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TECHNO-ECONOMIC ASSESSMENT OF H₂-DRI AND NG-DRI-CCS PROCESSES FOR LOW-EMISSION IRON PRODUCTION

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DIGIMET



DANIELI AUTOMATION

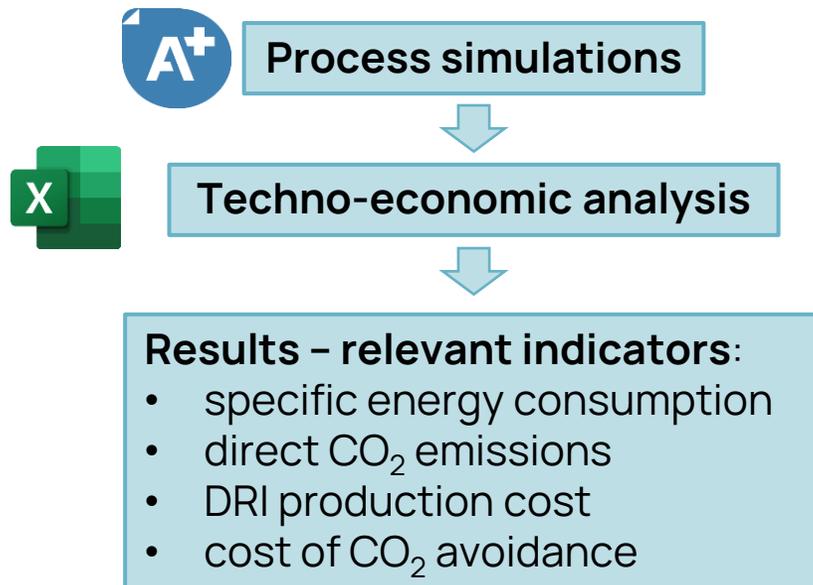


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Research goal

Techno-economic assessment of low-emission direct reduced iron (**DRI**) configurations based on carbon capture and storage (**CCS**), **electrification**, and **hydrogen**.

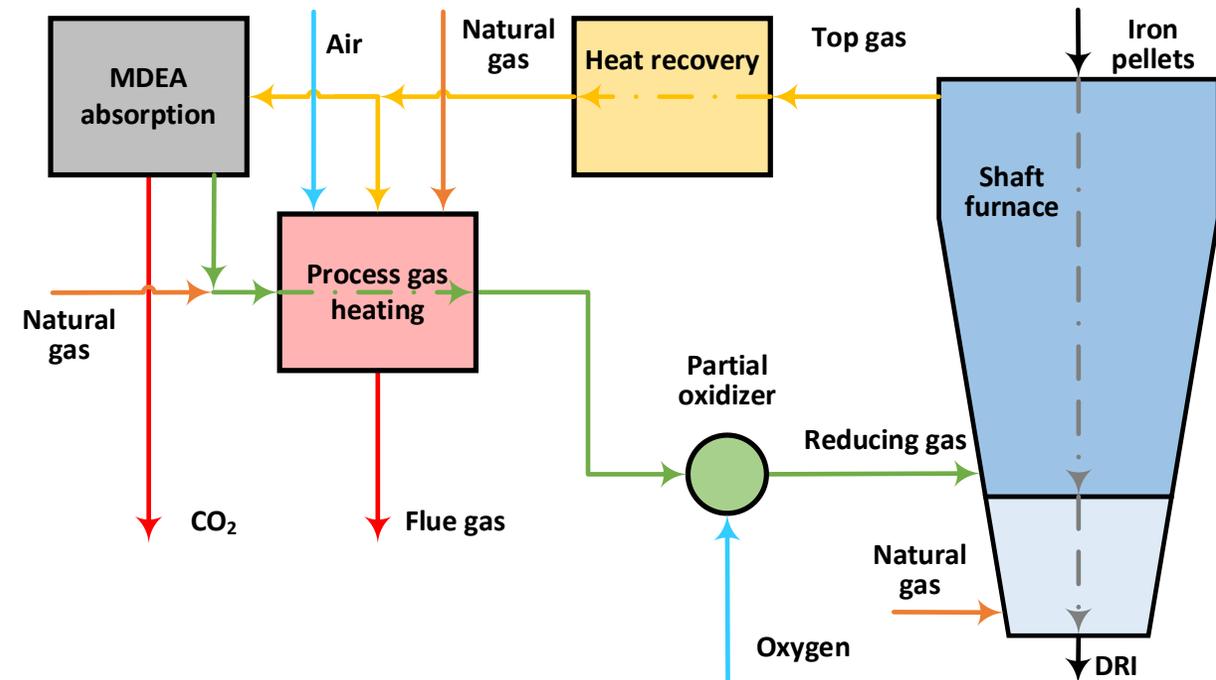
Configurations	Reducing gas	Process gas heater	Carbon capture
NG-DRI	Natural gas	NG fuel	-
NG-DRI-CCS (sel)	Natural gas	NG fuel	Separated CO ₂ stream
NG-DRI-CCS	Natural gas	NG fuel	Separated CO ₂ stream + flue gas
NG-DRI-el	Natural gas	Electrified	-
NG-DRI-el-CCS (sel)	Natural gas	Electrified	Separated CO ₂ stream
NG-DRI-el-CCS	Natural gas	Electrified	Separated CO ₂ stream + flue gas
H2-DRI-HTE	Hydrogen (high-temperature electrolysis)	Electrified	-
H2-DRI-LTE	Hydrogen (low-temperature electrolysis)	Electrified	-



NG-DRI

Reducing gas	Process gas heater	Carbon capture
Natural gas	NG fuel	-

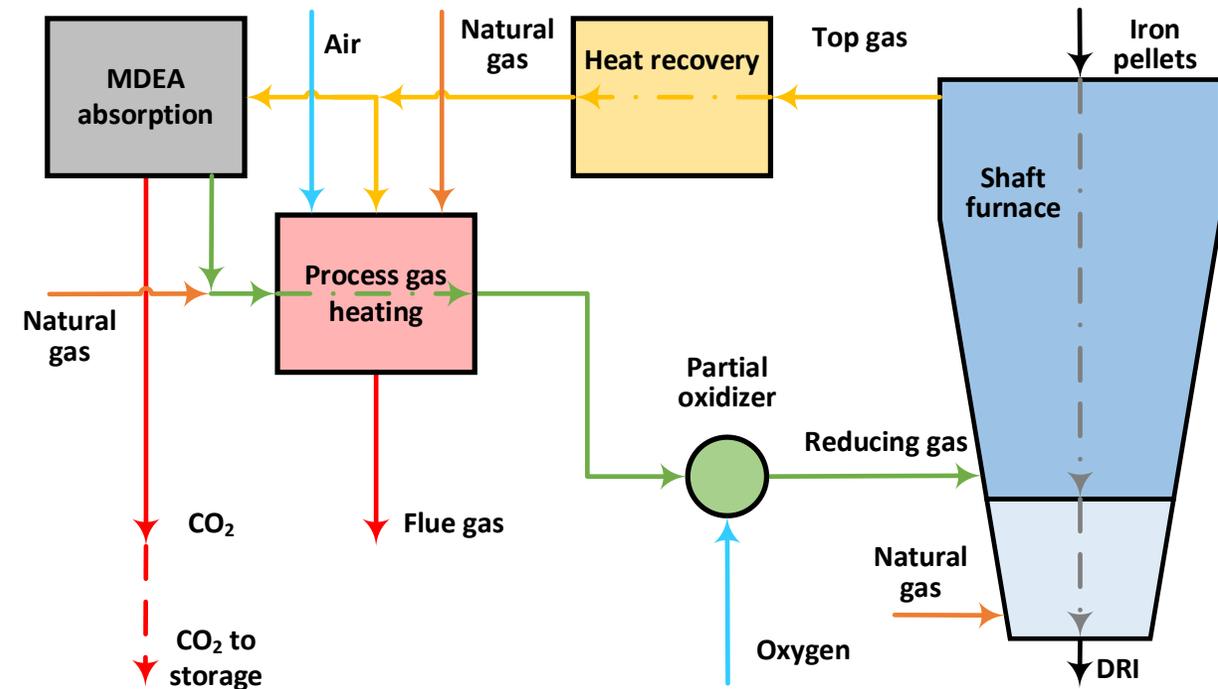
- Reference process based on **Energiron Zero Reformer (ZR)**
- **Natural gas** as fuel in **process gas heater**
- **Oxygen injection** prior to shaft furnace entrance
- **Natural gas for cooling and carburization** in the bottom of shaft furnace
- **CO₂ stream separated** from reducing gas recirculation



NG-DRI-CCS (sel)

Reducing gas	Process gas heater	Carbon capture
Natural gas	NG fuel	Separated CO ₂ stream

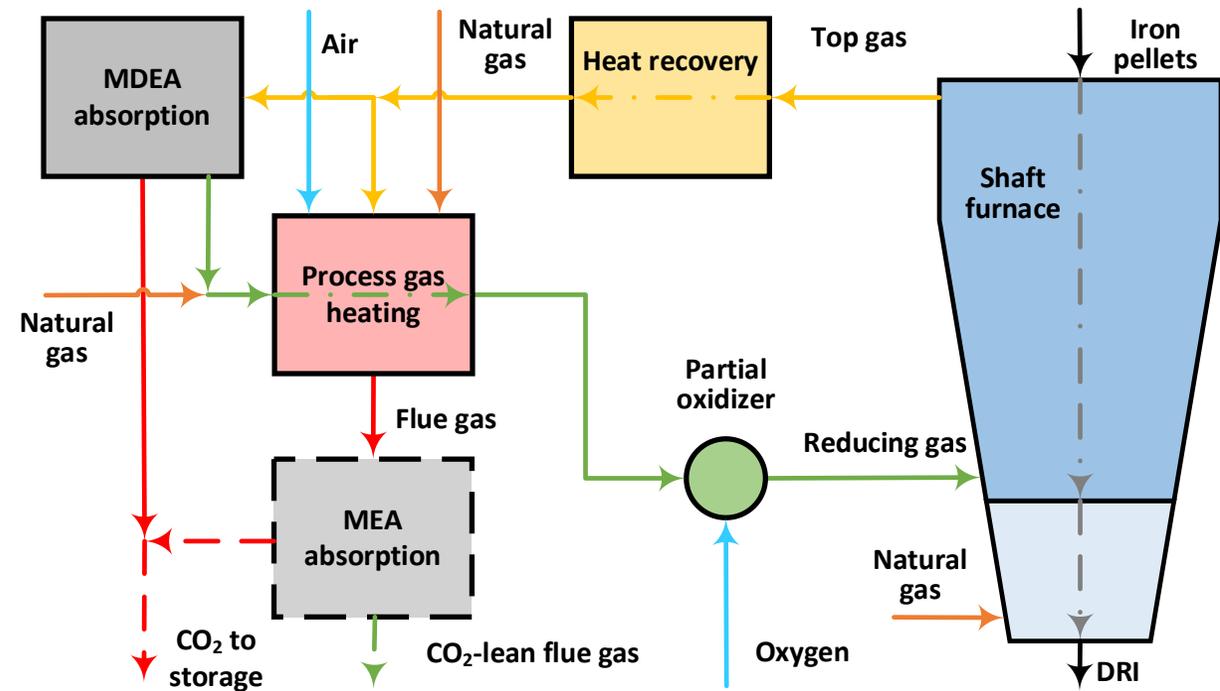
- **CO₂ stream separated** from reducing gas recirculation is **compressed and sent to storage**



NG-DRI-CCS

Reducing gas	Process gas heater	Carbon capture
Natural gas	NG fuel	Separated CO ₂ stream + flue gas

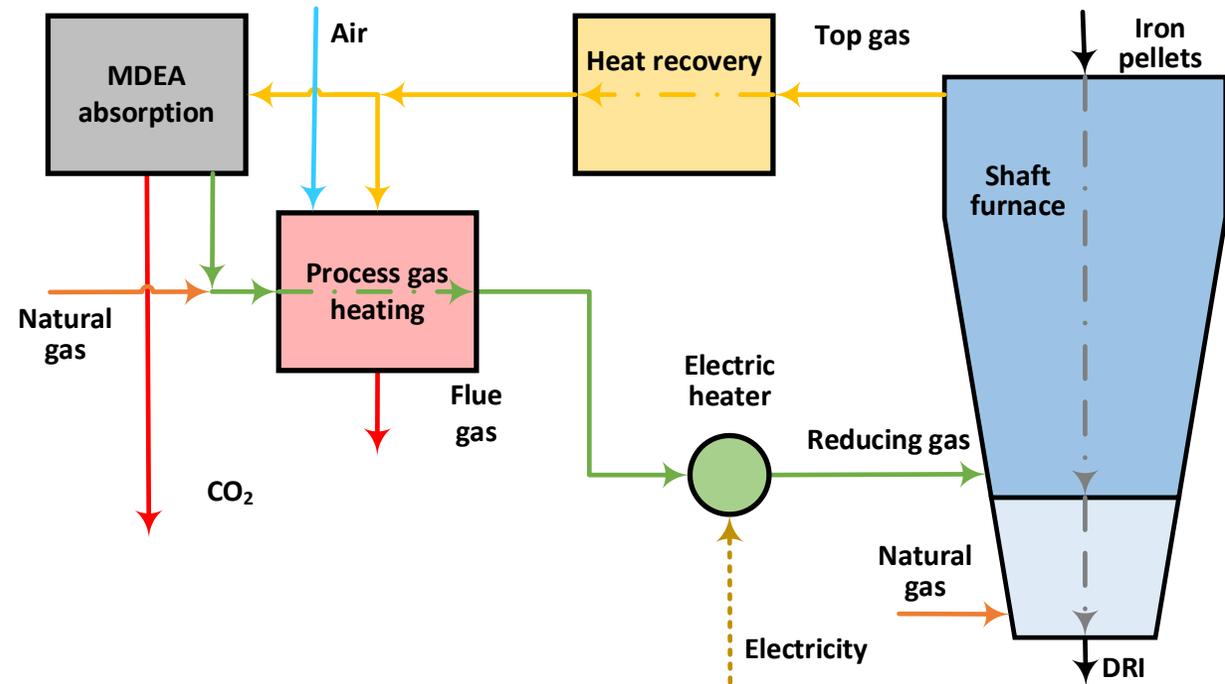
- In addition, **post-combustion CO₂ capture** from process gas heater flue gas



NG-DRI-e

Reducing gas	Process gas heater	Carbon capture
Natural gas	Electrified	-

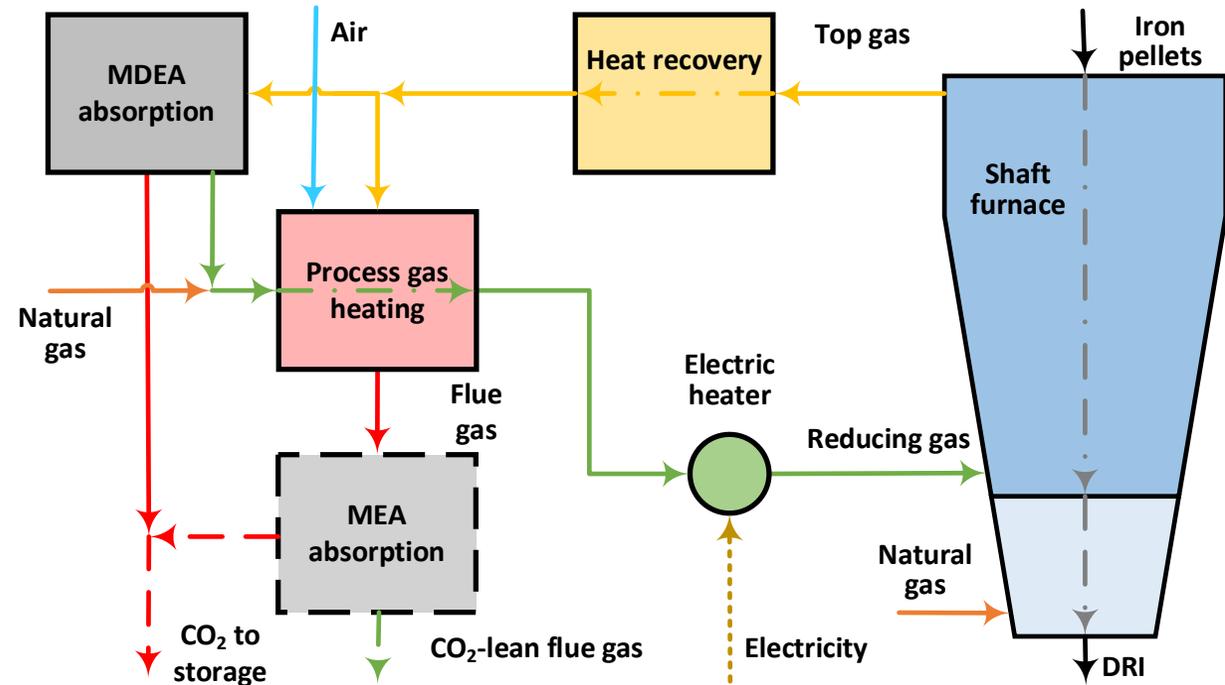
- Removal of natural gas injection in the process gas heater
 - Removal of oxygen injection
- Electric heater



NG-DRI-eI-CCS

Reducing gas	Process gas heater	Carbon capture
Natural gas	Electrified	Separated CO ₂ stream + flue gas

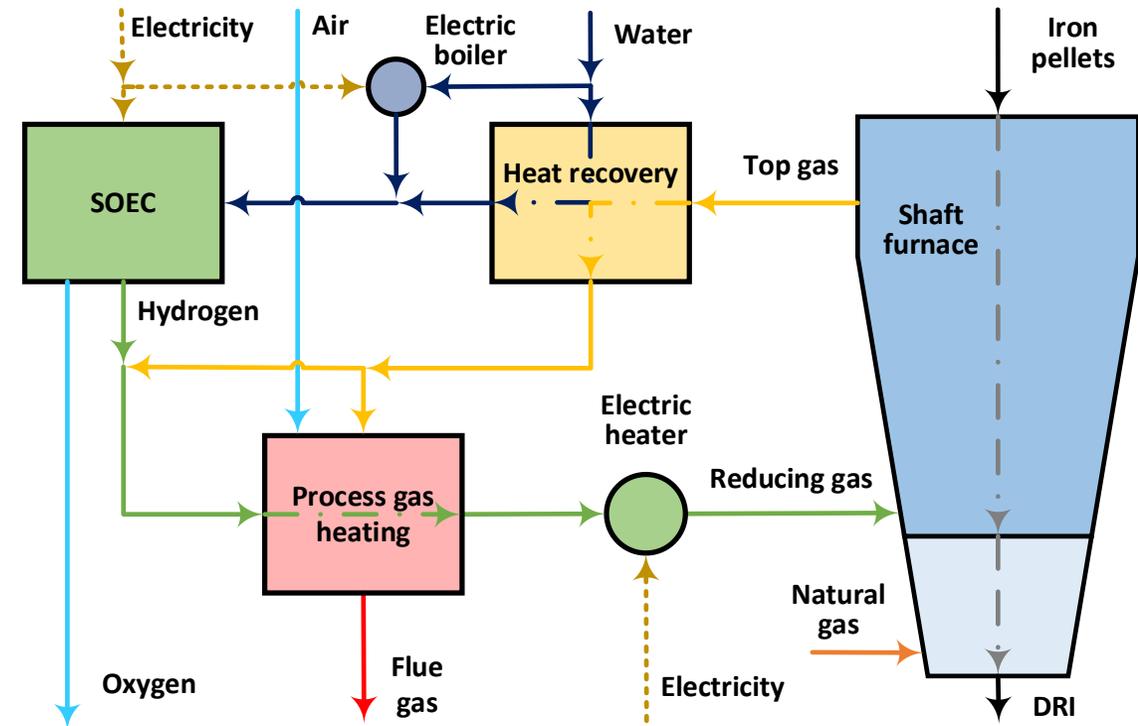
- In addition, **post-combustion CO₂ capture** from process gas heater flue gas



H₂-DRI-HTE

Reducing gas	Process gas heater	Carbon capture
Hydrogen (high-temperature electrolysis)	Electrified	-

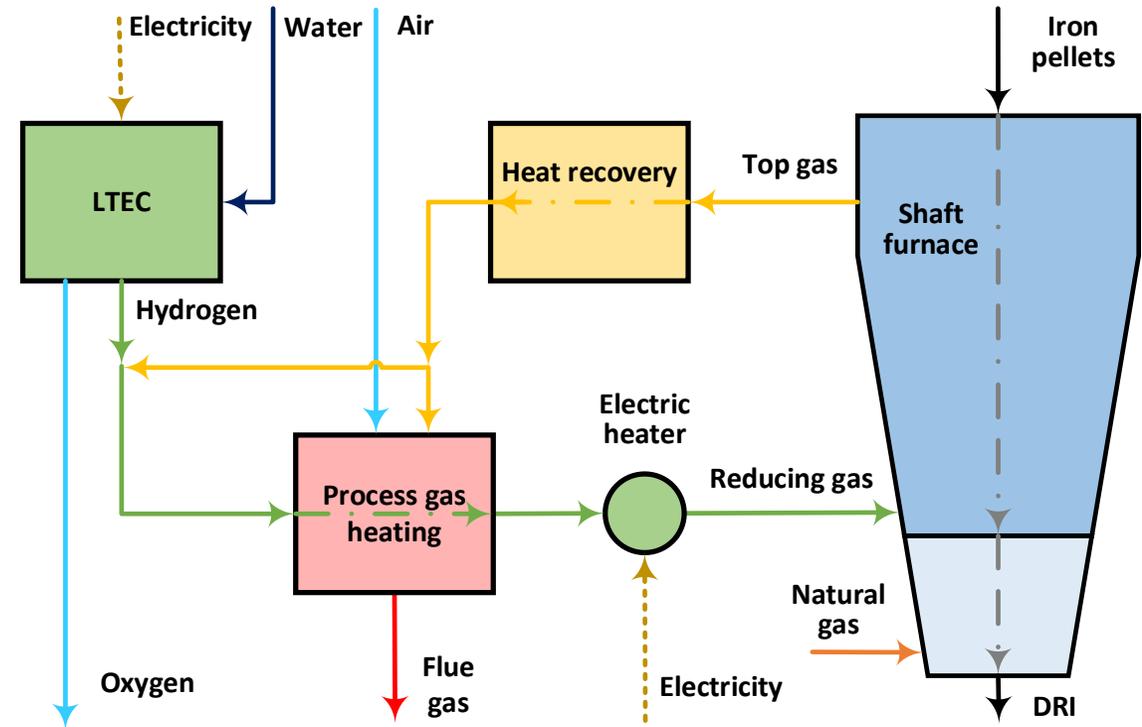
- **SOEC system** to produce hydrogen as reducing agent
- **Thermal integration:** steam for SOEC is partially produced through internal heat recovery
- **Natural gas for cooling and carburization** in the bottom of shaft furnace



H₂-DRI-LTE

Reducing gas	Process gas heater	Carbon capture
Hydrogen (low-temperature electrolysis)	Electrified	-

- **LTE system** to produce hydrogen as reducing agent
- **No thermal integration**



MODELING ASSUMPTIONS

Process simulations on **Aspen Plus**[®]: representative plant capacity of **2 Mt_{DRI}/y**



Electrolysis section (H₂-DRI cases):

- SOEC: lumped model ($UF_{H_2O} = 70\%$, $T = 700^\circ\text{C}$, $p = 8 \text{ bar}$)
- LTE: $\eta_{LHV} = 60\%$

CO₂ capture section (NG-DRI-CCS cases):

- MDEA:
 - Thermal duty = $1.5 \text{ MJ}_{th}/\text{kg}_{CO_2}$
 - Capture ratio ~ 90%
- MEA:
 - Thermal duty = $4 \text{ MJ}_{th}/\text{kg}_{CO_2}$
 - Capture ratio = 95%

Top gas:

- Shaft furnace outlet $T = 475^\circ\text{C}$
- Cooling to 200°C for heat recovery

DRI product:

- Outlet $T = 650^\circ\text{C}$
- Metallization = 95%
- Carbon (C) content:
 - $3\%_{wt}$ for NG-DRI
 - $0.9\%_{wt}$ for H₂-DRI

TECHNO-ECONOMIC ASSUMPTIONS

- Plant lifetime: 25 years
- Discount rate: 8%
- **CAPEX**: sum of individual component costs multiplied by an installation factor of 2

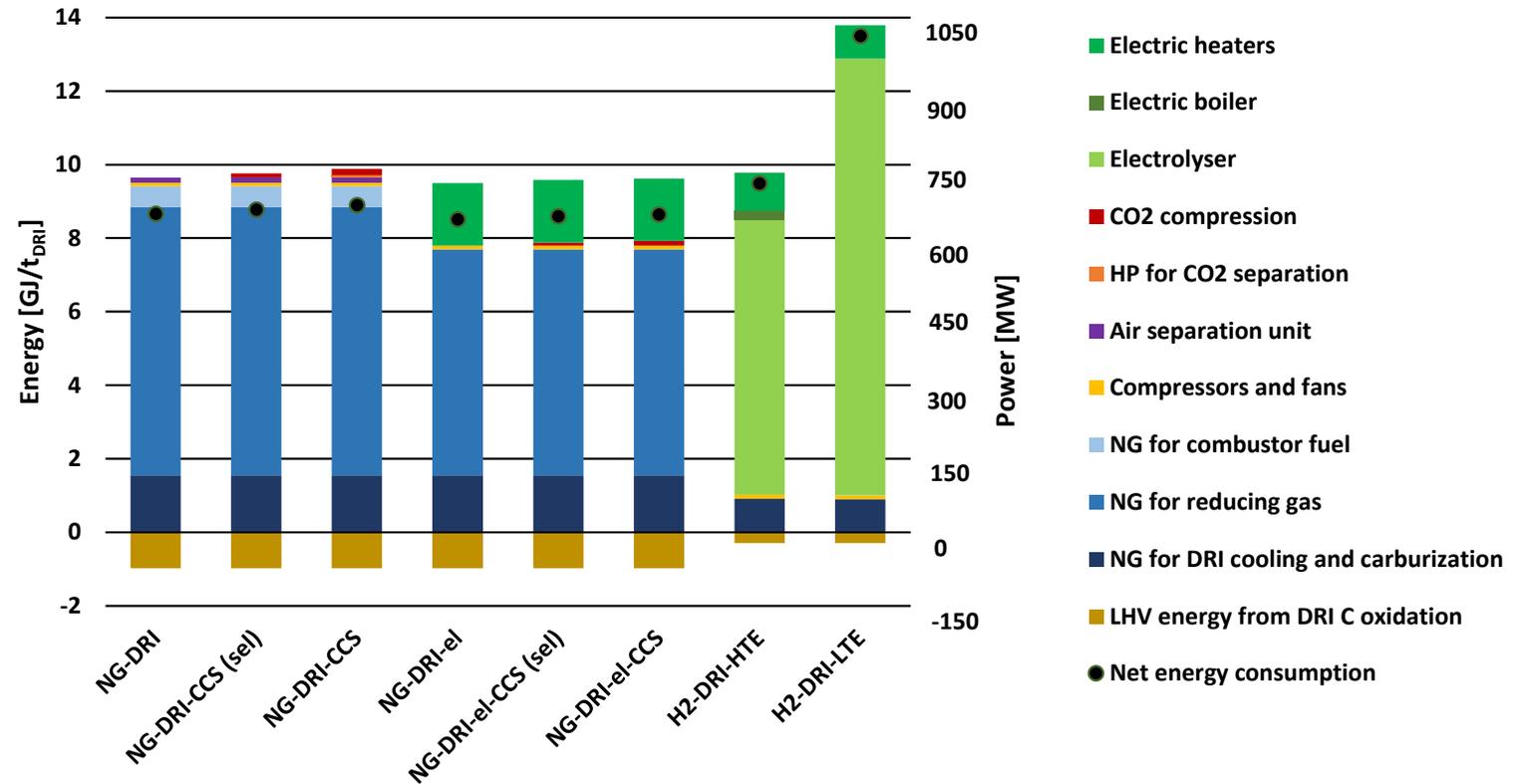
DOE targets based on the assumption of fully developed manufacturing scales

- **OPEX**:
 - **OPEX_{fix}** = 3%/y of the total CAPEX
 - **cost of feedstocks, utilities and externalities** (varied in sensitivity analysis)

Component	Specific cost
DRI plant	230 €/tpa
CO ₂ capture and compression	4.04 M€/tph
SOEC system	775 €/kW _e
LTE system	425 €/kW _e
Iron ore	100 €/t _{iron ore}
Natural gas	30 €/MWh _{LHV}
Electricity (high)	100 €/MWh _e
Electricity (low)	40 €/MWh _e
Carbon tax	150 €/t _{CO2}
CO ₂ transport and storage	50 €/t _{CO2}

ENERGY PERFORMANCE

- **Energy consumption:**
electricity + natural gas (LHV)
- **LHV from DRI C oxidation** as negative contribution
- **Similar total energy inputs** for all configurations (-1.5% to +3% wrt reference) **except H₂-DRI-LTE**
→ low efficiency of electrolysis system



* the reducing mass flow rates are tuned to keep a constant top gas outlet temperature

ENVIRONMENTAL PERFORMANCE

- **Direct CO₂ emissions:**

DRI plant + DRI use



- **Selective CO₂ capture:**

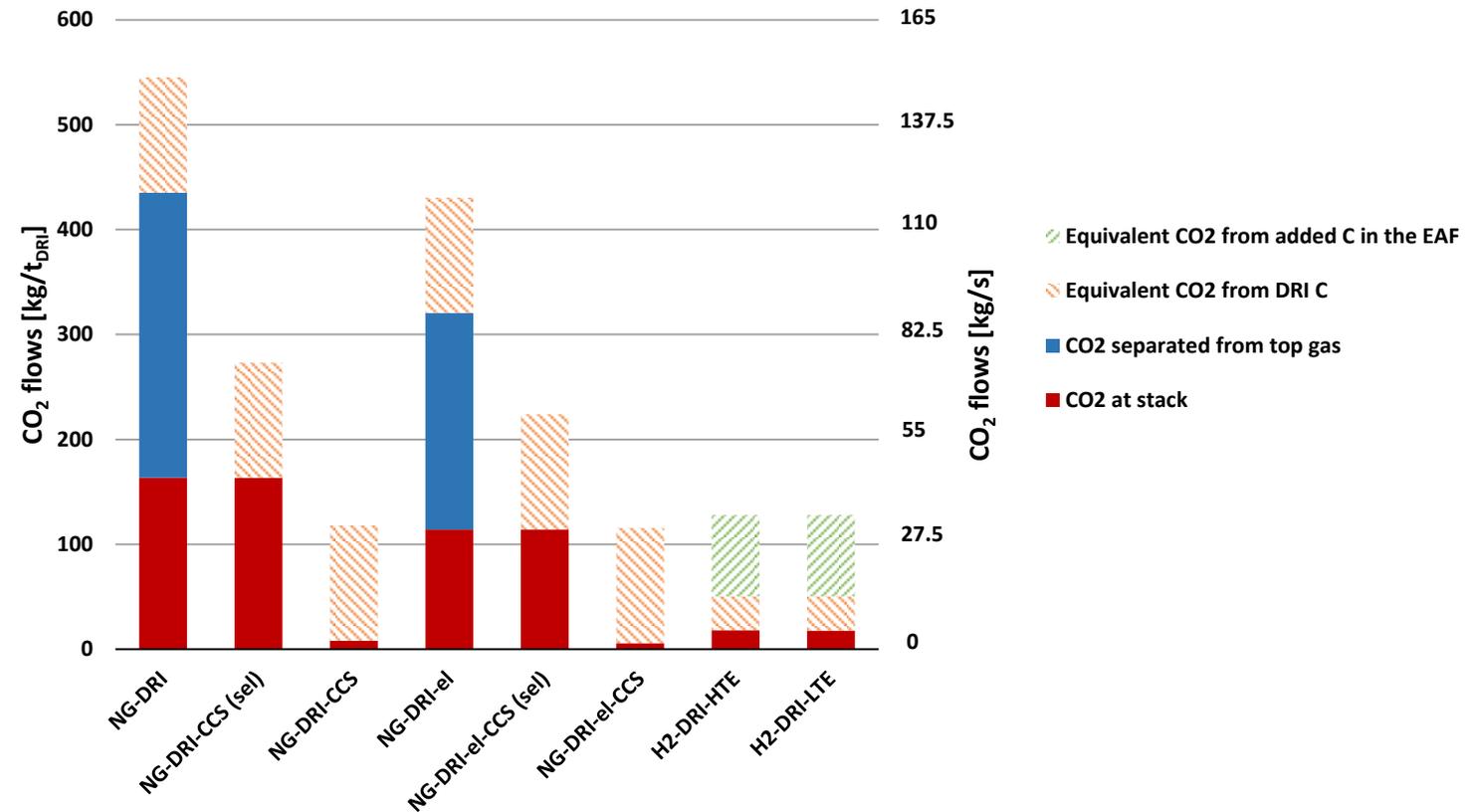
cuts emissions by 62%

- **Electrified configuration:**

cuts emission by 26%

- **Full-CCS and H₂ cases:**

< 20 kg_{CO2}/t_{DRI}



ECONOMIC PERFORMANCE

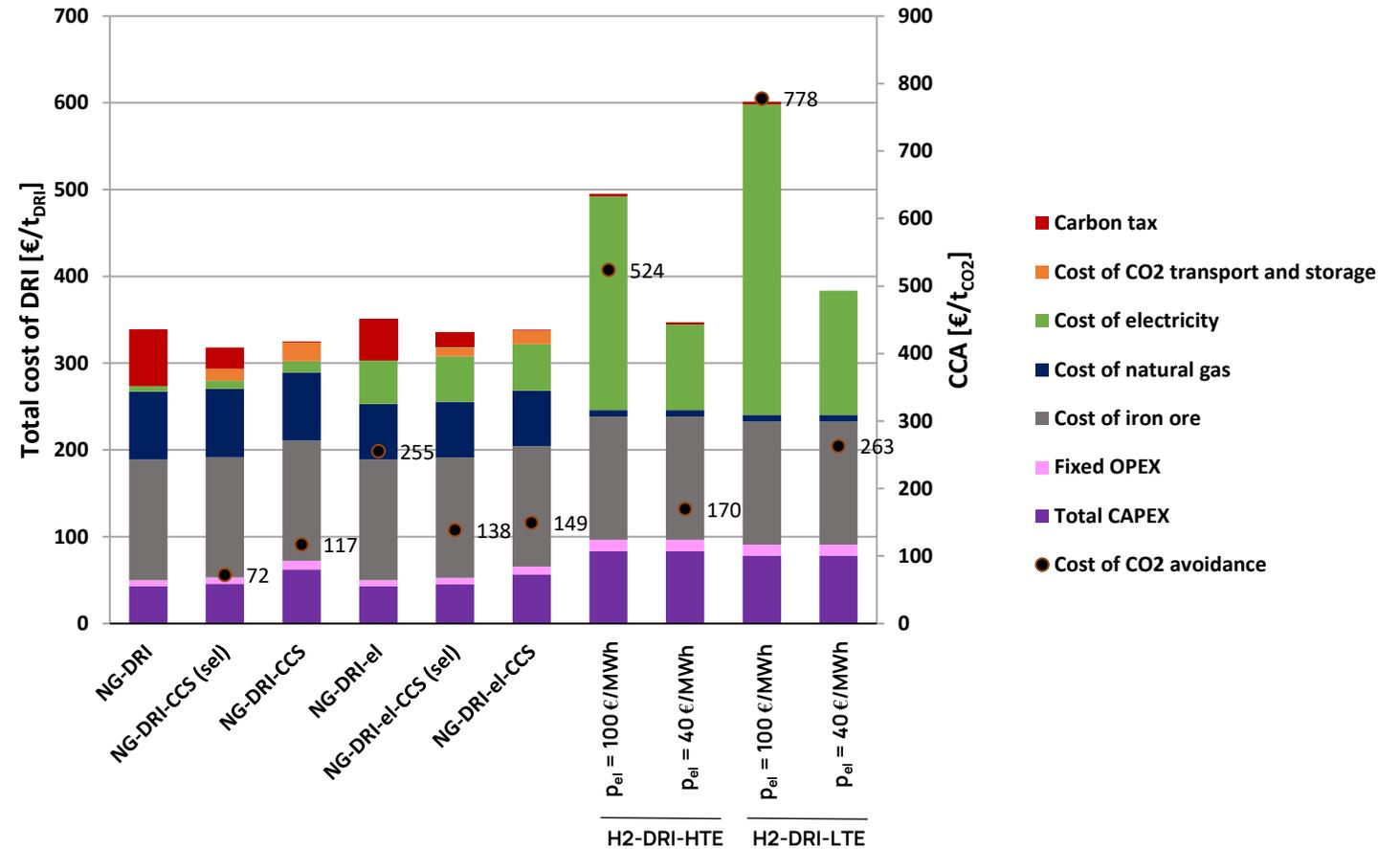
- **Cost of CO₂ avoidance:**

$$CCA = \frac{\Delta Cost_{DRI}}{\Delta CO_2 \text{ emissions}} \text{ [€/t}_{CO_2}\text{]}$$

- **NG-DRI-CCS cases:** lower total costs than reference

(CCA < carbon tax)

- **H₂-DRI:** much higher costs under high electricity price scenario
- **H₂-DRI-HTE:** cost-competitive under low electricity price scenario

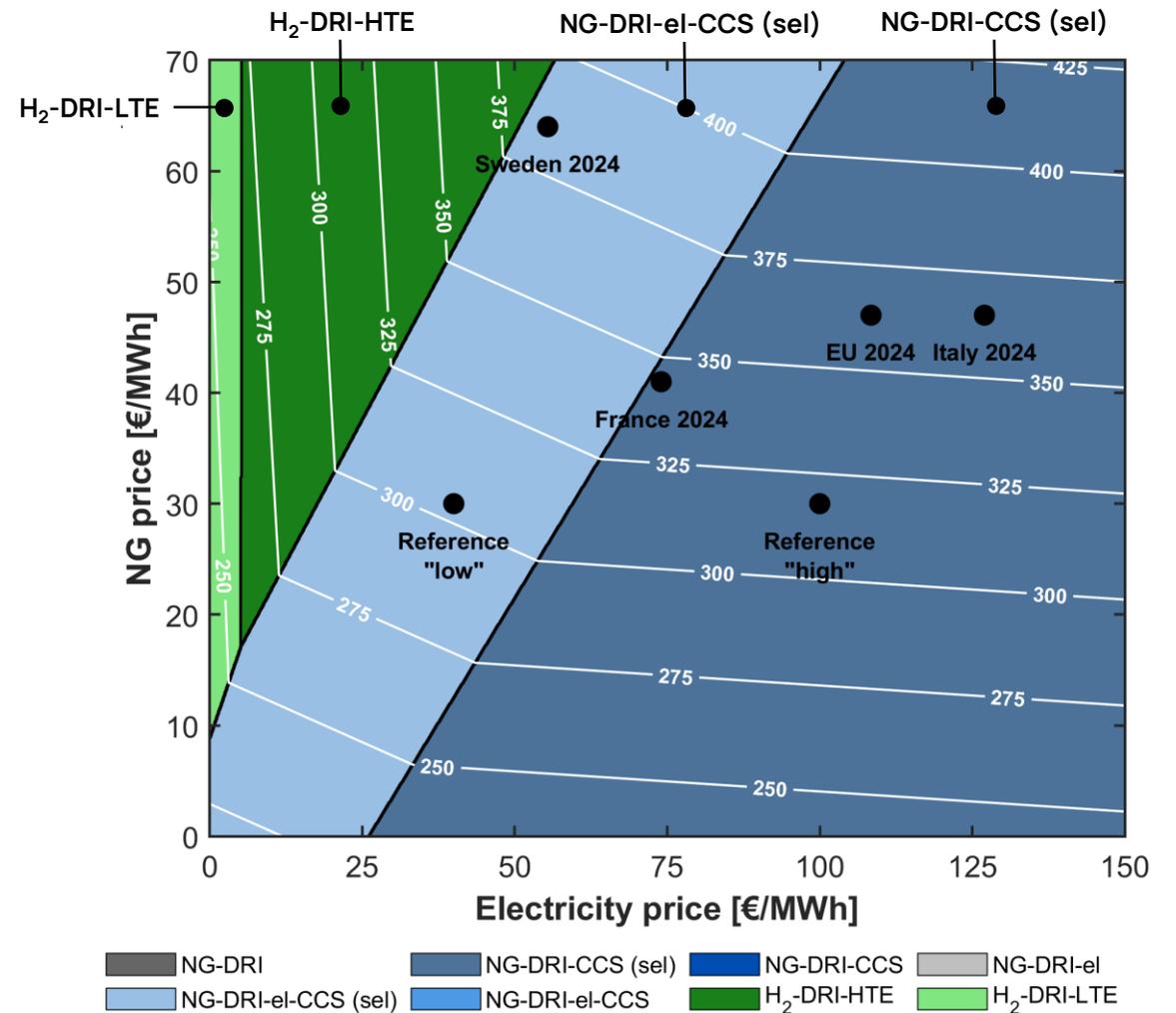


OPTIMAL DRI TECHNOLOGY REGIONS

Economic optimal configuration as a function of natural gas and electricity prices:

→ electricity price is the main driver!

- **NG-DRI-CCS cases:** most competitive in wide price ranges
- **H₂-DRI-HTE:** for high NG and low electricity prices
- **H₂-DRI-LTE:** only in a narrow region



* Energy prices from Eurostat (non-household large consumers)

CONCLUSIONS



Electrification of the process gas heater can reduce CO₂ emission by 26% vs. reference, and is penalized economically by higher electricity costs compared to natural gas



For **high CO₂ avoidance targets**, the **full-CCS** option appears the most cost-competitive



H₂-DRI configurations become competitive only if the **electricity-to-natural gas price ratio** is **low** (< 0.8)



NG-DRI with selective CCS offers an interesting **trade-off for partial decarbonization** under current reference prices



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Thank you for your attention!

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