Techno-economic study of CO_2 capture plant with heat pump

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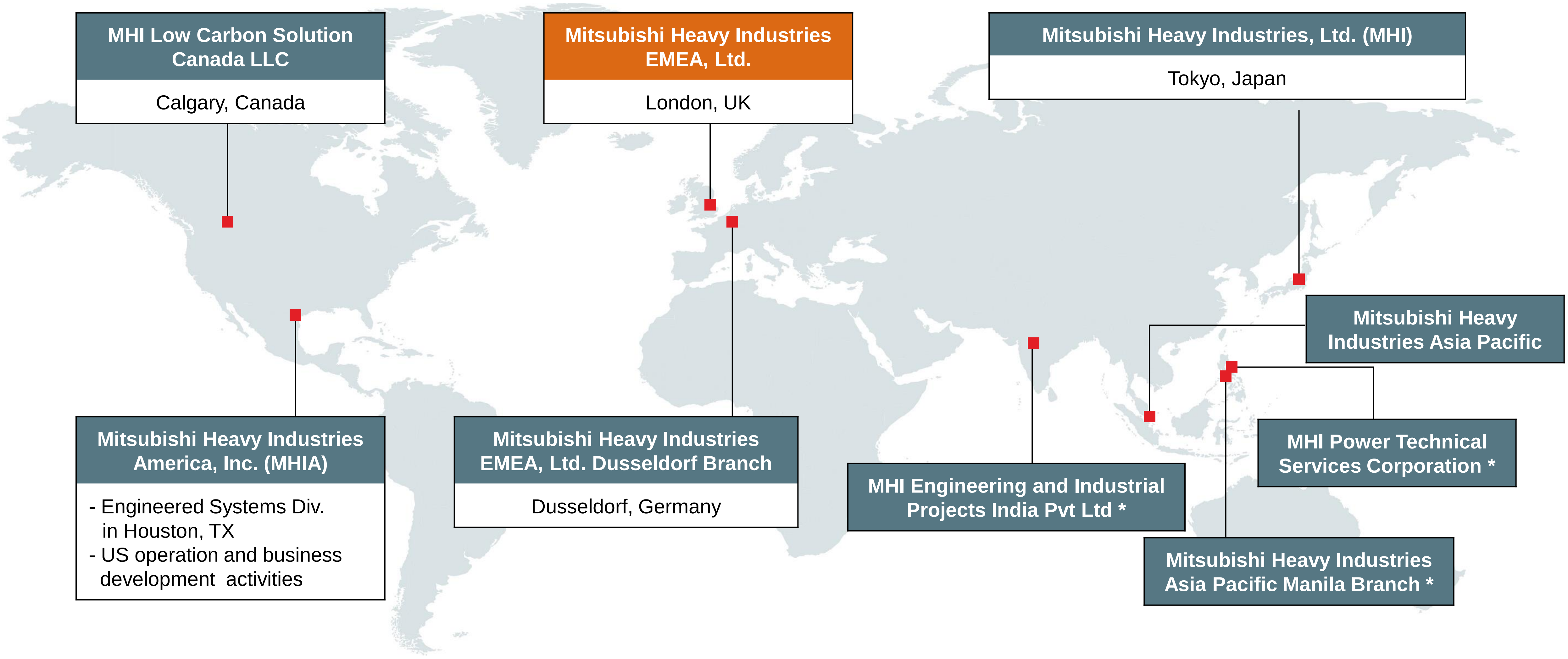
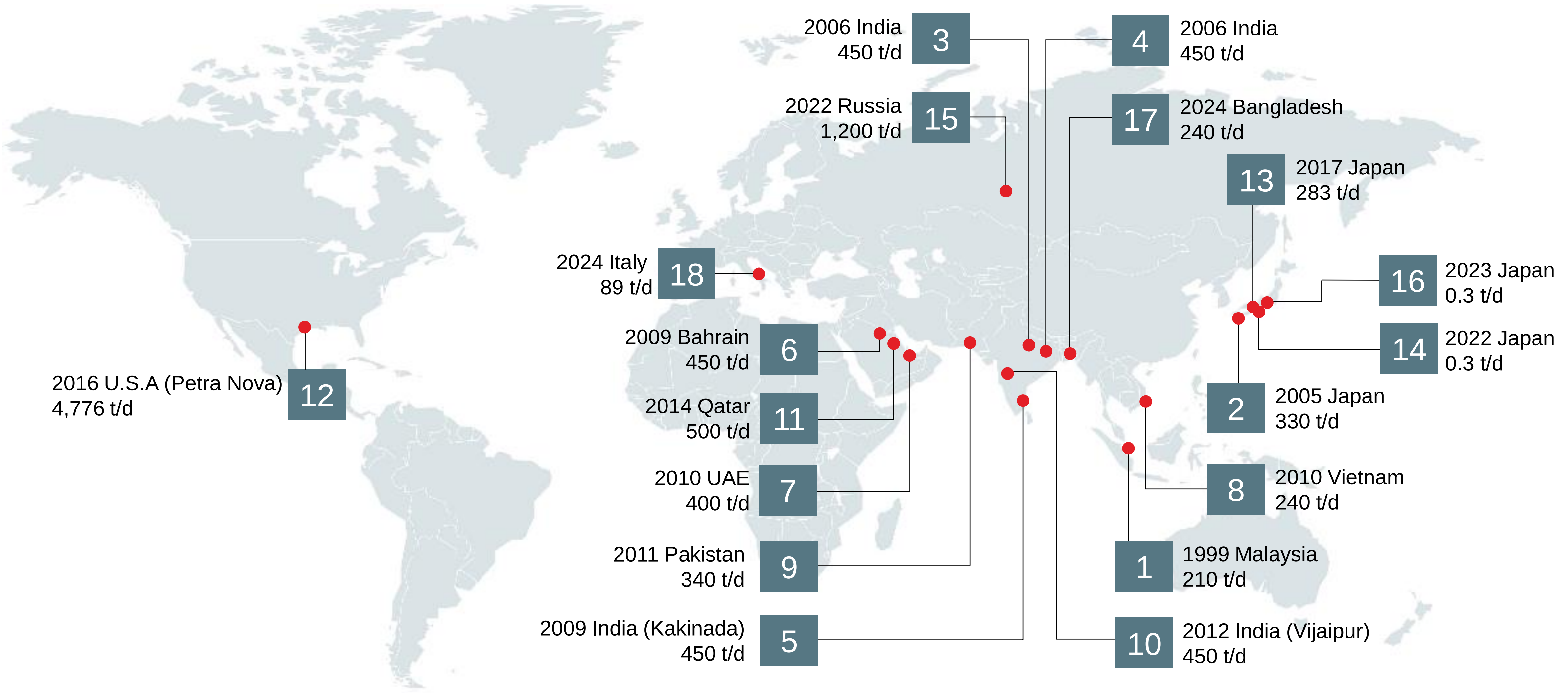
Mitsubishi Heavy Industries (MHI) CO_2 capture business global operation

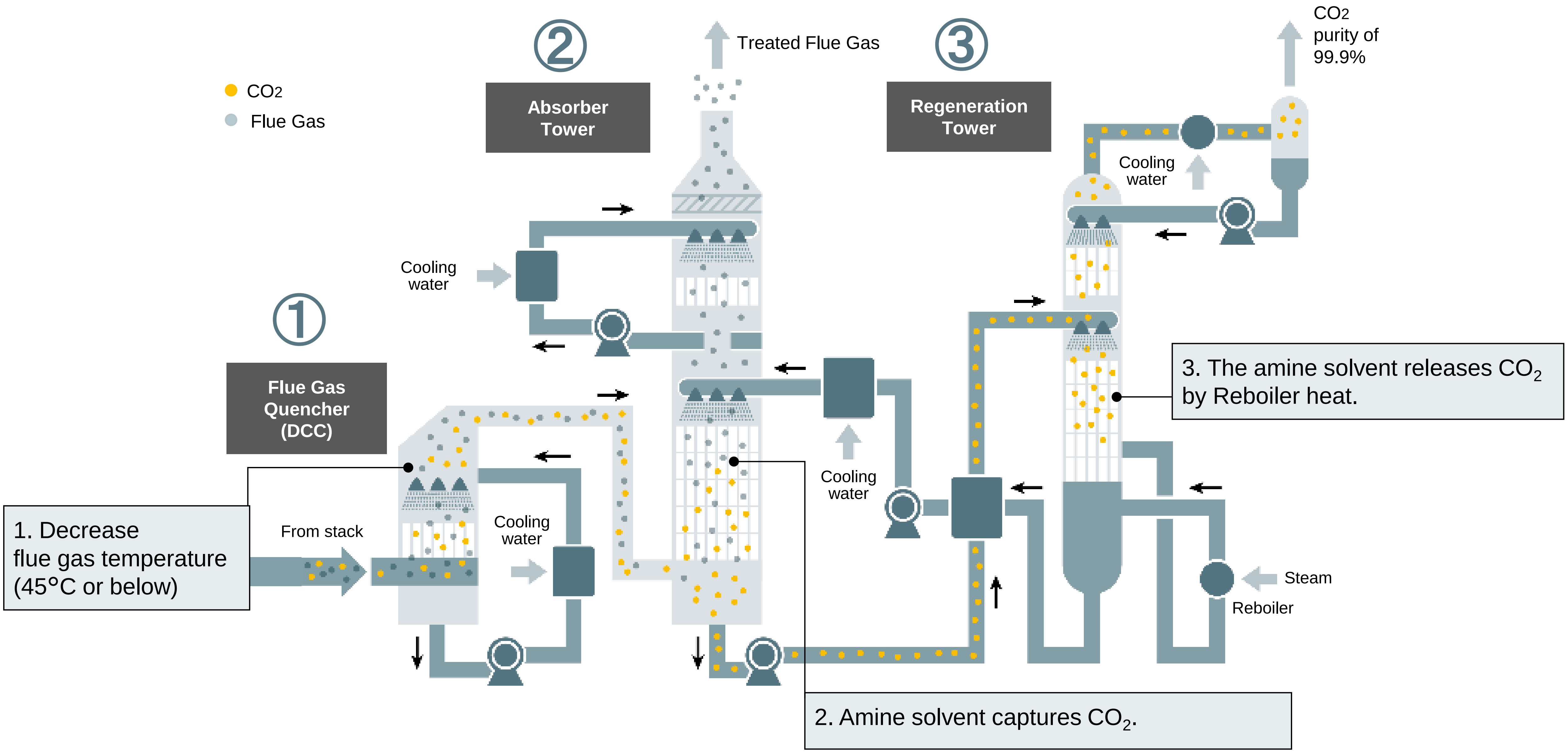


* High value engineering function in India and Philippines

KM CDR Process™ - Worldwide Commercial Experience



Technology with World's Top Share – KM CDR Process™



OVER 40 YEARS
OF A VIABLE SUSTAINABILITY

Since 1980, Turboden S.p.A. is a pioneer in the energy transition, offering technological solutions to industries and utilities for **heat decarbonization and power generation, in particular:**

- **Large Heat Pump (LHP)** and **Mechanical Vapor Recompression (MVR)** for heat supply decarbonization.
- **Organic Rankine Cycle (ORC) System** and **Gas Expander** for green distributed electrical power generation in multiple applications (geothermal, biomass, waste heat recovery);

Having established itself as a **world-leading company in sustainable power production**, with 460 Organic Rankine Cycle (ORC) plants in more than 50 countries, Turboden is one of the major technology partners for energy efficiency and sustainability.

From 2013, Turboden is part of MHI Group. Today, **Turboden and MHI** are committed to **achieving carbon neutrality by 2040** – *Mission Net Zero* – both in their operations as well as in their value chain.

Turboden S.p.A, MHI group company, received orders of large heat pump

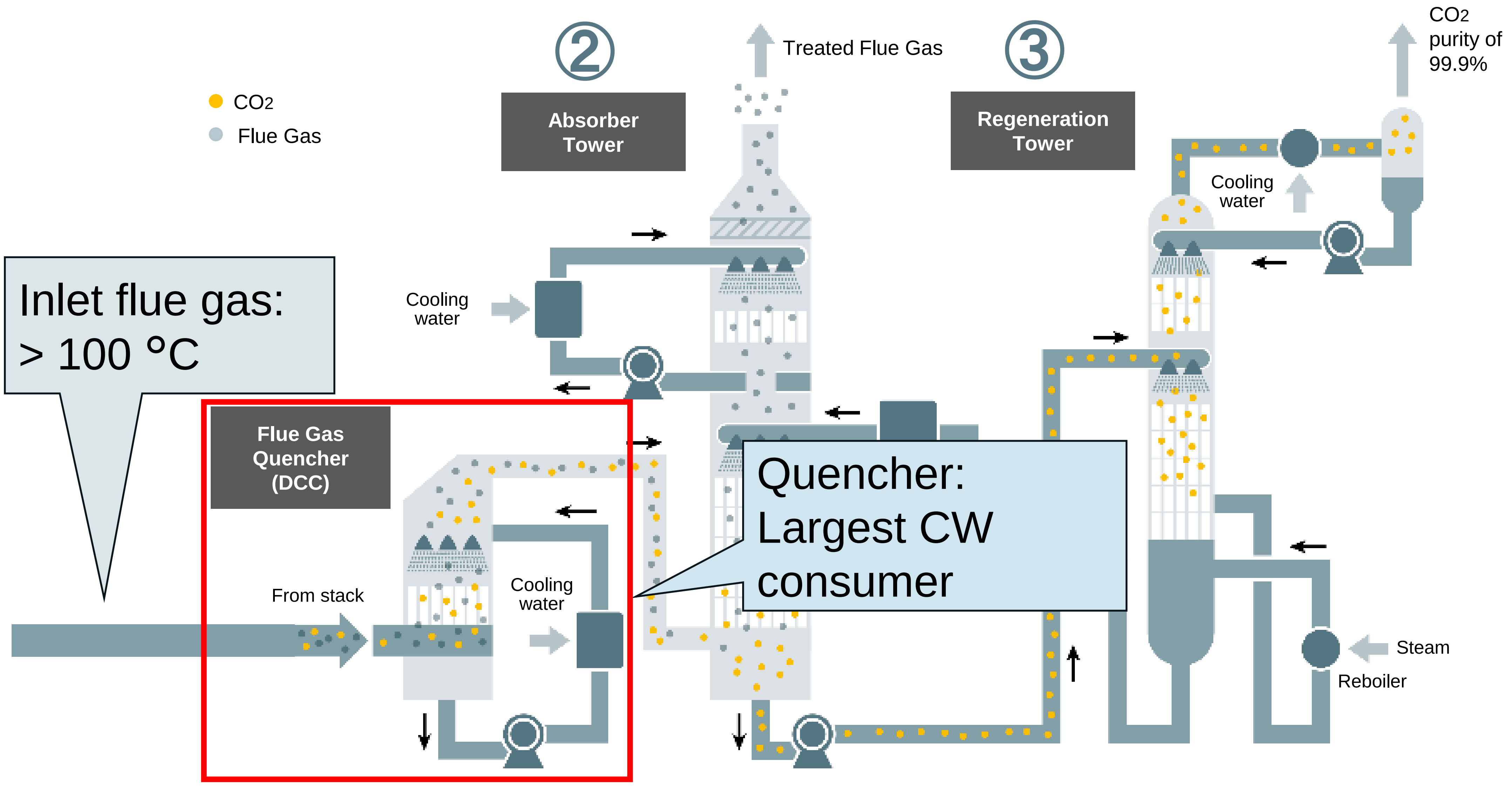
Site: Brescia, Italy
Customer: Ironworks(O.R.I. MARTIN S.P.A.)

Power: **6MWt** up to 120deg.C

Site: Northern EU
Customer: Pulp & paper company

Power: **12MWt** steam @170deg.C

KM CDR Process™ with Heat Pump Concept



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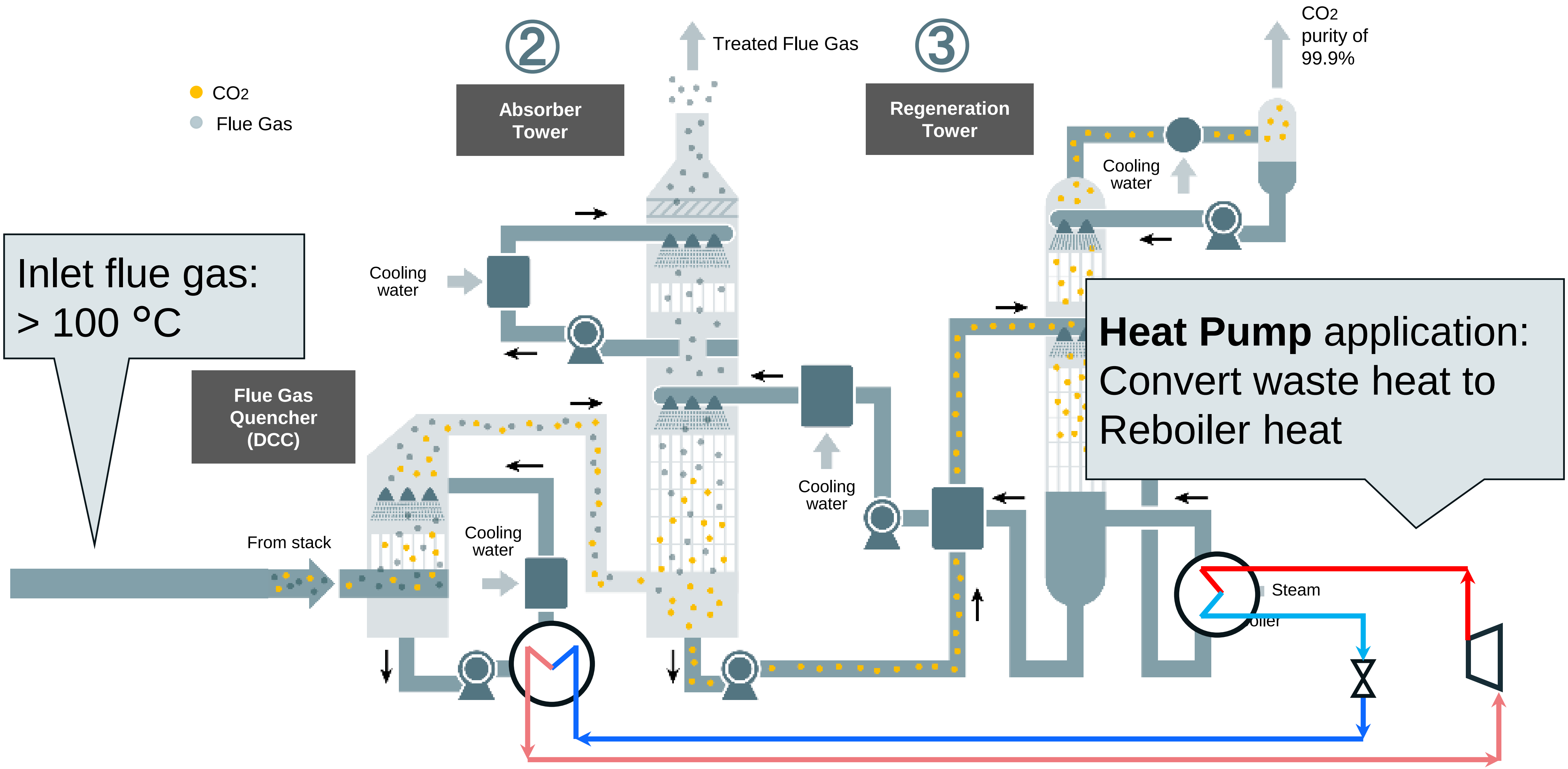
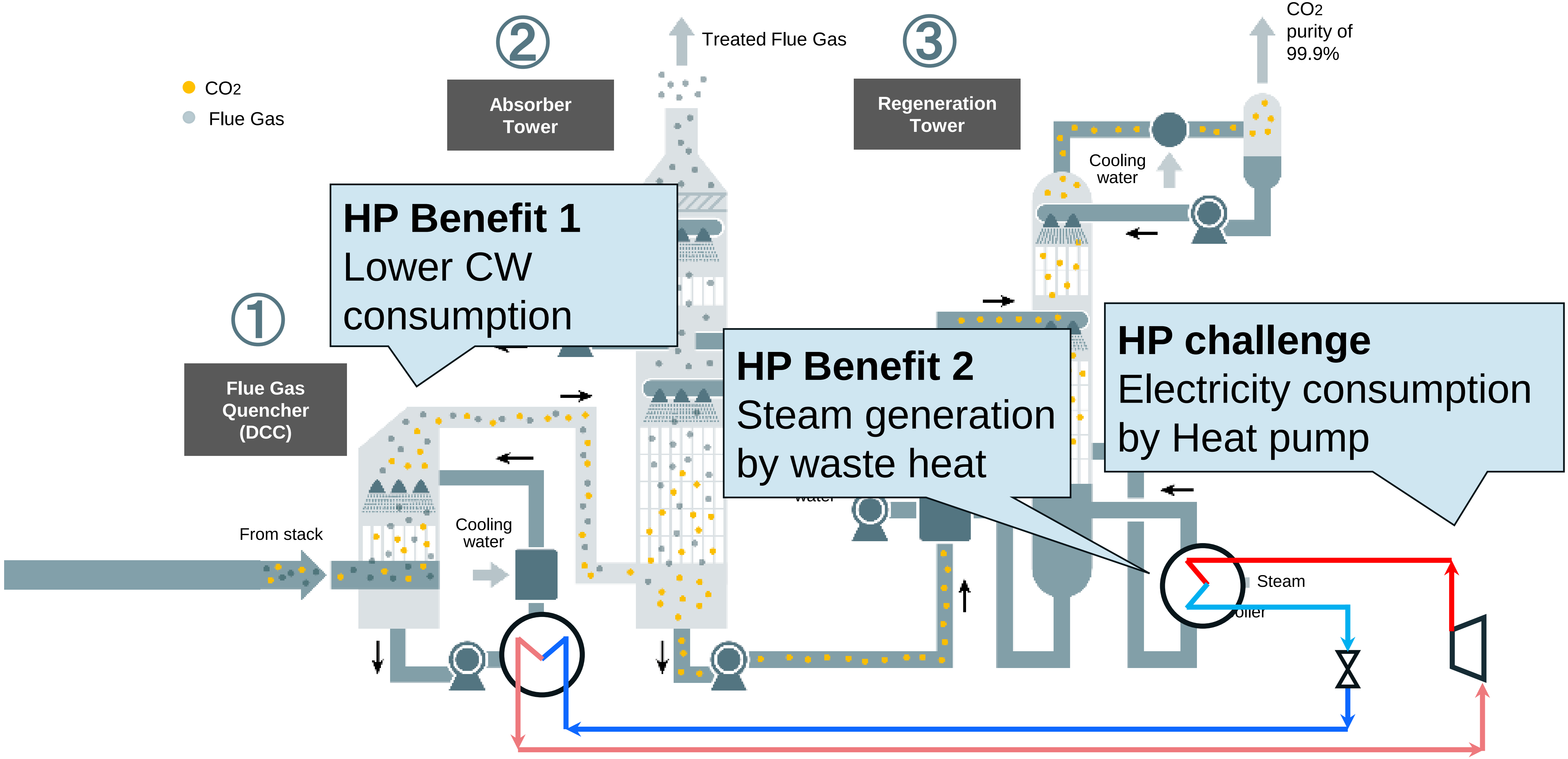


KM CDR Process™ with Heat Pump Concept



HP Benefit 1
Lower CW consumption

HP Benefit 2
Steam generation by waste heat

HP challenge
Electricity consumption by Heat pump

Aim of this study

KM CDR™ with Heat Pump vs Steam Boiler

- Sensitive analysis of utility price
  (Electricity price VS Steam price)

Utility Cost's Sensitive analysis

- CAPEX
- OPEX
- Total of CAPEX+OPEX
- COP analysis
- Cost matrix evaluation

Key performance indicator: COP

$$\text{COP (Coefficient of Performance)} = \frac{\boldsymbol{Q}}{\boldsymbol{W}}$$

*Higher COP = efficient heat pump system

$\boldsymbol{Q}$: Heat supplied by the heat pump (Heat)
$\boldsymbol{W}$: Net work input to the system (Electricity)

- Case study conditions

	Project A (Europe)
Flue gas source	Cement
Capture ratio (%)	90
Flue gas flow rate (Nm^3/hr @101.3kPa 15 ℃)	310,000
Flue gas pressure (barG)	0
Flue gas temperature (℃)	130
Flue gas H_2O concentration (mol%)	34
Flue gas CO_2 concentration (mol%-dry)	18.6
Product CO_2 capacity (tonne/day)	1,700 (0.6 TPA)
Product CO_2 concentration (%-dry)	More than 99.9
Product CO_2 temperature (℃)	35

→Heat Pump COP=2.8

- CAPEX components

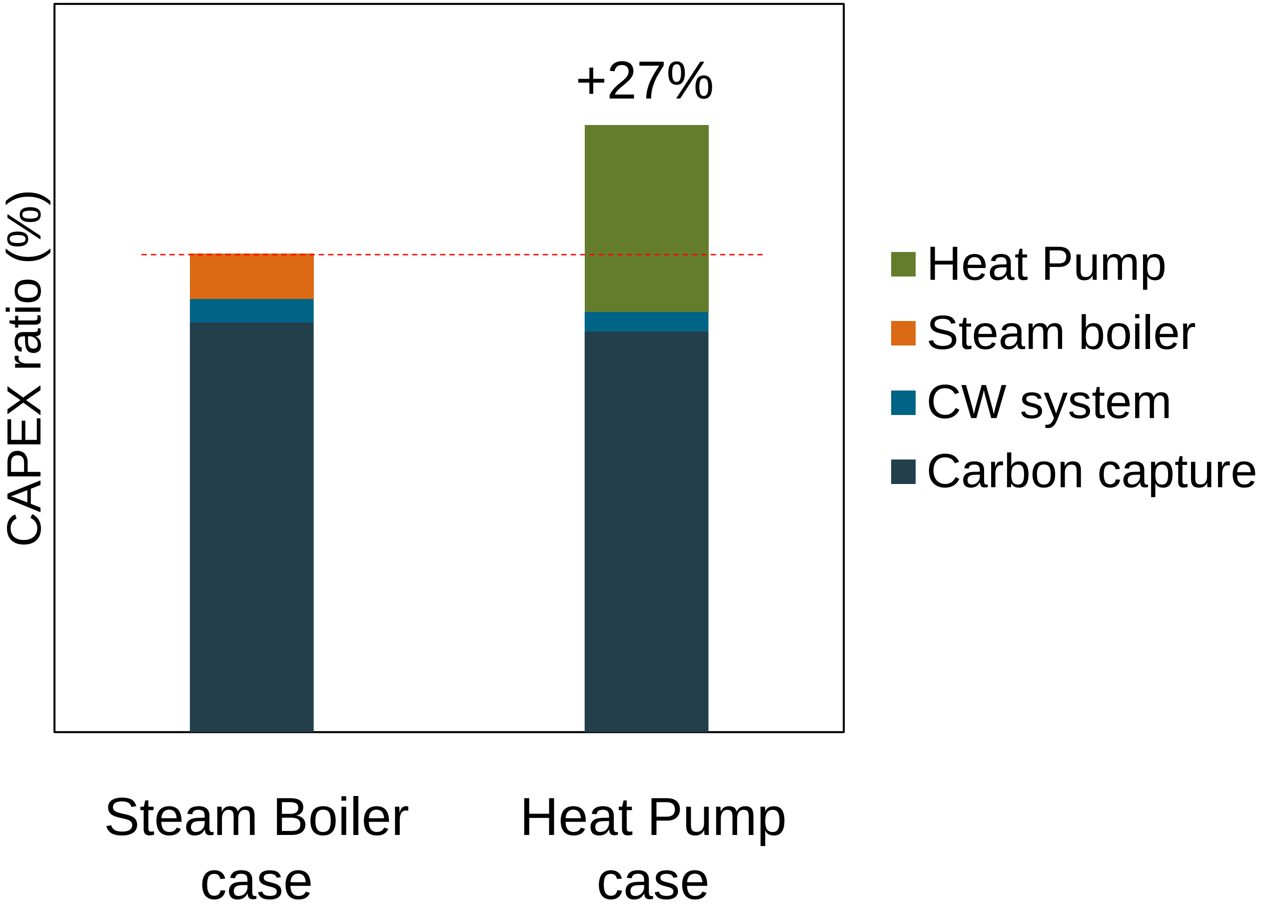
CAPEX	Direct cost	Purchased equipment
		Instrumentation
		Electrical
		Piping
		Construction
	Indirect cost	Engineering
		Construction
		Transportation
		Process license fee
		Contingency
		KS-21™ initial fill

→EPC price

CAPEX comparison

MITSUBISHI HEAVY INDUSTRIES

Steam boiler case: Reboiler heat generation by steam boiler
Heat pump case: Reboiler heat generation by heat pump



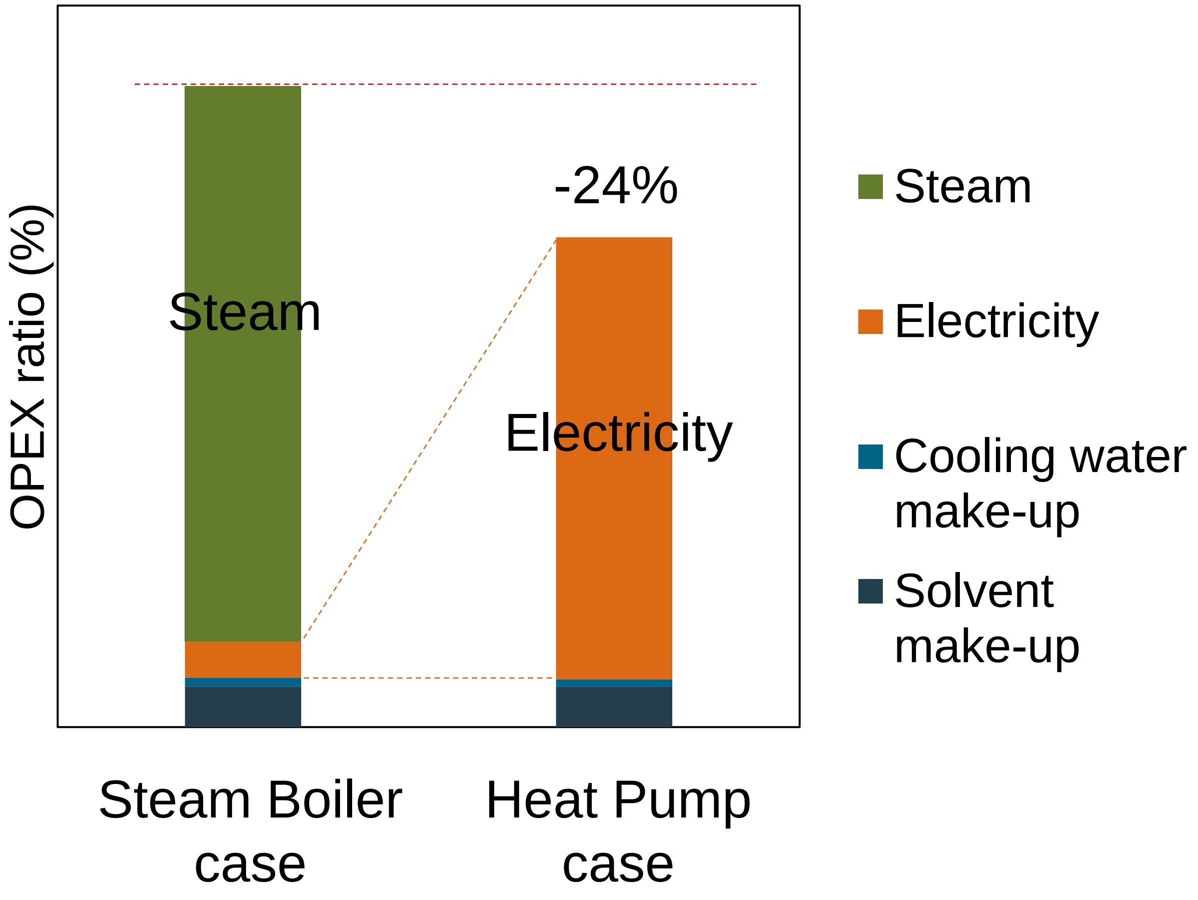
Next step:
How much OPEX benefit is required to overcome CAPEX increase?

OPEX case study

Electricity price	100 Euro/MWh
	(Example of European price)

LP steam price	30 Euro/ton-steam
Equivalent Natural Gas price	12 Euro/MMBTU
	(Example of European price)

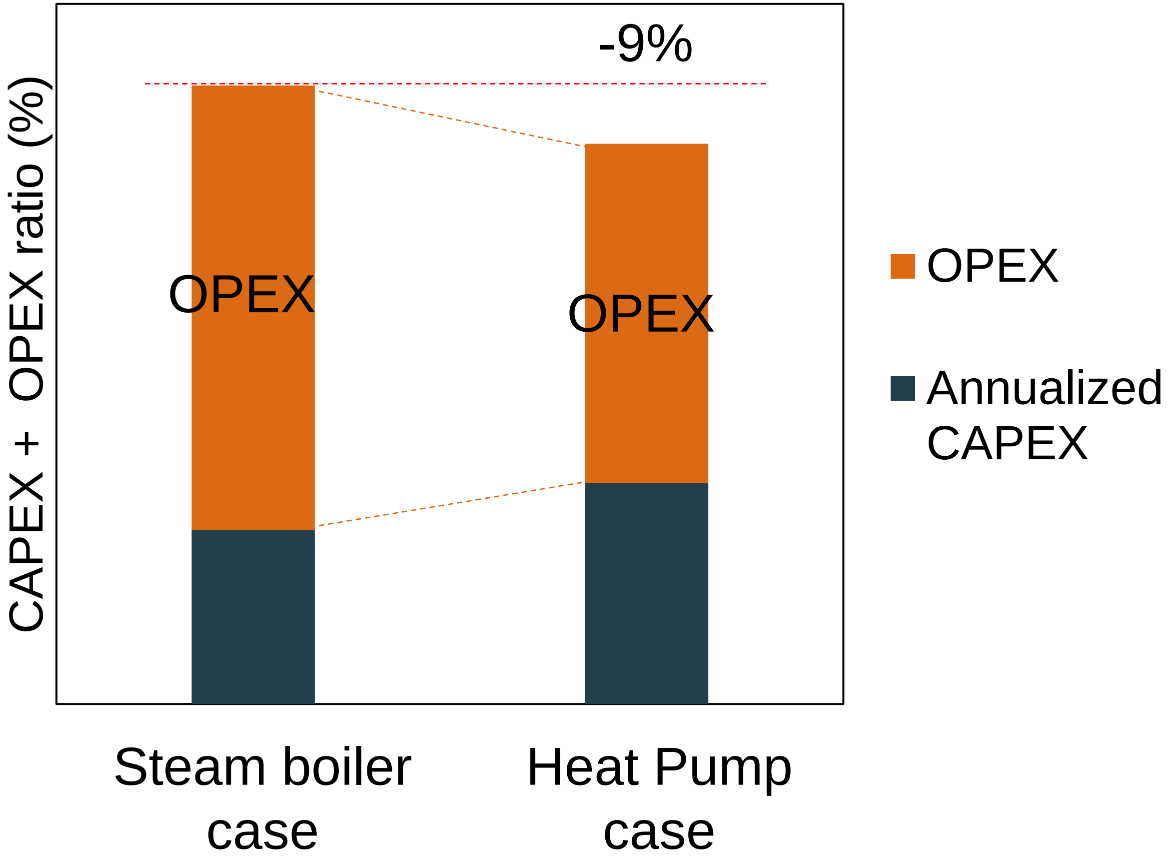
Cooling water make-up	0.2 Euro/m^3
Solvent cost	Be considered



- CAPEX annualization & normalization conditions

Availability	90%
Redundancy	10%
Discount rate	6.8%
Evaluation period	25 years
→Capital charge factor	0.084 1/yr

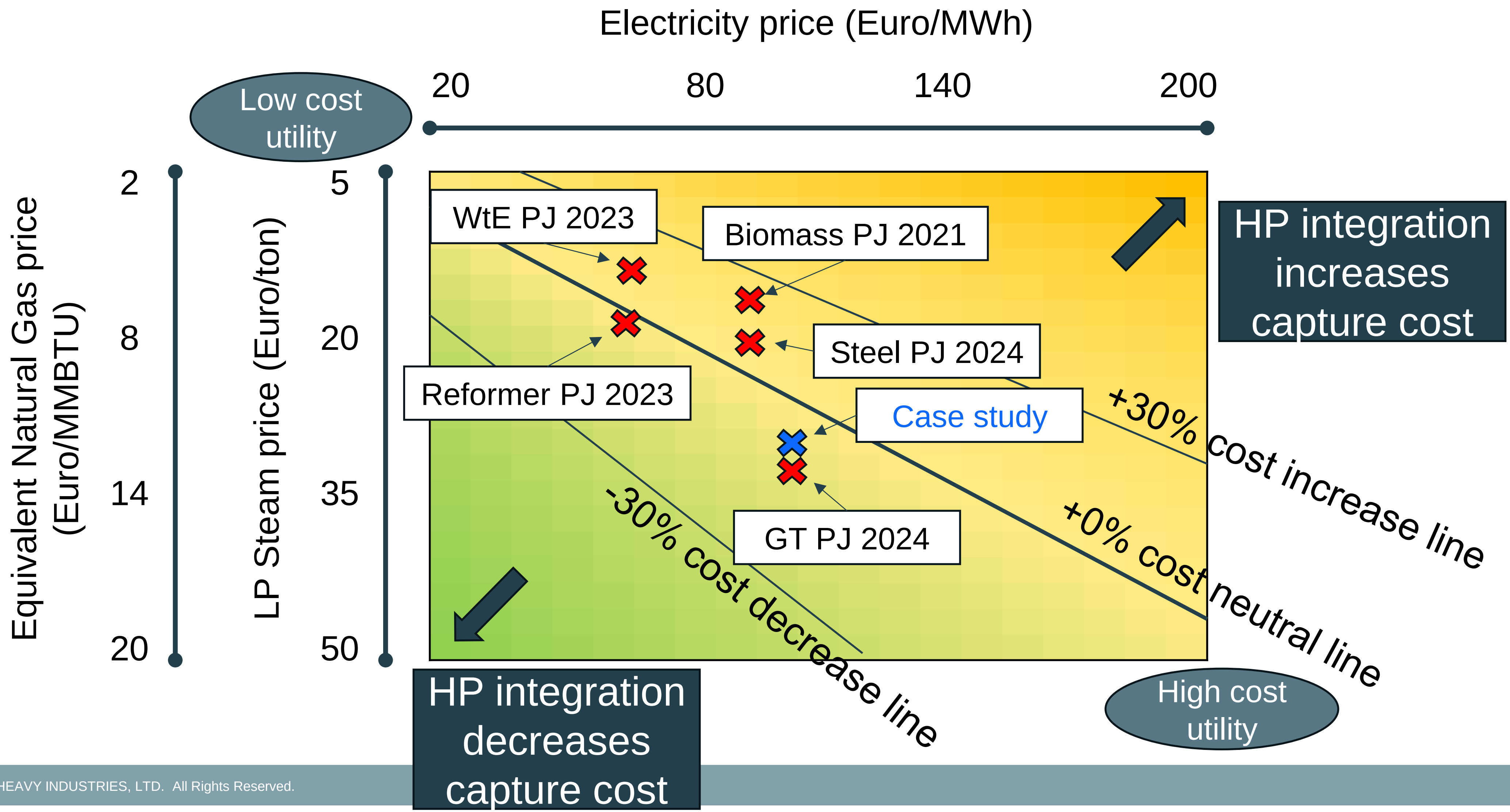
In this case study with Project A, capture cost decreases due to OPEX.



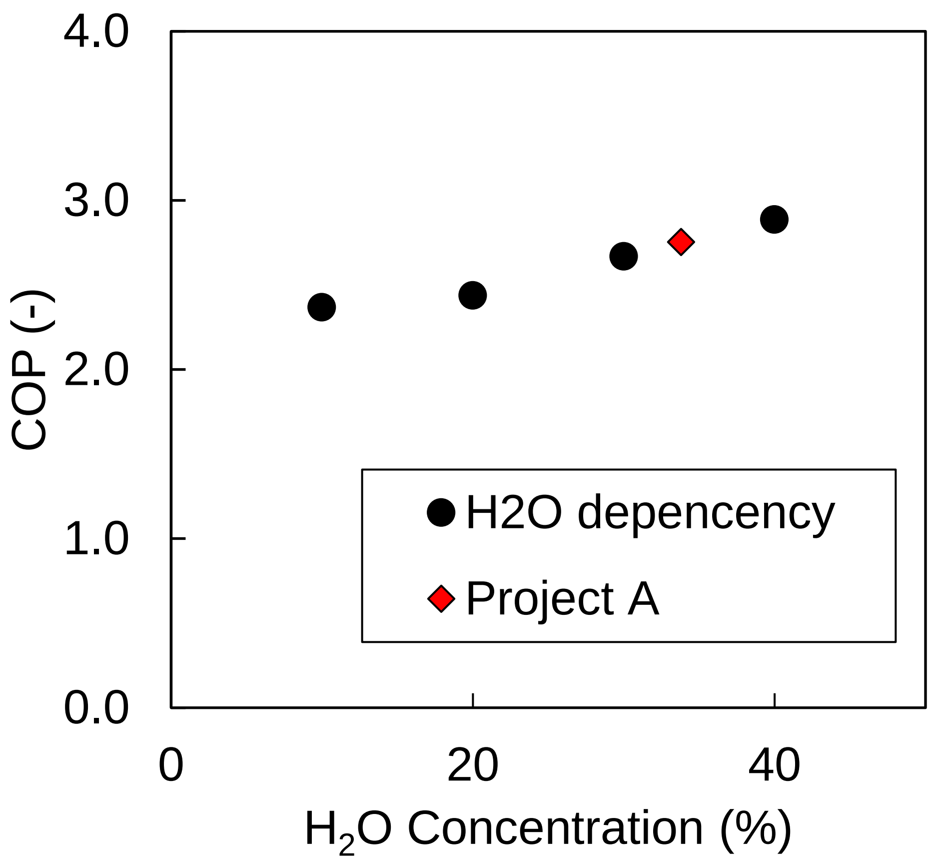
CAPEX+OPEX analysis – cost matrix

PJ A basis cost matrix (COP=2.8)

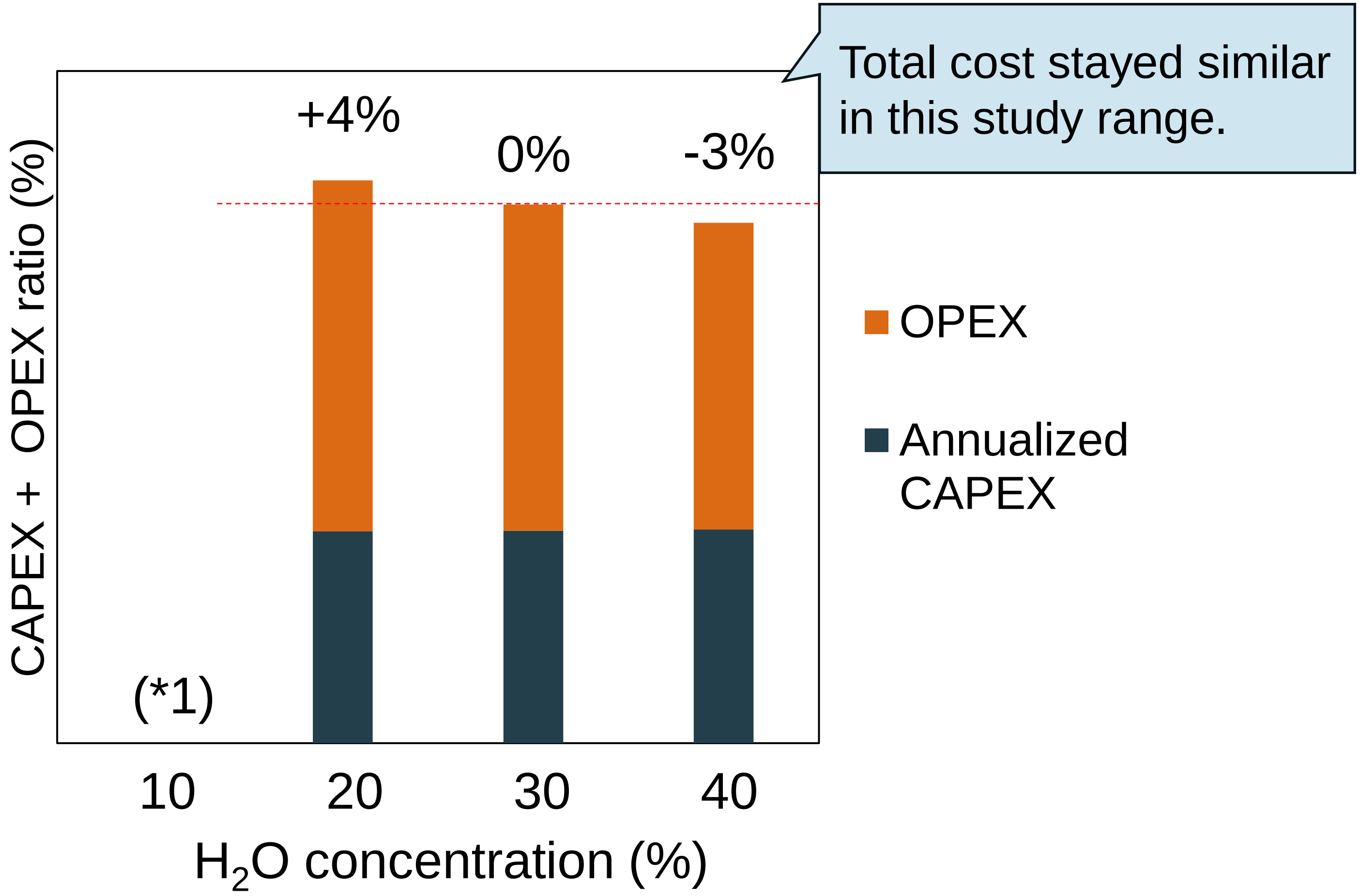
$$\text{Initial assessment of } \frac{\text{Capture Cost of HP case}}{\text{Capture Cost of Boiler case}} \text{ (\%) using utility price}$$



COP vs H_2O concentration



Capture cost vs H_2O concentration



(*1) Not enough heat to generate required steam amount.

Techno-economic study

- Electricity vs Steam price setting has big impact on effectiveness of HP integration.

CAPEX + OPEX study

- Cost matrix is useful for initial assessment of HP effectiveness.

NEXT STEP

- Confirm effects of parameters on COP and cost matrix:
  - H_2O conc. in FG dependency: done, limited effect in study range
  - CO_2 conc. in FG dependency: next
  - Inlet FG temperature dependency: next

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