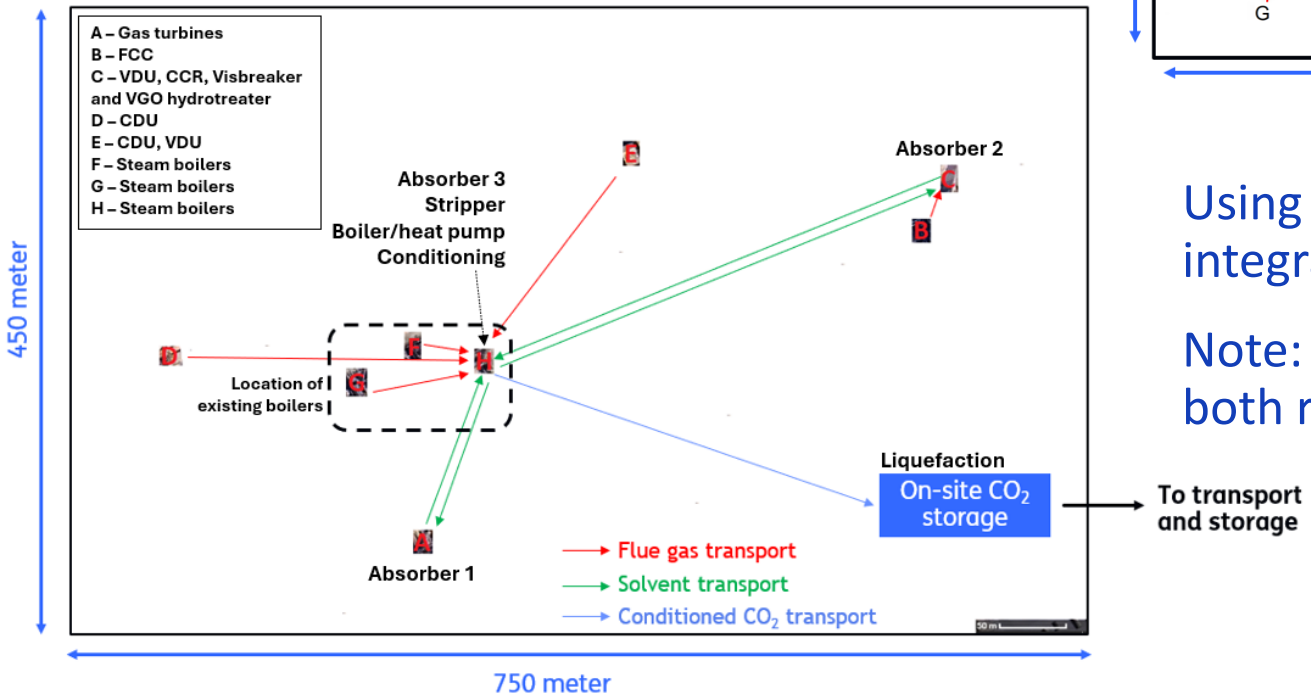



# Optimal integration route for refineries

## Refinery 2




## Refinery 1




To transport and storage

Using the lessons from the screening tool, the optimal integration pathway per refinery is determined

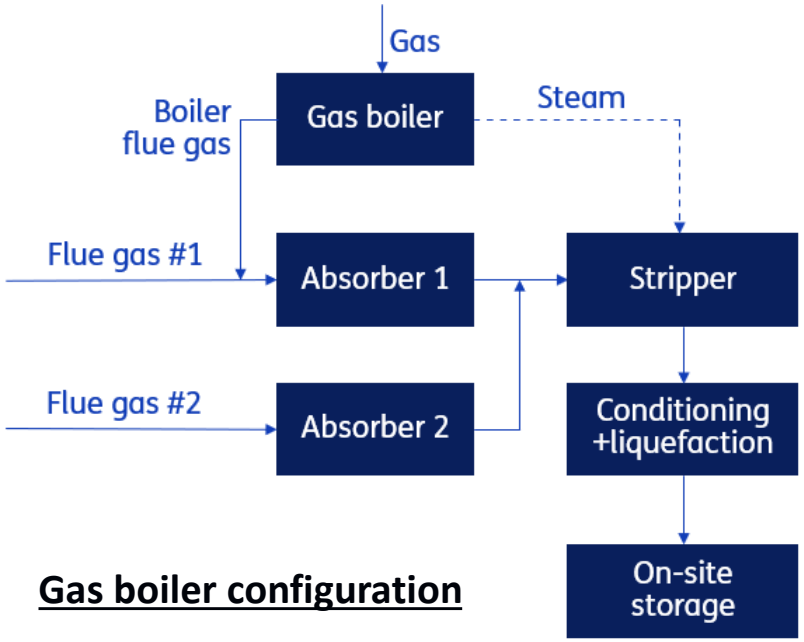
Note: A single desorber column is technically feasible for both refineries (<10 meter diameter)

# Simulation framework

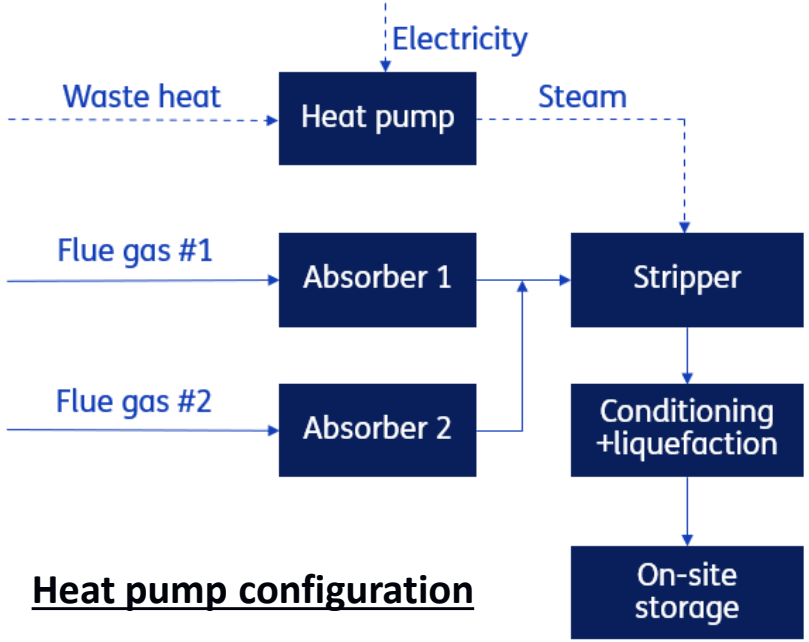
No excess heat is available on site: Gas boilers and heat pumps are considered to deliver the required heat to the capture system

Detailed process simulations (ProTreat®) are performed for the determined optimal integration pathway per refinery → 95% overall capture rate is targeted

The capture process conditions are optimized for the heat pump case → Regeneration at 90 ºC is considered (at 0.63 bara), instead of the conventional temperature (ca. 120 ºC, 1.9 bara)



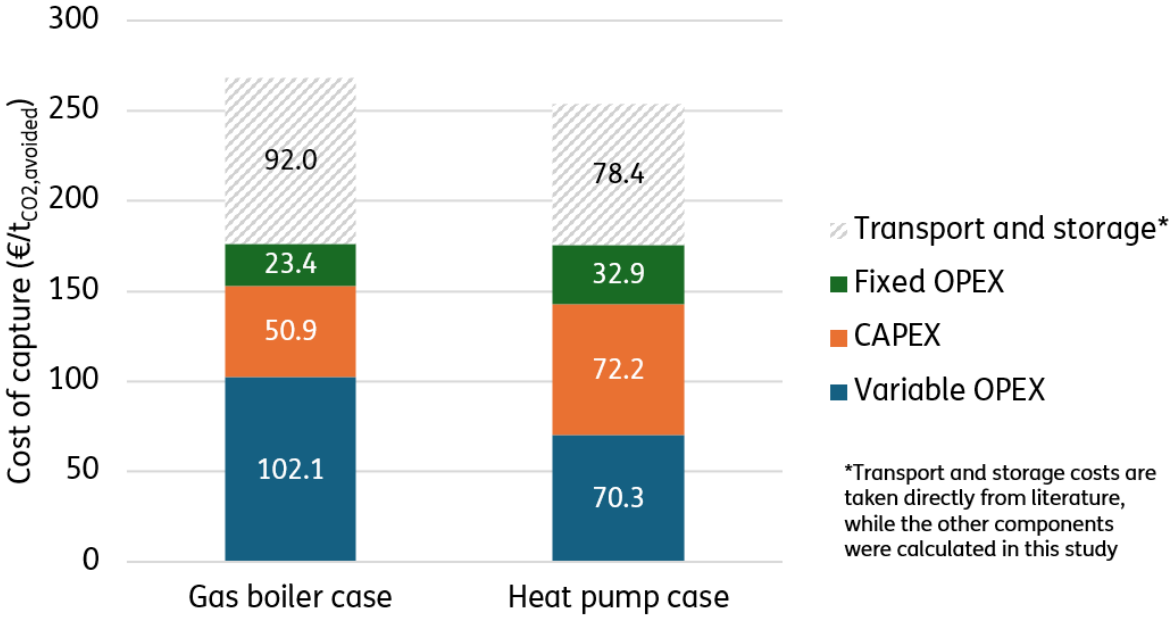

**Gas boiler configuration**

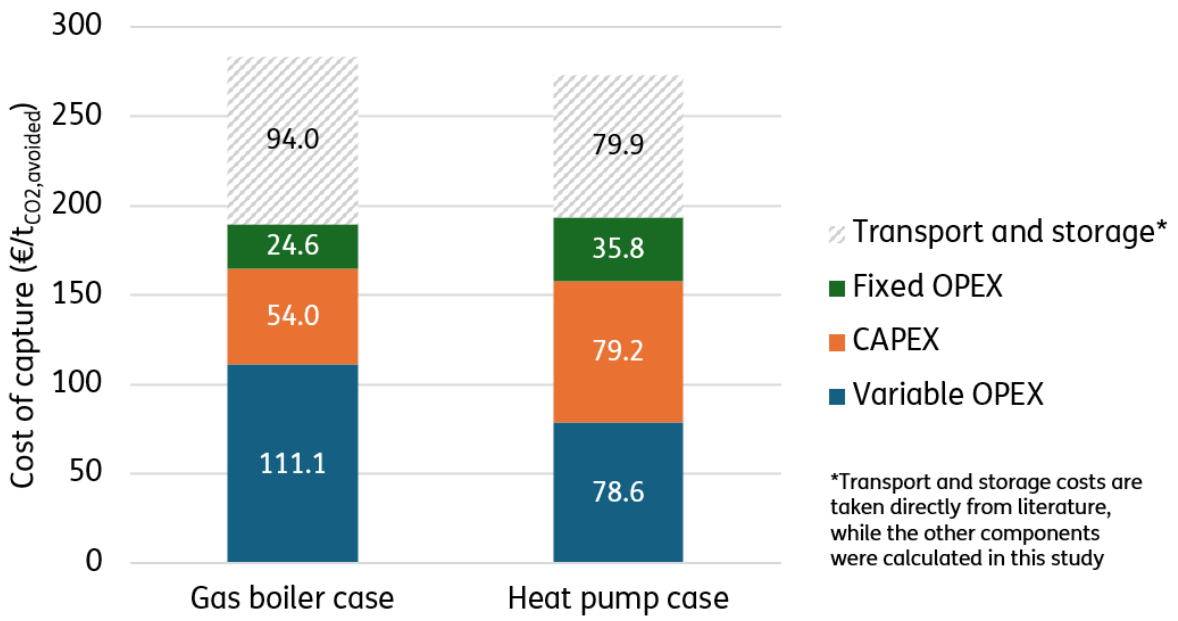



**Heat pump configuration**

# TEA results – Total cost of capture

- Total cost of capture is comparable between the gas boiler and heat pump cases, and cost of capture is somewhat higher for refinery 2 compared to refinery 1
- The gas boiler case has higher variable OPEX contribution, while the heat pump case has a higher CAPEX contribution to the total cost of capture (mainly caused by heat pump CAPEX)
- The heat pump case has significantly lower transport and storage costs, as 20% less $CO_2$ transport is required for this case (as the emissions of the gas boiler are also captured)



# Sensitivity study

The impact of varying the main contributors to the total cost is explored

| | Values considered in sensitivity | | | |
|---|---|---|---|---|
| | **Low** | **Base** | **High** | **Unit** |
| Any excess heat available for the capture process significantly decreases the total costs (ca. 27-28% at 50% availability) | 50 | 0 | N/A | % |
| Gas and electricity prices have a large effect on the total costs (±23-30%)* | 40 | 115.6 | 200 | €/MWh$_e$ |
| A decarbonizing grid has a large effect on the cost of capture of the heat pump case (ca. -16% at 0 g/kWh$_e$) | 0 | 363.8 | 400 | g/kWh$_e$ |
| A lower heat pump CAPEX significantly reduces the cost of capture for that case (ca. -18% at 300 €/kW$_{th}$) | 300 | 1300 | 1500 | €/kW$_{th}$ |

*The variation in electricity price is shown. Gas is assumed at 50% of the electricity price in this study

# Main takeaways from study

- Integrating two stacks in carbon capture systems can give a CAPEX reduction of up to 20%, while variable OPEX is largely unaffected by the integration
- For both refinery case studies, it is shown that a combination of flue gas and solvent integration gives the lowest total cost of capture
- In the gas boiler case, approximately 20% additional $CO_2$ needs to be transported and stored compared to the heat pump case
- While heat pumps have a higher CAPEX than gas boilers, they can be cost competitive when considering the total cost of $CO_2$ avoidance
- In a fully decarbonized grid, the $CO_2$ avoidance of a heat pump driven capture system can increase to 94% (at 95% capture rate), while the avoidance of the gas boiler system remains lower at 85% (at a 95% capture rate).



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