Gas processing at integrated steelworks

– Syngas makeup and CO valorization

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voestalpine Stahl, Linz, Austria

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In this presentation…

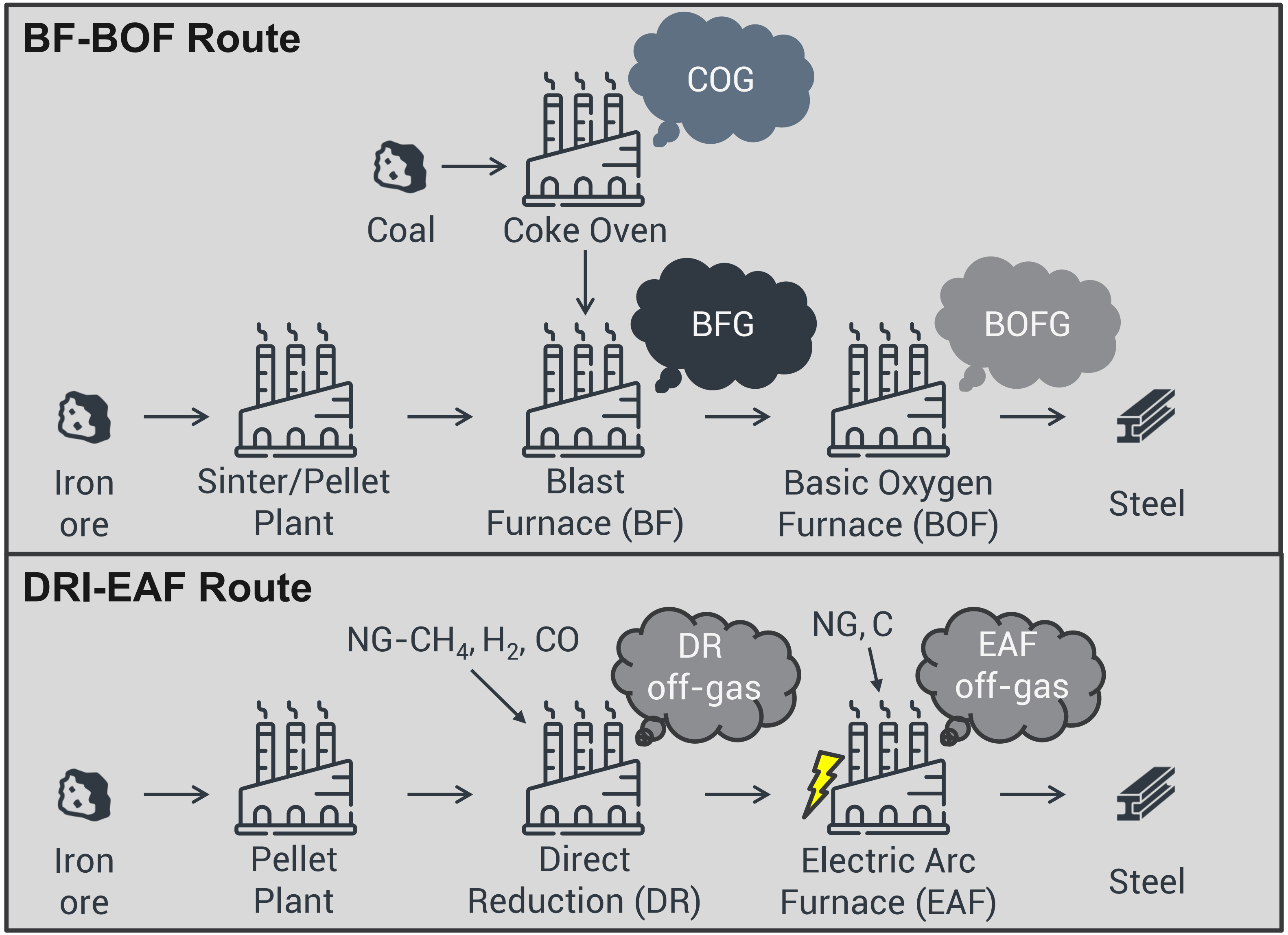
- Introduction
- Steel off-gases – Applications
- Pressure Swing Adsorption (PSA) – for carbon rich off-gas streams
- Case studies
  - CO recovery from PSA
  - H_2 from electrolysis
  - Make-up syngas for Direct Reduction Process (DRP)
- Conclusions

2.8 Gt CO_2

~8% of global emissions

Source: IEA (2023)

Net zero emissions by 2050



Typical steel off-gases composition

Composition (vol. %)	BF-BOF route			DRI-EAF route	
	Blast Furnace Gas (BFG)	Basic Oxygen Furnace Gas (BOFG)	Coke Oven Gas (COG)*	DRI Off-gas	EAF Off-gas
CO	24	54	4	14	28
CO_2	22	20	1	7	7
C_xH_y	-	-	25	6	0
H_2	4	3	60	43	0
H_2O	4	4	4	29	3
N_2	46	19	6	1	62

Source: Collis (2021)   Source: Zugliano (2013)   Source: Lotfy (2015)

* Publication from previous edition of H_2 for Green Steel conference:
Ramani, B., van der Stel, J., Jagers, G., & Buijs, W. (2023). Hydrogen production from coke oven gas using pressure swing adsorption process. Matériaux & Techniques, 111, 205. https://doi.org/10.1051/mattech/2023027

Steel off-gases | Applications

Current applications → Heating

Current applications → Electricity

Valorization of carbon rich off-gas streams (CO_2/CO)

CCU

Hydrogenation of CO_2/CO to C1-chemicals (CH_4, CH_3OH)

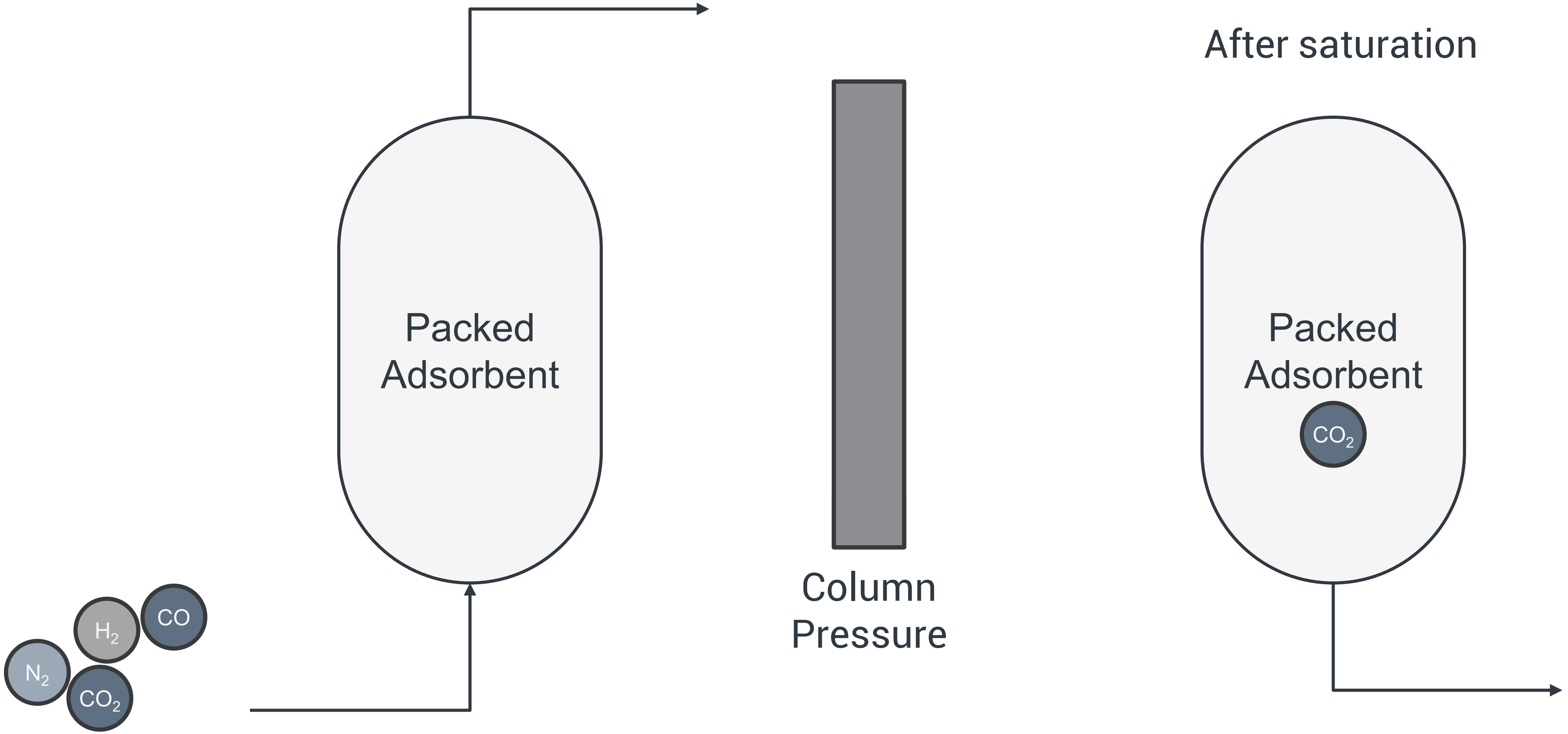
→ development of dedicated infrastructure

Recovery & Reuse of CO internally

Syngas makeup for DRP reducing gas

→ enabler of green H_2 use in ironmaking process

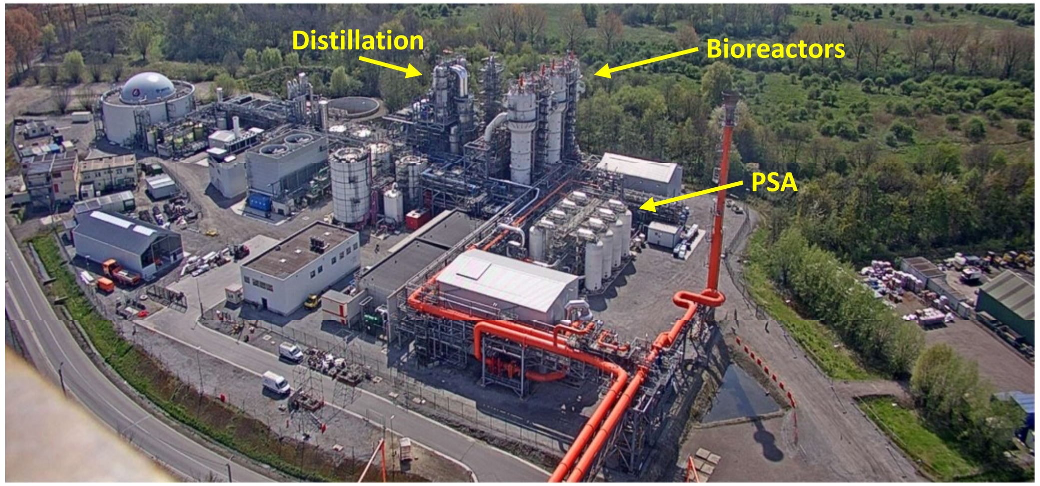
Pressure Swing Adsorption (PSA)



- **Selective separation of gas mixtures (CO_2 - CO - N_2 - H_2)**
- **Efficient separation of CO from N_2**

PSA | Carbon Dioxide Capture Projects

Arcelor Mittal, Gent



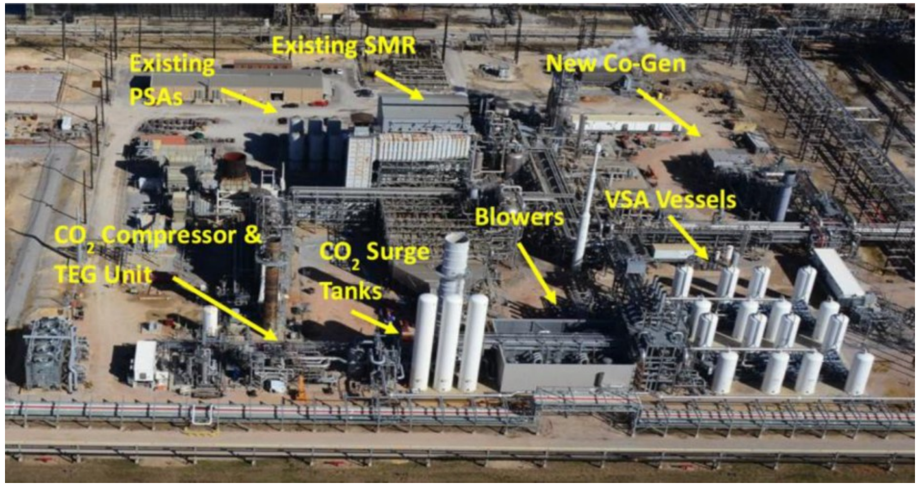
Source: Steelanol (2007)

Capacity : 320 kton CO_2/y

Feed stream $CO_2 \approx$ 20-25 vol. % (BFG+BOFG)

Product stream CO_2 > 99 vol. % (EtOH)

Valero Refinery, Port Arthur, Texas



Source: Preston (2018)

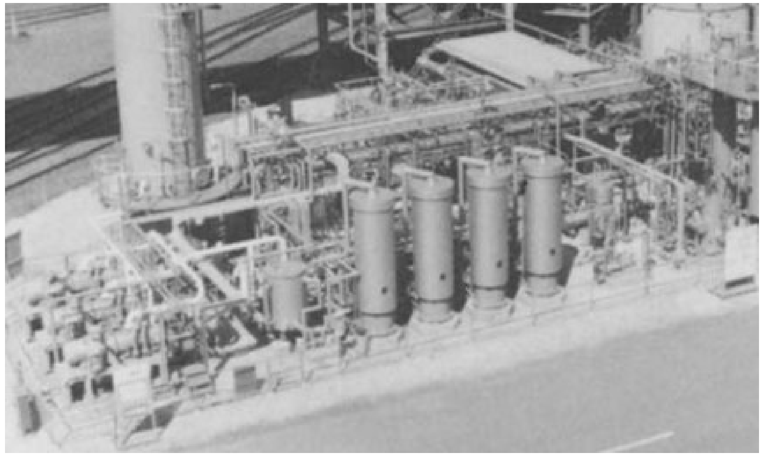
Capacity : 1 Mt CO_2/y

Feed stream $CO_2 \approx$ 15 vol. % (SMR)

Product stream CO_2 > 97 vol. % (EOR)

PSA | Carbon Monoxide Capture Projects

Kobe Steel, Japan



Source: Kasuya and Tsuji (1991)

Capacity: 20 kton CO/y

Feed stream CO ≈ 68 vol. % (LDG)

Product stream CO > 99 vol. % (syngas)

PKU Pioneer, China

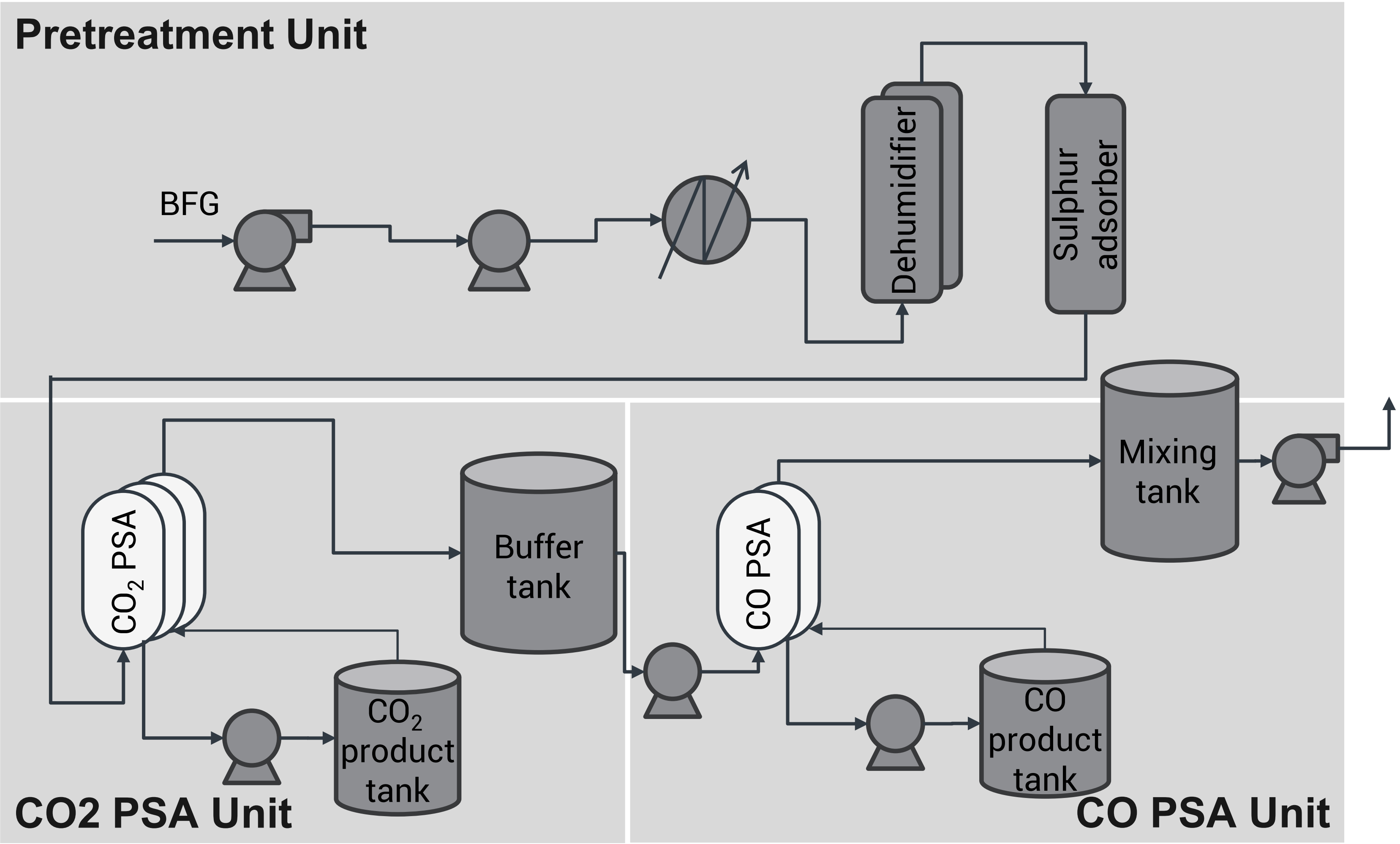
Source: Xie et al. (2007)

Capacity: 200 kton CO/y

Feed stream CO ≈ 30 vol. % (BFG)

Product stream CO > 99 vol. % (syngas)

PSA | Reference case for model | ASCOA-3 (JFE Steel)



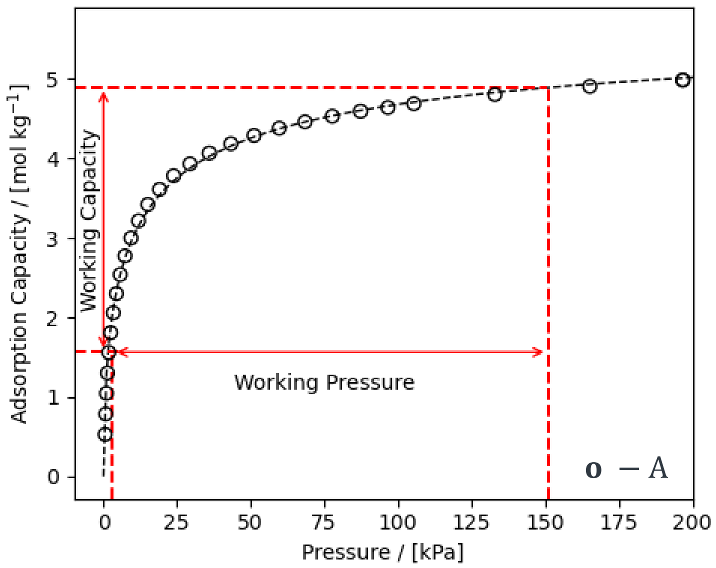
Recreated from: Saima et al.(2013)

Capacity: 3-5 ton CO_2/day
CO_2 Recovery > 80%
CO_2 Purity > 90%

- Used as reference to validate Aspen Adsorption simulation

PSA | Process Performance

Working Capacity



Selectivity

$$S_{A/B} = \frac{\text{Working Capacity of A}}{\text{Working Capacity of B}}$$

Recovery [%]

$$\frac{x * A}{\text{Total } A}$$

Purity [%]

$$\frac{x * A}{(x * A) + (y * B)}$$

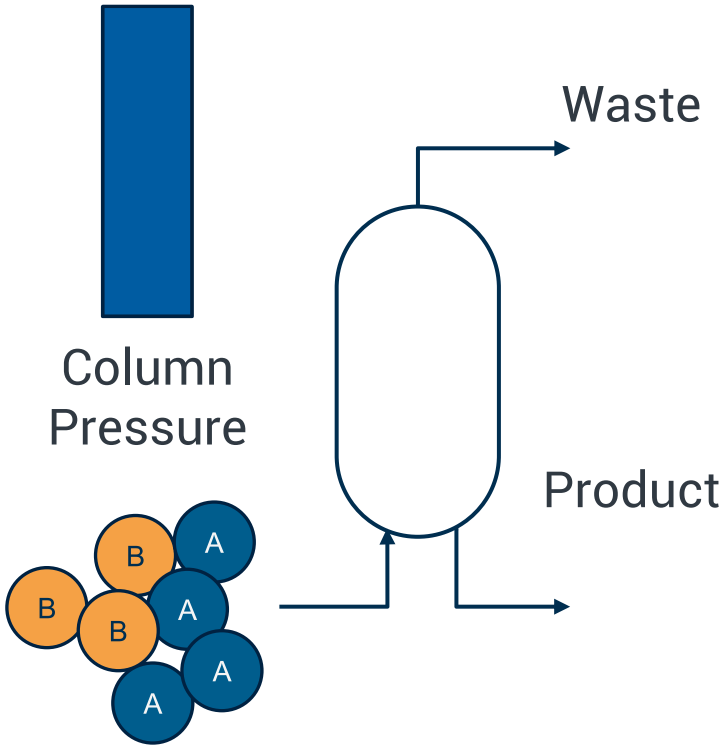
Productivity [ton_A/h]

$$\frac{x * A}{\text{Cycle Time}}$$

Energy Consumption [kWh/ton_A]

$$\frac{\text{Energy to operate}}{x * A}$$

Illustration



PSA | Adsorbent Selection & Isotherm Fitting

Materials from Review Paper

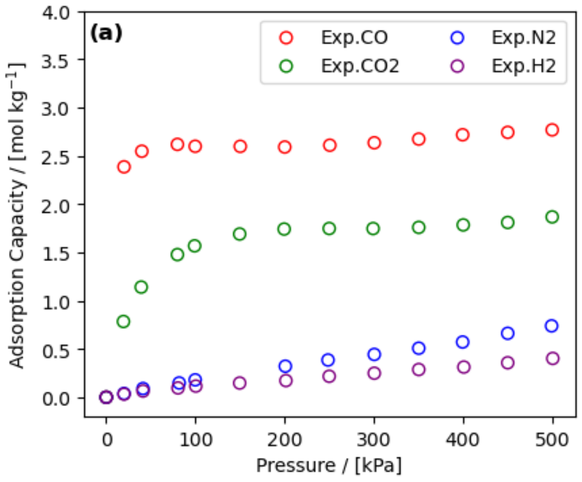
Criteria
A B C

CO_2 Adsorbent (Zeolite 13X)

CO Adsorbent (CuCl-Zeolite)

A : Isotherm Availability
B : Working Capacity
C : Working Selectivity

Experimental data from literature

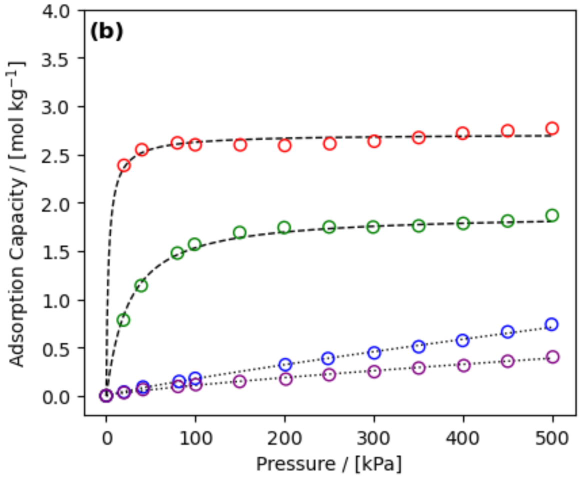


Exp data source: Zhou (2017)

Selected Adsorbents

Non-linear fitting to Langmuir Freundlich model

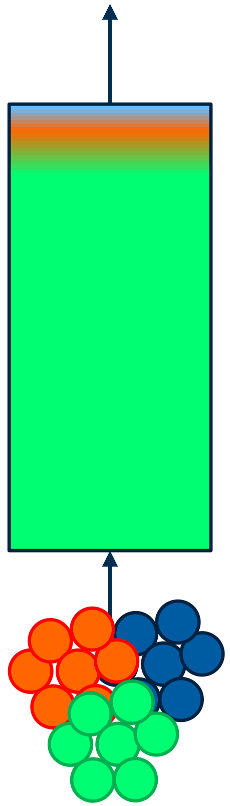
Adsorption isotherm model



Isotherm parameters

PSA | Validation | Breakthrough simulations

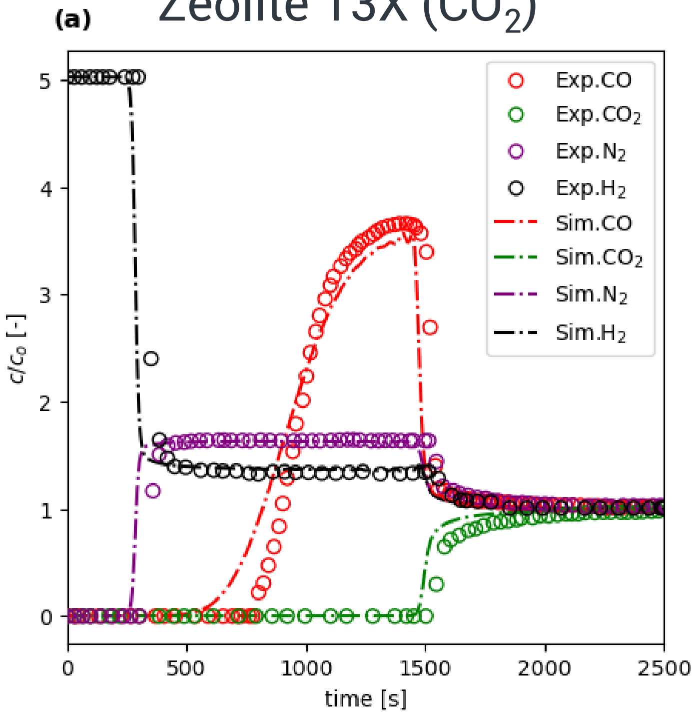
Illustration



Outlet concentration is measured as breakthrough curve

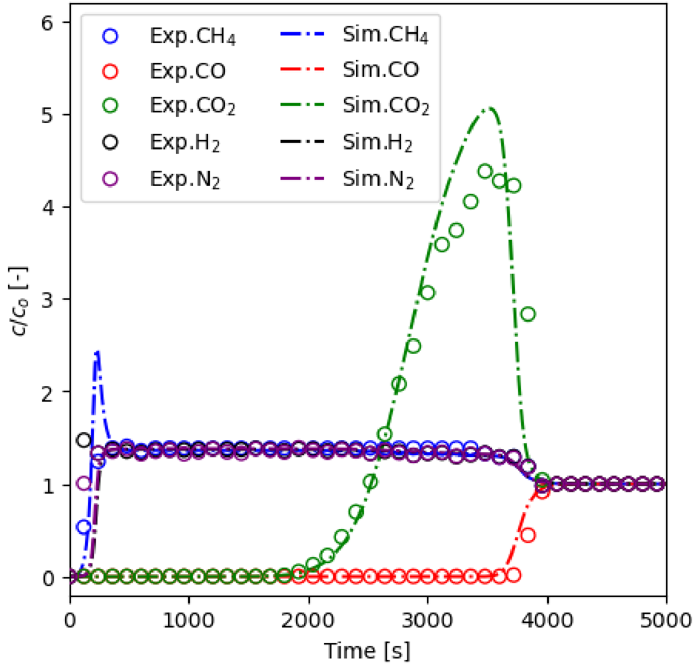
Breakthrough curves for CO_2 & CO adsorption systems (Aspen simulation vs experimental literature data)

Zeolite 13X (CO_2)



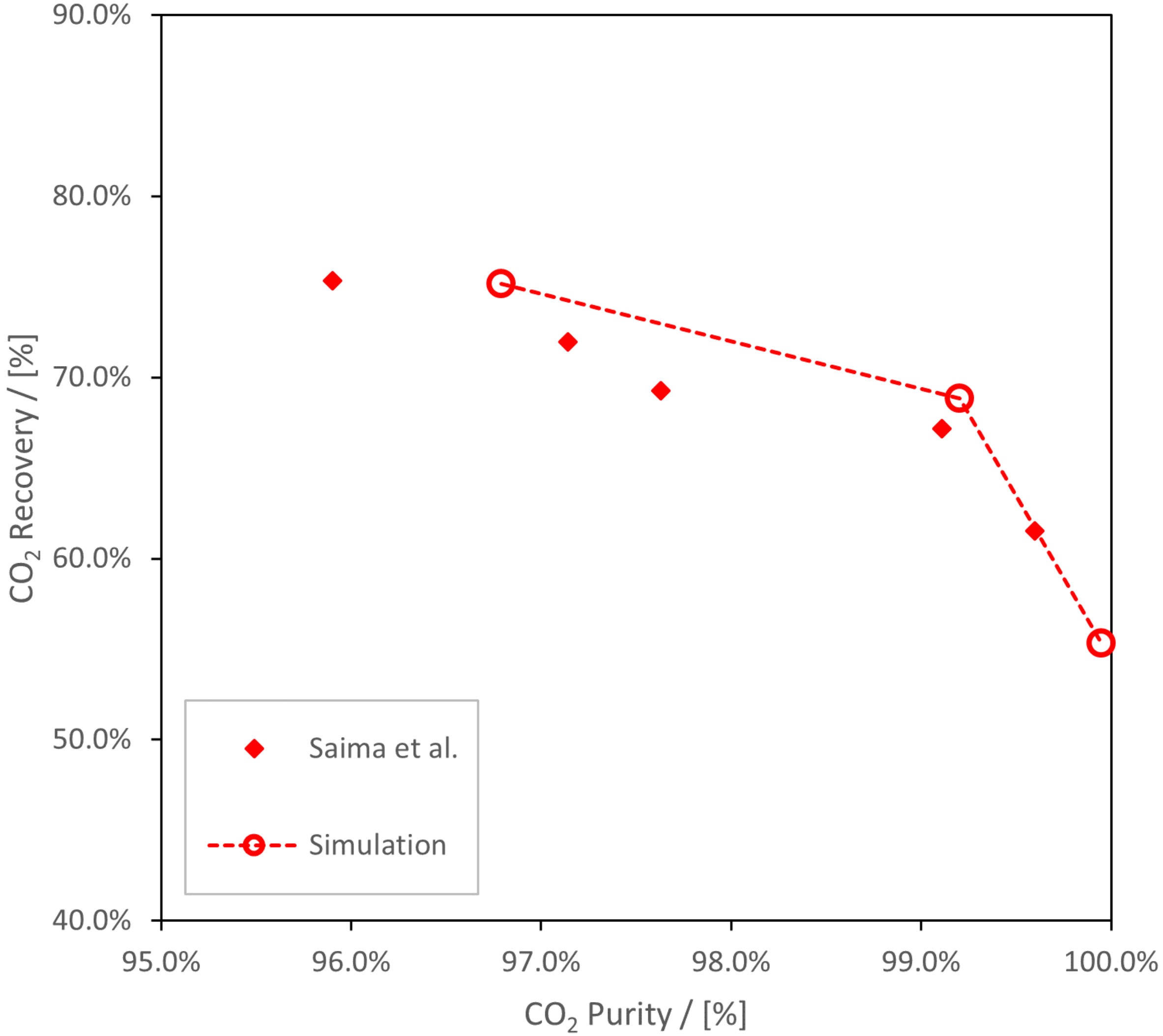
Exp data source: Park (2021)

CuCl-Zeolite Y (CO)



Exp data source: Zhou (2017)

PSA | Validation | Cycle simulations



Changing rinse flow rate

- Simulated results closely follow experimental data trend
- Trade-off between CO_2 purity & recovery
- Target: CO_2 purity ≥ 95%

PSA | Optimized case

Reference case (ASCOA-3)

Target performance

Purity ≥95%

Recovery x

CO_2 Column

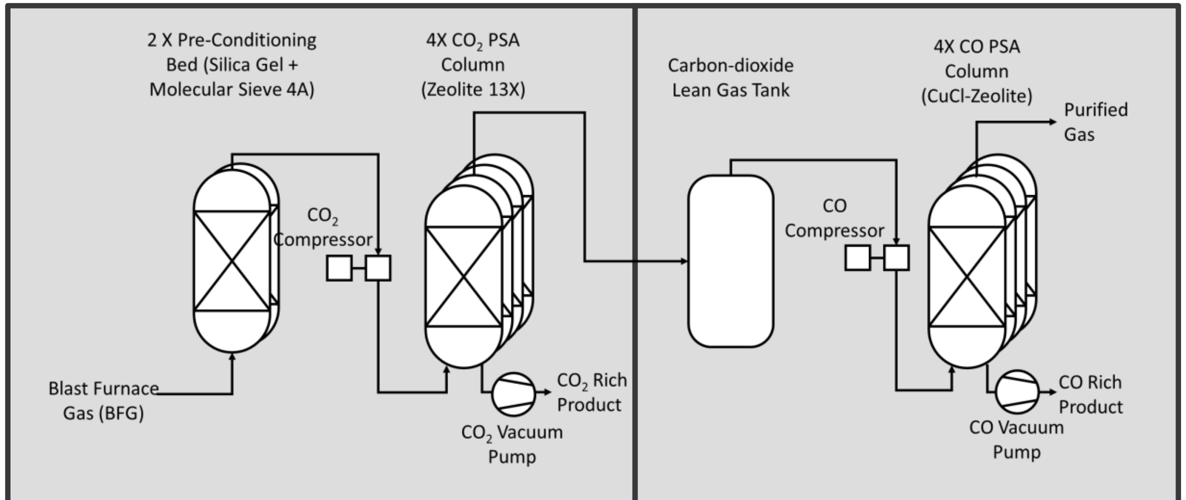
Process Performance	Units	Value
CO_2 Recovery	[%]	**89.2**
CO_2 Purity	[%]	95.4
CO_2 Productivity	[tCO_2/day]	**5.7**
Annual Productivity	[$ktCO_2$/y]	1.9
Specific Energy Consumption	[kWh/tCO_2]	88.7

CO Column

Process Performance	Units	Value
CO Recovery	[%]	**85.2**
CO Purity	[%]	94.9
CO Productivity	[tCO/day]	**3.3**
Annual Productivity	[ktCO/y]	1.1
Specific Energy Consumption	[kWh/tCO]	164.4

PSA | Preliminary Economic Analysis

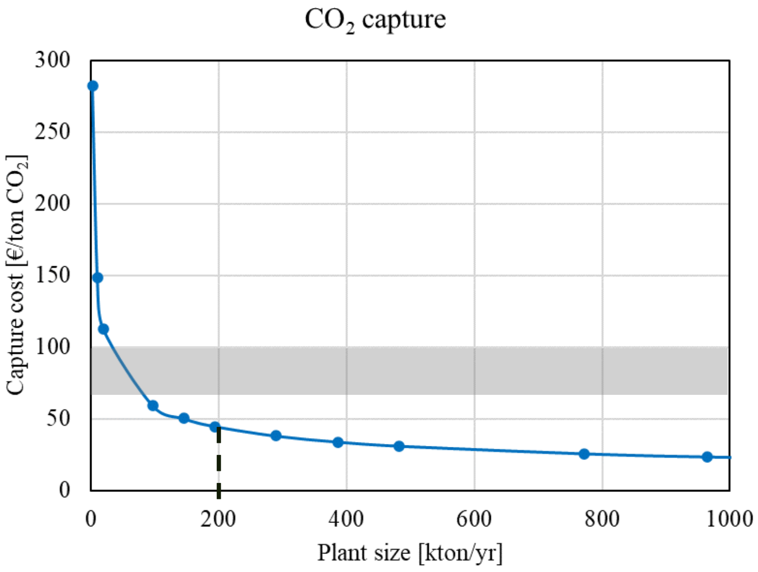
CO_2 & CO capture costs for Reference case (ASCOA-3)

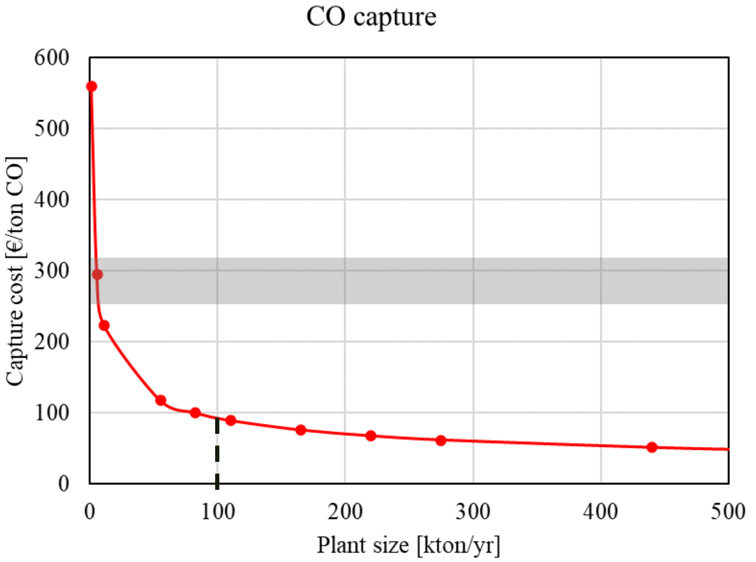


Investment: € 4.5 Million
€ **282** / tCO_2

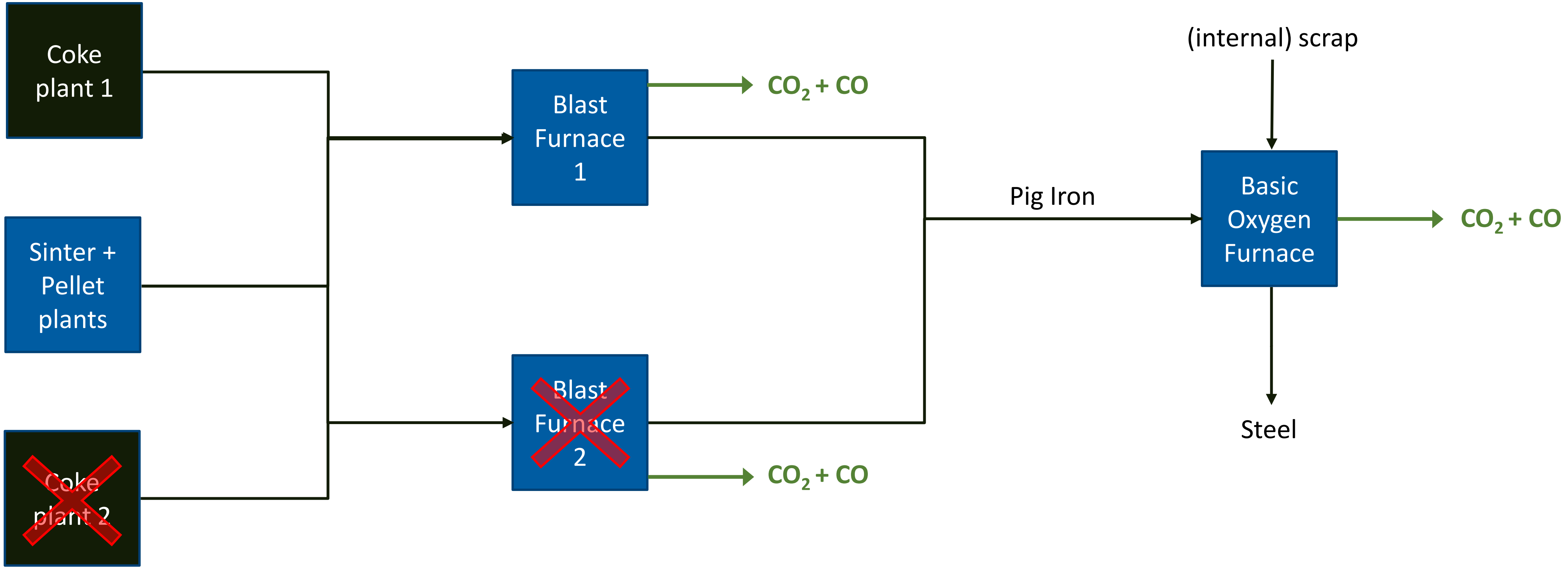
€ 5.2 Million
€ **560** / tCO

Equipment cost source: Towler and Sinnot (2021)

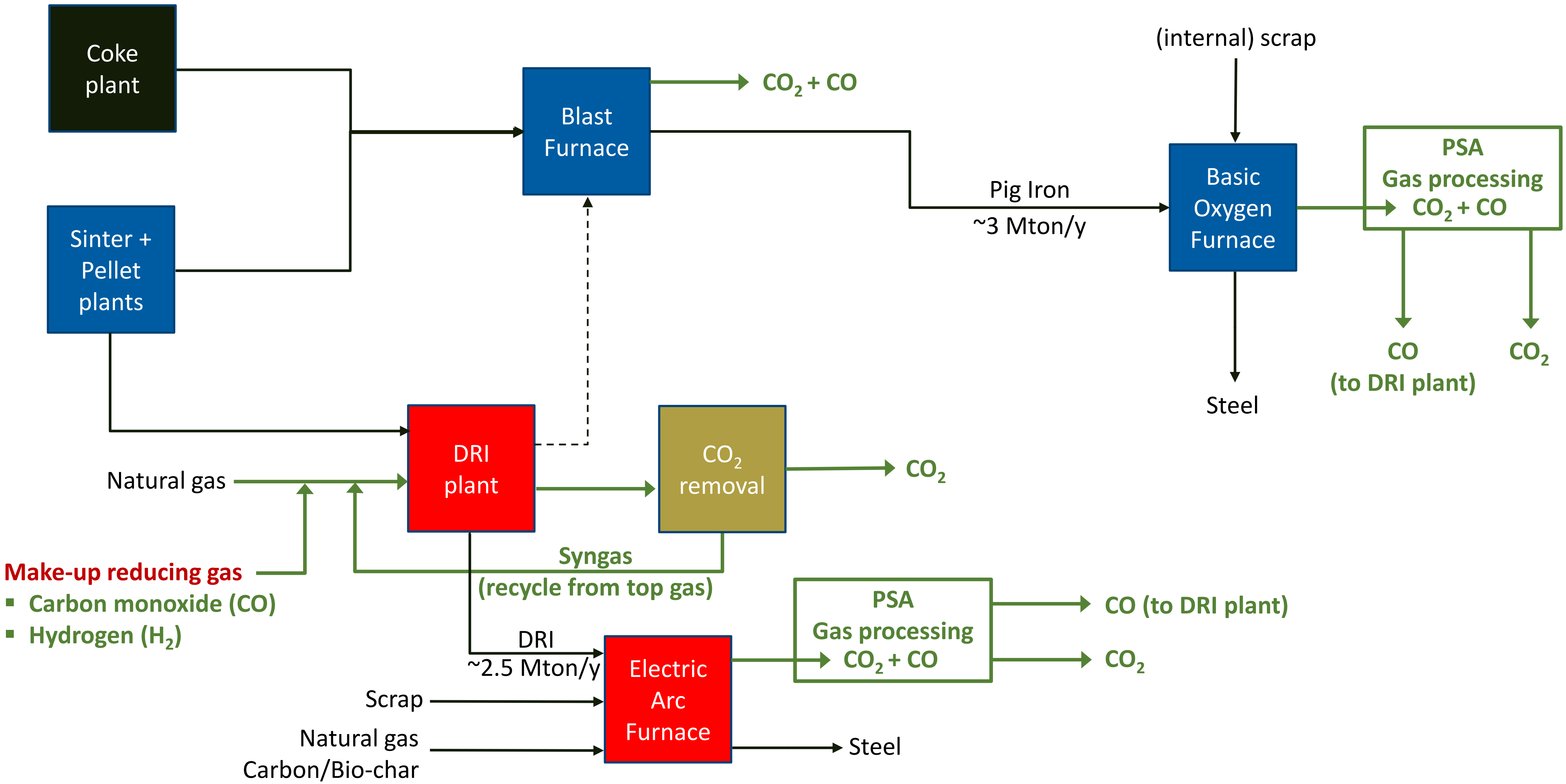




Current Scenario | BF-BOF route

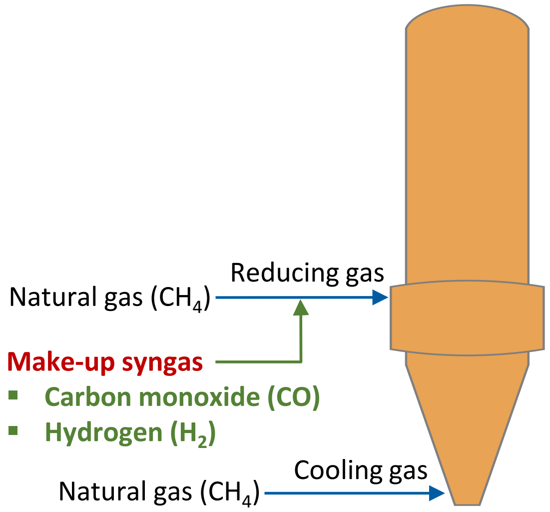


Future Scenario | Transition BF-BOF – DRI-EAF route



Case studies

- **Scenario analysis for CO-rich streams:**
  - BOF, EAF, mix of BOF+EAF off-gas streams
  - Scaling-up PSA ⇒ 2 kton/year → 100kton/year productivity
  - 1-step PSA (direct CO capture) ⇒ CO purity ≈ 90%
  - 2-steps PSA (CO_2 capture followed by CO capture) ⇒ CO purity > 95%

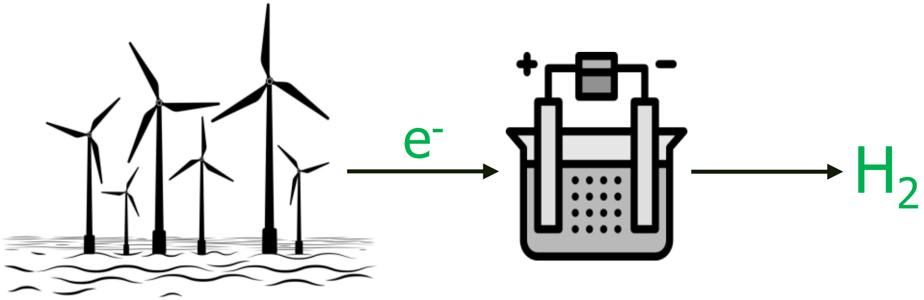


- **H_2 requirement for make-up syngas:**
  - Electrolytic H_2 from water electrolysis using renewable electricity
  - How much green H_2 can be used (to replace fossil-based H_2 or CH_4 in the reducing gas)?

Note:

- No changes to the composition of the reducing (and cooling) gas
- Carburization of DRI in the range of 2 to 4 wt. % carbon
- Minimum adjustment to plant configuration and operation
- Reduce CO_2 emission by reusing CO recovered from off-gases ⇒ reduce natural gas consumption

Electrolysis – H_2



- **H_2 requirement for DRI plant:**

  For 2.5 Mton/year DRI production using 100% H_2,

  H_2 ~ 140 kton H_2/year (*56 kg H_2/ton DRI*)

   ~ 800 MW PEM water electrolyzer (*20 kg H_2/MWh*)

   ~ 1600 MW off-shore wind farm (*capacity factor = 0.5*)

- Possible Integrations: Heat recovery from steel off-gases, O_2 from electrolysis for BOF, EAF

- Economics for PEM electrolyzer, and offshore wind turbines (*cost of H_2 ~ 5 to 10 €/kg!*)

Make-up syngas for Direct Reduction Process

For 2.5 Mton/year DRI plant,

- Add CO (recovered by PSA) and H_2 (electrolysis) for syngas make-up
- Match amount of H_2 to amount of CO (or the other way around)

H_2	66.3 vol. %	94 kton/year
CO	16.2 vol. %	329 kton/year
H_2:CO	4 : 1 (mol. basis)	**1 : 3.5** (wt. basis)

Estimations based on Zugliano (2013) for 1.76 Mton DRI/year at 2.3 wt. % C

- **Sources of CO**
  - Basic Oxygen Furnace (BOF) for 3 Mton HM/year ⇒ 100 kton CO/year
  - Electric Arc Furnace (EAF) for 2.5 Mton DRI/year ⇒ 50-150 kton CO/year
  - CO from PSA ⇒ **~120-200 kton CO/year** (@80% CO recovery)

- **Largest PEM electrolyzer – 100 MW**
  - Electrolytic H_2 ⇒ **17 kton H_2/year**
  - H_2:CO = 1 : 3.5 ⇒ **60 kton CO/year (~40% of available CO from PSA)**

- **15-20% reduction in natural gas consumption possible** !!

  (reduction up to 50% possible – subject to electrolytic H2 development !)

Conclusions

- Valorisation of steel off-gases during transition to BF-BOF – DRI-EAF route
- Combine PSA for CO recovery from steel off-gases with electrolytic H_2 for syngas make-up
- Decrease in steel off-gas availability (& lower heating value) – electrification is an option

Advantages:

- Reduce CO_2 emission by reusing CO in make-up syngas for DRP (+ CO_2 capture)
- Enabler of green H_2 use in ironmaking process
- Minimum adjustment to plant configuration and operation
- Reduction in natural gas consumption ⇒ 15-20%
  (reduction up to 50% possible – subject to electrolytic H_2 development !)

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Thank you for the attention

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