# INITIATE
## A STEPWISE PROJECT

# Definition of the base and reference cases for KPIs assessment

Deliverable report D5.3

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PUBLIC

# Presentation outlines

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# INITIATE project

Accelerate the transition towards sustainable symbiotic industrial systems



Intensity values per ton of residual steel gas
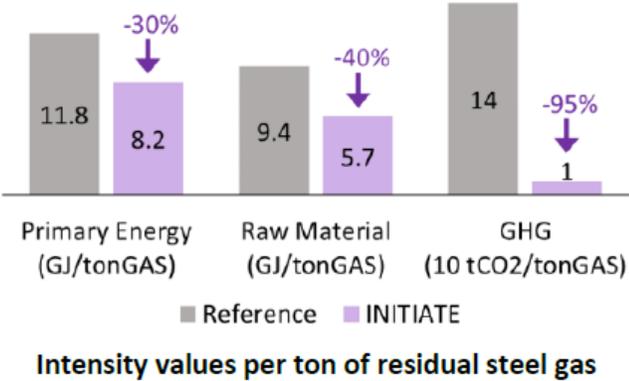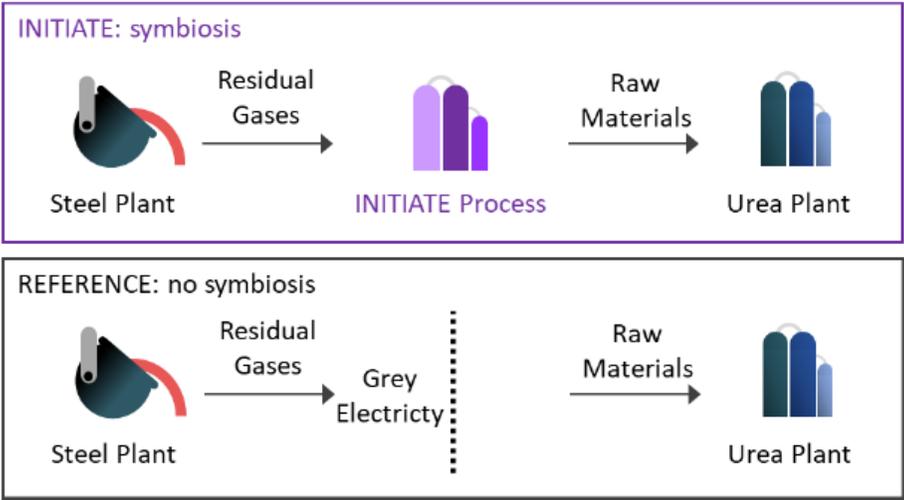
by demonstrating **Urea production** from **Steel Works Arising Gases**

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# Conventional approach

Separate steel and urea production

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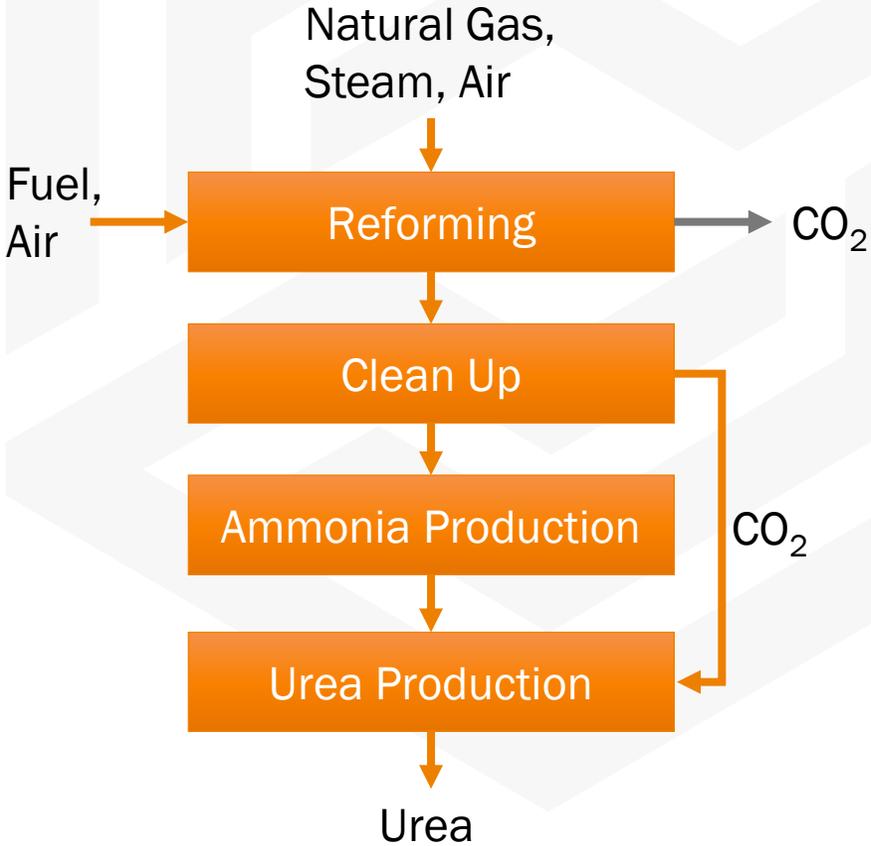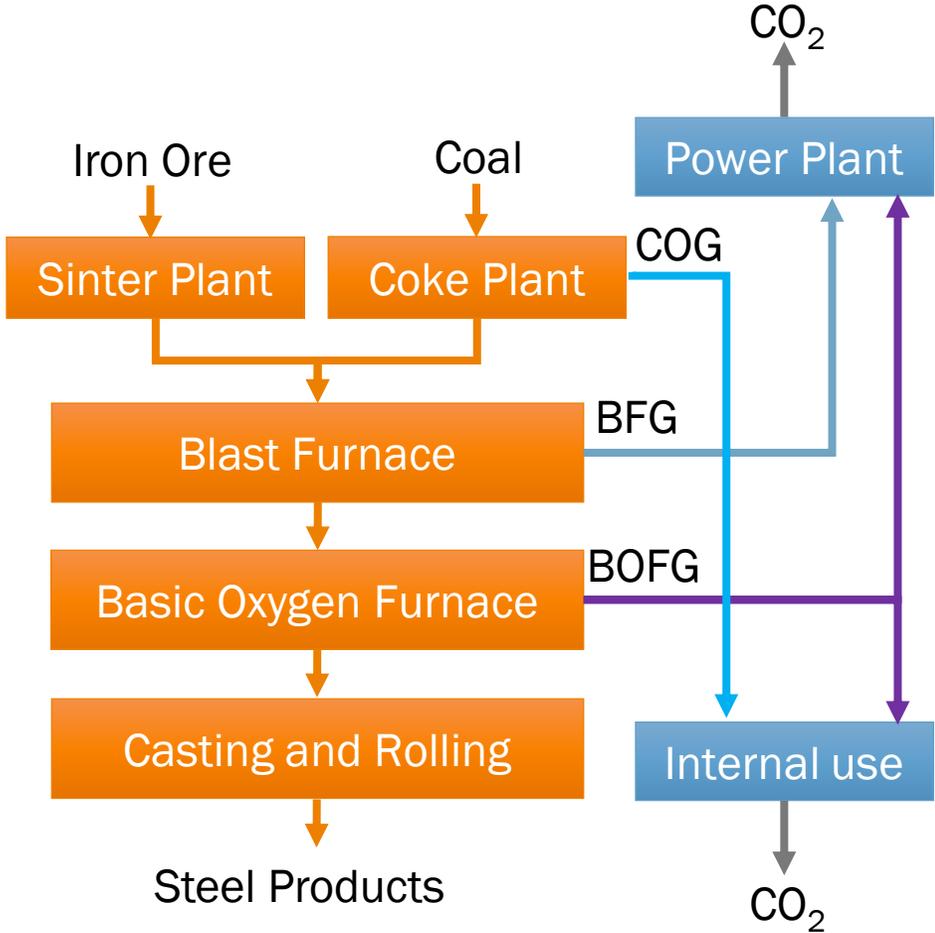
# INITIATE project

Combined steel and urea production thanks to industrial symbiosis between steel and fertilizer industries
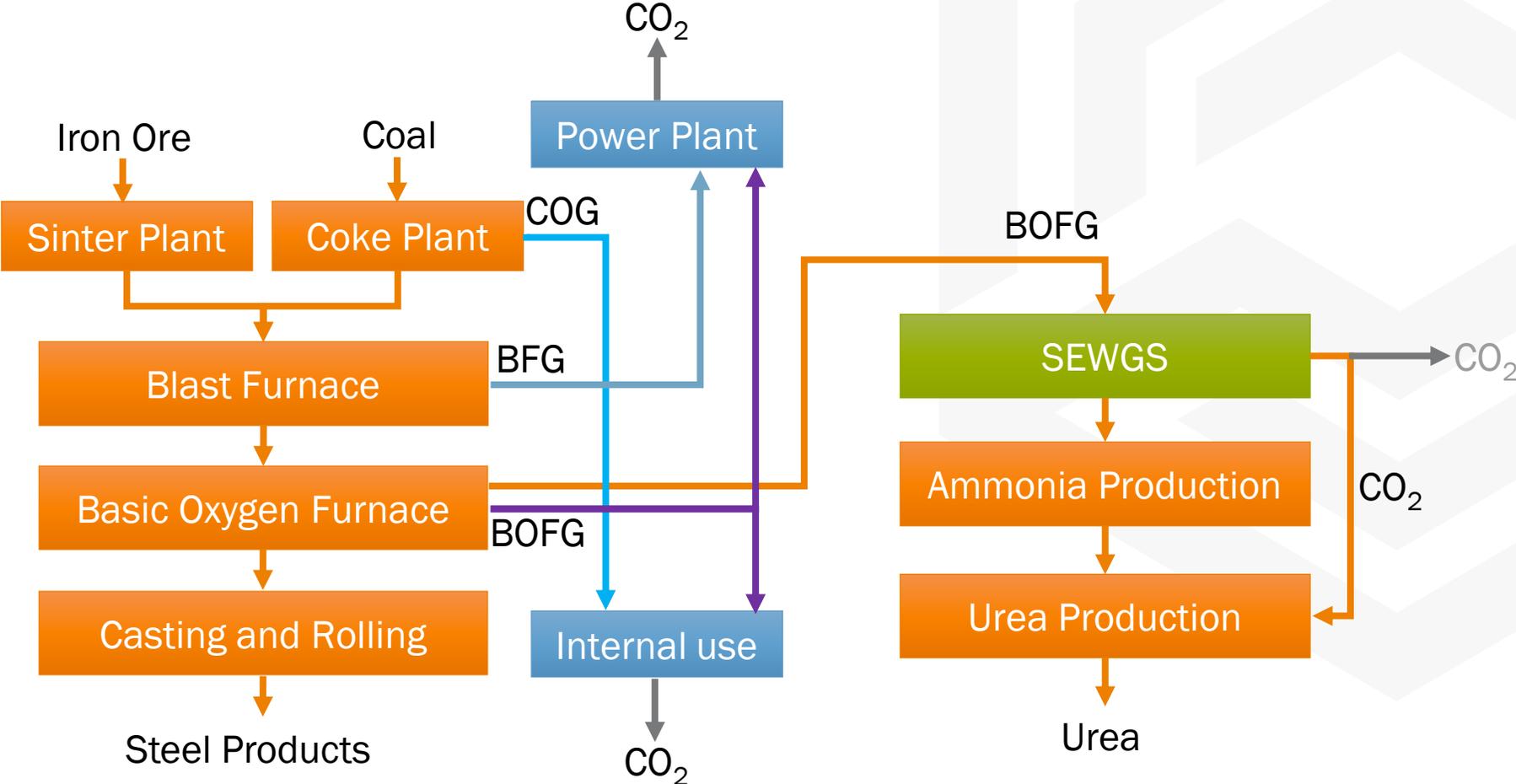
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| **3** | Definition of the Reference cases |
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# Base cases

State-of-the-art commercially available plants

| Plant | Product | Size | Technology | Application |
|---|---|---|---|---|
| Steel Plant | Hot rolled coil | 3.16 Mt/y[a] | | |
| Ammonia Plant | Ammonia | 86 t/d[b] | NG steam reforming | Stand alone or coupled with urea plant |
| | | 848 t/d[c] | NG steam reforming | Stand alone or coupled with urea plant |
| Urea Plant | Liquid Urea | 150 t/d | Conventional total recycling | AdBlue |
| | | 1500 t/d | $CO_2$ Stripping | Liquid Fertilizer |

[a] C4U project – Advancing Carbon Capture for Steel Industry
[b] Size of the ammonia plant for AdBlue application
[c] Size of the ammonia plant for Fertilizer application

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# Base Cases - Schematic of commercially available plants
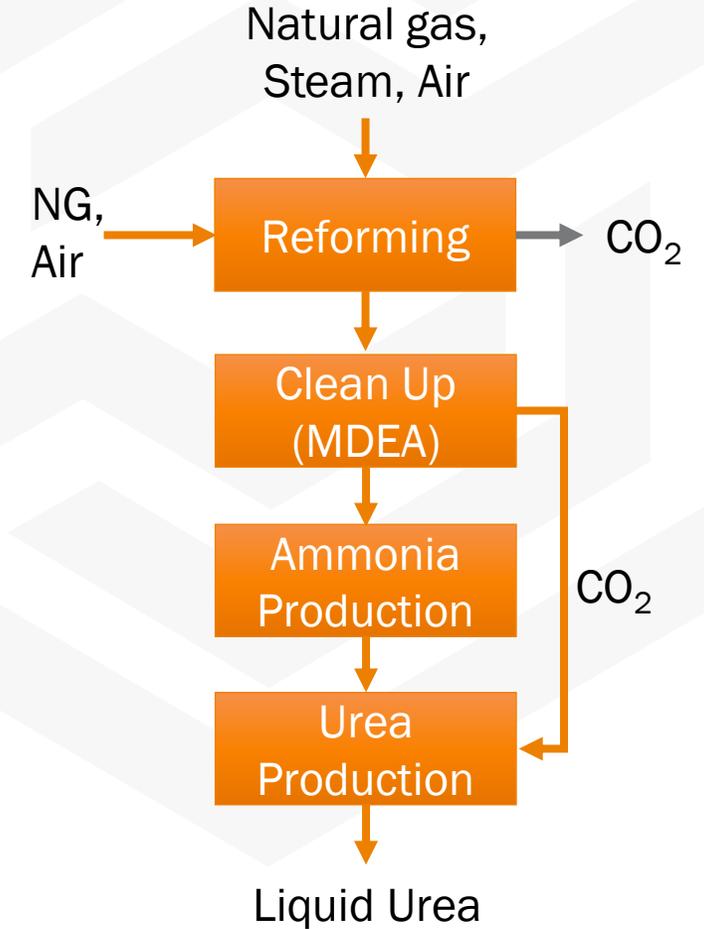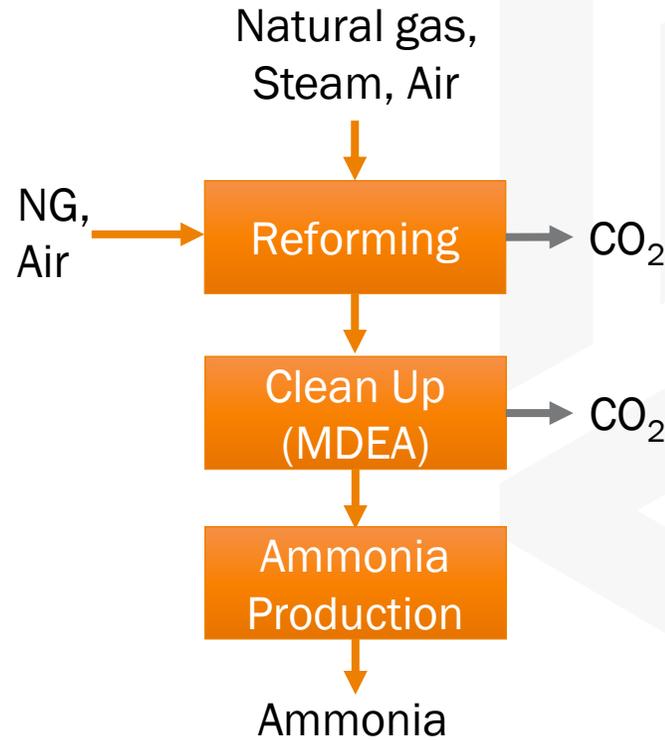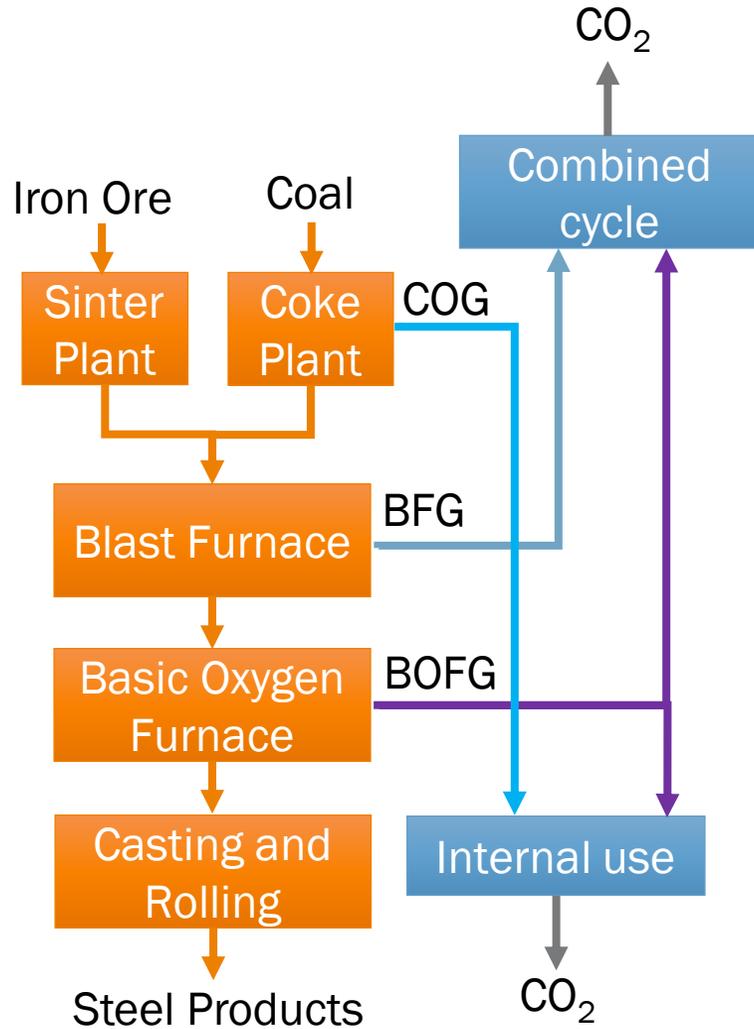
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# Reference Case

State-of-the-art commercially available plants with $CO_2$ capture technologies

| Plant | Product | Size | Technology | $CO_2$ capture | Application |
|---|---|---|---|---|---|
| Steel Plant | Hot rolled coil | 3.16 Mt/y[a] | | MDEA pre-comb on BFG | |
| Ammonia Plant | Ammonia | 86 t/d[b] | NG steam reforming | MEA post-comb | Stand alone or coupled with urea plant |
| | | 848 t/d[c] | NG steam reforming | MEA post-comb | Stand alone or coupled with urea plant |
| Urea Plant | Liquid Urea | 150 t/d | Conventional | None | AdBlue |
| | | 1500 t/d | $CO_2$ Stripping | None | Liquid Fertilizer |

[a] C4U project – Advancing Carbon Capture for Steel Industry
[b] Size of the ammonia plant for AdBlue application
[c] Size of the ammonia plant for Fertilizer application

# Reference cases

State-of-the-art commercially available plants with $CO_2$ capture technologies
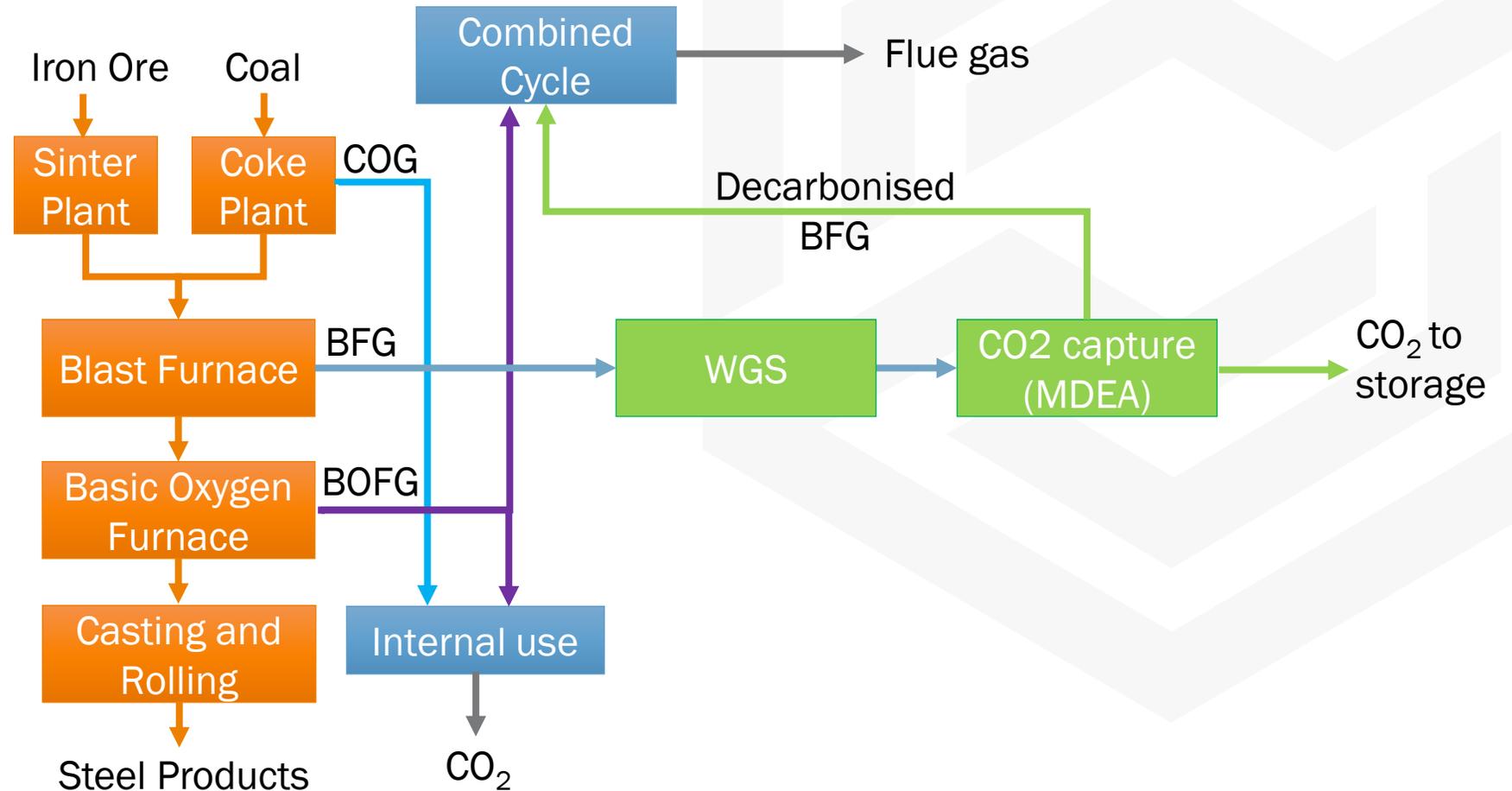
# Reference cases

State-of-the-art commercially available plants with $CO_2$ capture technologies
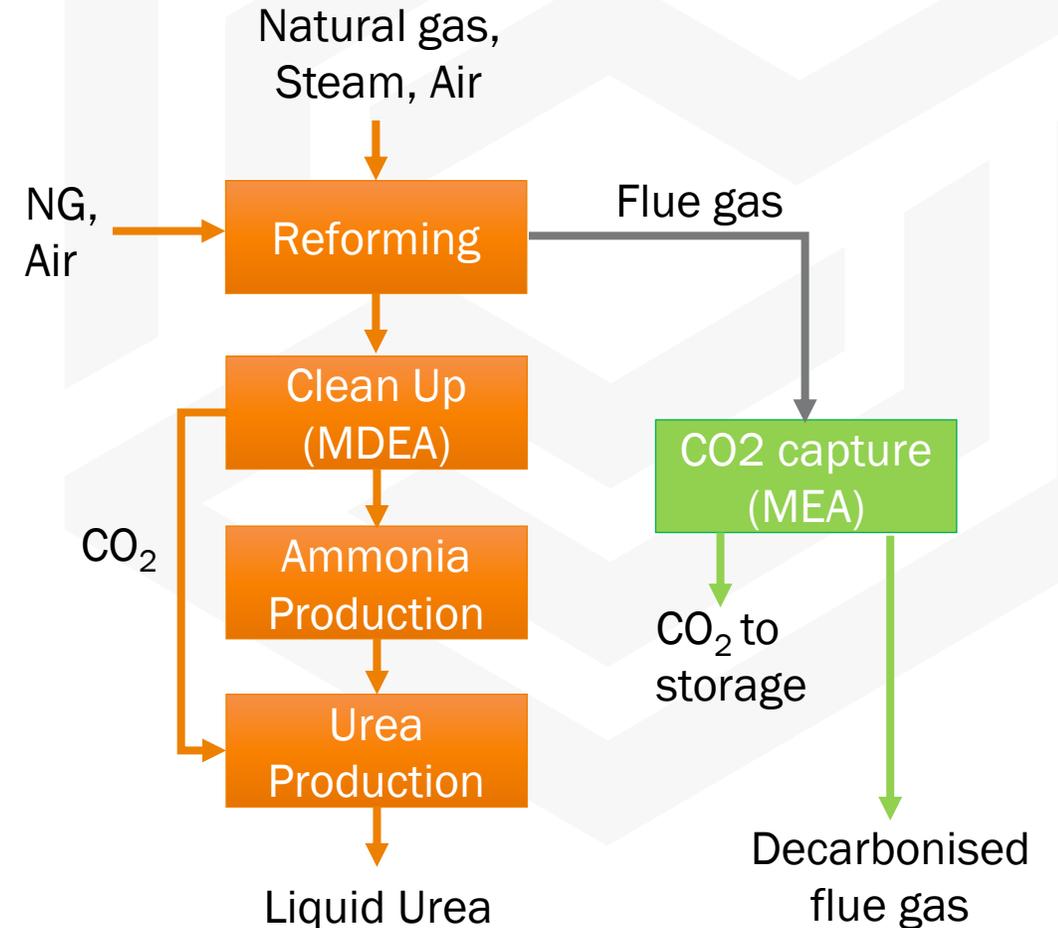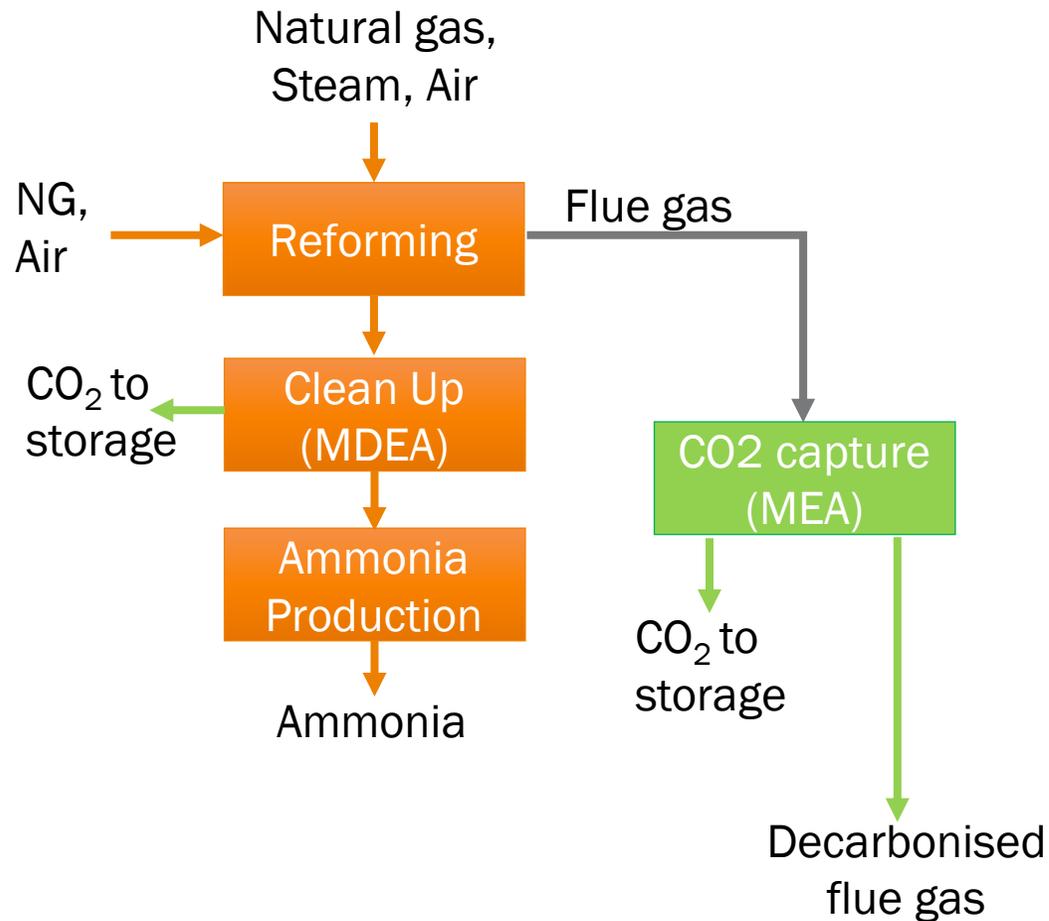
# Presentation outlines

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# Key Performance Indicators

- Primary Energy Consumption: $PEC \left[\dfrac{GJ_{LHV}}{t_x}\right] = \dfrac{\dot{m}_{fuel}LHV_{fuel} + \dot{W}_{req}/\eta_{el} + \dot{Q}_{req}/\eta_{th}}{\dot{m}_x}$

- Process carbon intensity: $e_{CO_2} \left[\dfrac{t_{CO_2}}{t_x}\right] = \dfrac{\dot{m}_{CO_2}}{\dot{m}_x}$

- Cost of CO$_2$ Avoided: $CCA \left[\dfrac{€}{t_{CO_2}}\right] = \dfrac{Cost_{capture} - Cost_{nocapture}}{e_{nocapture} - e_{capture}}$

- Specific Energy Consumption for CO$_2$ Avoided: $SPECCA \left[\dfrac{GJ}{t_{CO_2}}\right] = \dfrac{PEC_{capture} - PEC_{nocapture}}{e_{nocapture} - e_{capture}}$

- Carbon Capture Ratio: $CCR[\%] = \dfrac{e_{nocapture} - e_{capture}}{e_{nocapture}} \cdot 100$

- Levelized cost of x

X = product (i.e. urea, ammonia, hot rolled coil)

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# Results – Steel plants

## Primary energy consumption - Steel plants

Base case: 21.30 [GJ/t_HRC]
Reference case: 22.97 [GJ/t_HRC]

## Carbon intensity - Steel plants

Base case: Steel mill carbon intensity 1.11, Power section carbon intensity 0.71 [t_CO2/t_HRC]
Reference case: Steel mill carbon intensity 1.11, Power section carbon intensity 0.12 [t_CO2/t_HRC]

■ Steel mill carbon intensity   ■ Power section carbon intensity

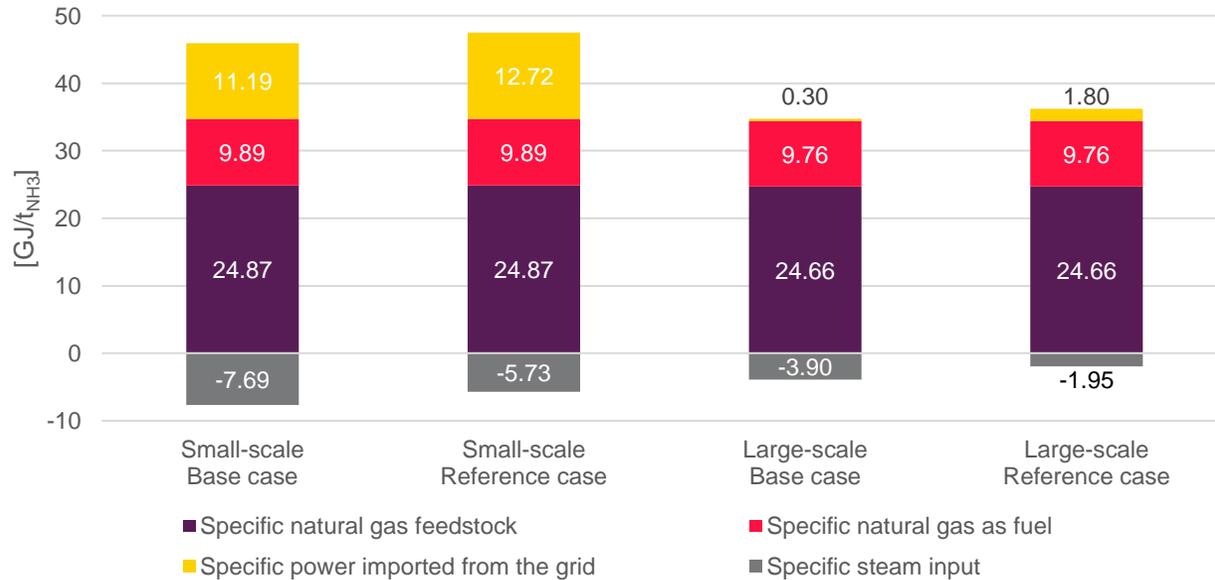## Levelized cost of hot rolled coil

Base case: 468.00 [€/t_HRC]
Reference case: 491.65 [€/t_HRC]
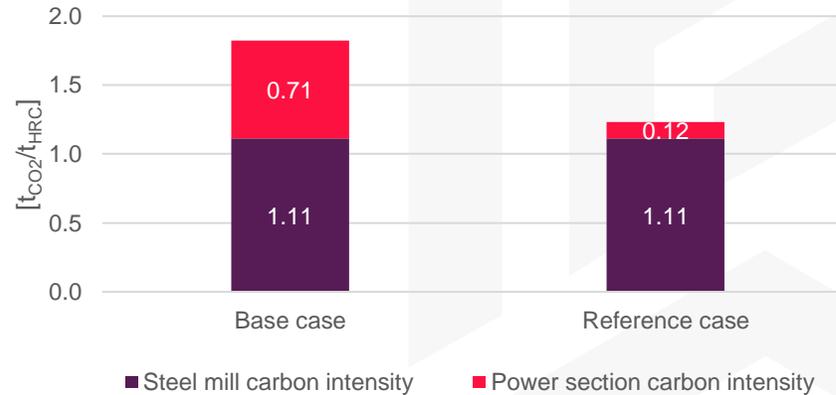
- PEC of reference case is higher than PEC of base case because of the additional heat necessary for the regeneration of solvent in CC section.
- Carbon intensity of the whole steel plant decreases from 1.82 $t_{CO2}/t_{HRC}$ to 1.28 $t_{CO2}/t_{HRC}$ corresponding to CA = 29.8% for the whole plant and a CA = 83.1% considering the power section only.
- Levelized cost of hot rolled coil is increased by 23.65 €/$t_{HRC}$ due to the installation of the CC section in the reference steel mill.

# Results – Stand-alone ammonia plants

## Primary energy consumption - Stand-alone ammonia plants



Legend:
- Specific natural gas feedstock
- Specific natural gas as fuel
- Specific power imported from the grid
- Specific steam input

| | | Small-scale | | Large-scale | |
|---|---|---|---|---|---|
| | | Base case | Ref. case | Base case | Ref. case |
| PEC | [GJ/t$_{NH3}$] | 38.26 | 41.75 | 30.82 | 34.27 |
| CI | [t$_{CO2}$/t$_{NH3}$] | 2.28 | 0.45 | 1.87 | 0.11 |

## Carbon intensity - Stand-alone ammonia plants



- In the small-scale ammonia plants the equipment are electrically driven so the specific power imported from the grid is much higher than in the large-scale ammonia plants where equipment are driven by steam turbines that use the steam generated by exploiting the heat sources available in the plant. Consequently, the steam export is higher in the small-scale ammonia plants with respect to the large-scale ones.
- The difference in the carbon intensity between small-scale base case and the large-scale base case is principally due to the emissions associated with the electricity imported from the grid (255 kg/MWh). This also impact on carbon intensity of small-scale reference case, since those emissions can be avoided only reducing the carbon footprint of the electricity generation.

# Results – Stand-alone ammonia plants

Comparison with European EFMA plants
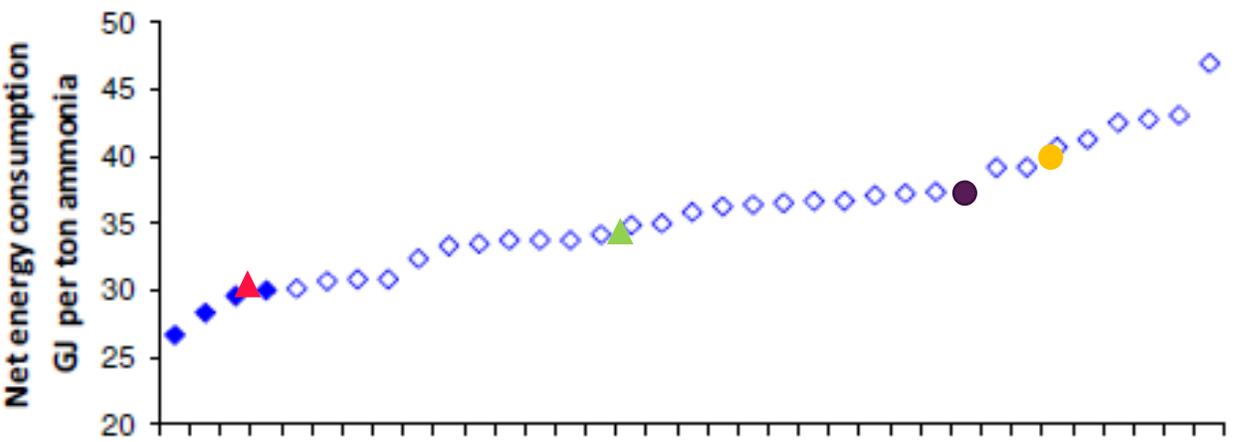


Energy benchmark curve including all 35 European EFMA plants and the input feed, fuel and steam (EFMA 2009a) [1]
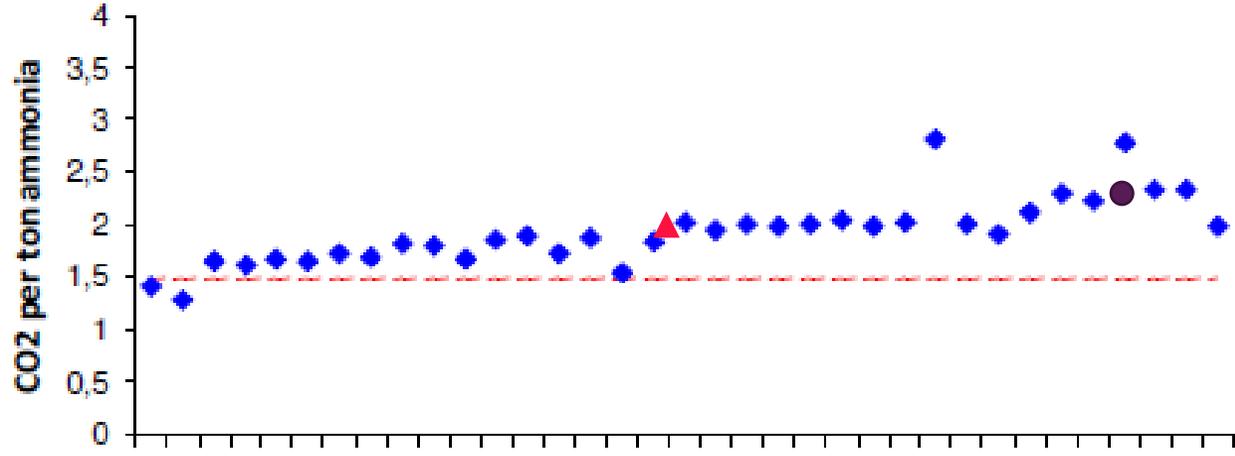
CO₂ benchmark curve including all 35 European EFMA plants (EFMA 2009a) [1]

- ● Small-scale base case
- ● Small-scale reference case
- ▲ Large-scale base case
- ▲ Large-scale reference case

[1] Fraunhofer Institute for Systems and Innovation Research, - Methodology for free allocation of emission allowances in the EU ETS post 2012 - Sector report for the chemical industry, November 2009

# Results – Stand-alone ammonia plants

## Levelized cost of ammonia



(Left chart, [€/t_NH3])

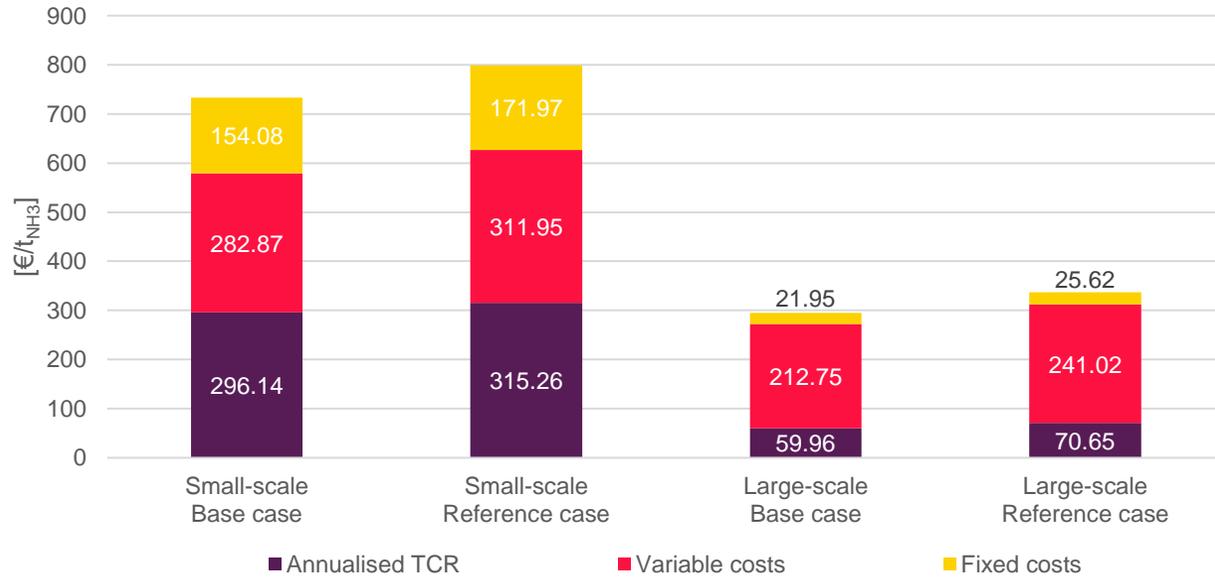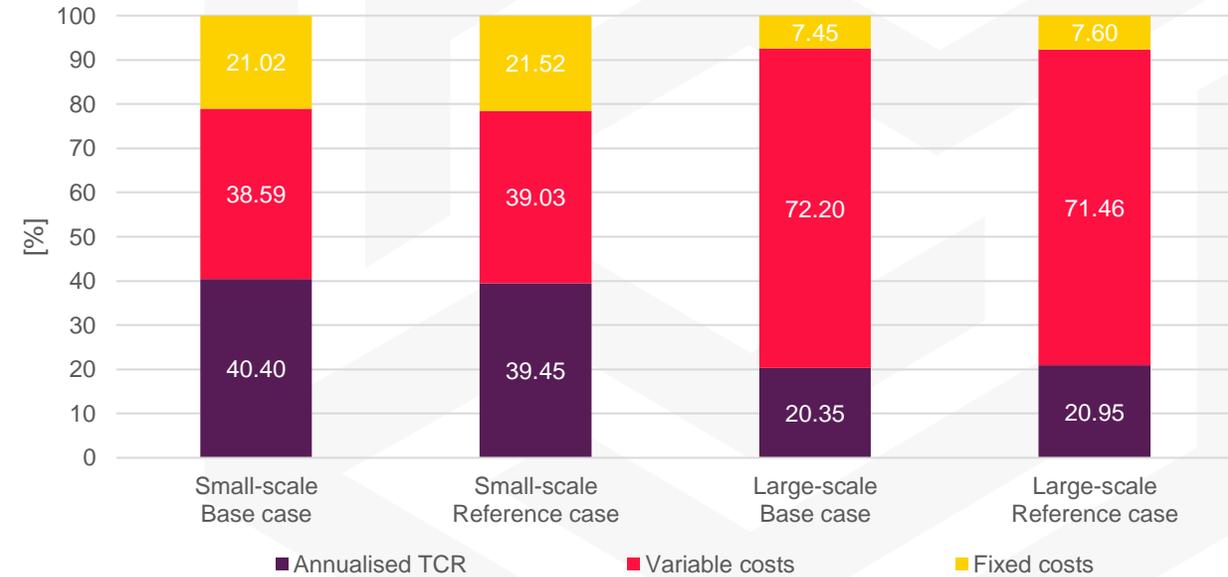| Category | Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|---|
| Fixed costs | 154.08 | 171.97 | 21.95 | 25.62 |
| Variable costs | 282.87 | 311.95 | 212.75 | 241.02 |
| Annualised TCR | 296.14 | 315.26 | 59.96 | 70.65 |

Legend: ■ Annualised TCR ■ Variable costs ■ Fixed costs

## Levelized cost of ammonia



(Right chart, [%])

| Category | Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|---|
| Fixed costs | 21.02 | 21.52 | 7.45 | 7.60 |
| Variable costs | 38.59 | 39.03 | 72.20 | 71.46 |
| Annualised TCR | 40.40 | 39.45 | 20.35 | 20.95 |

Legend: ■ Annualised TCR ■ Variable costs ■ Fixed costs

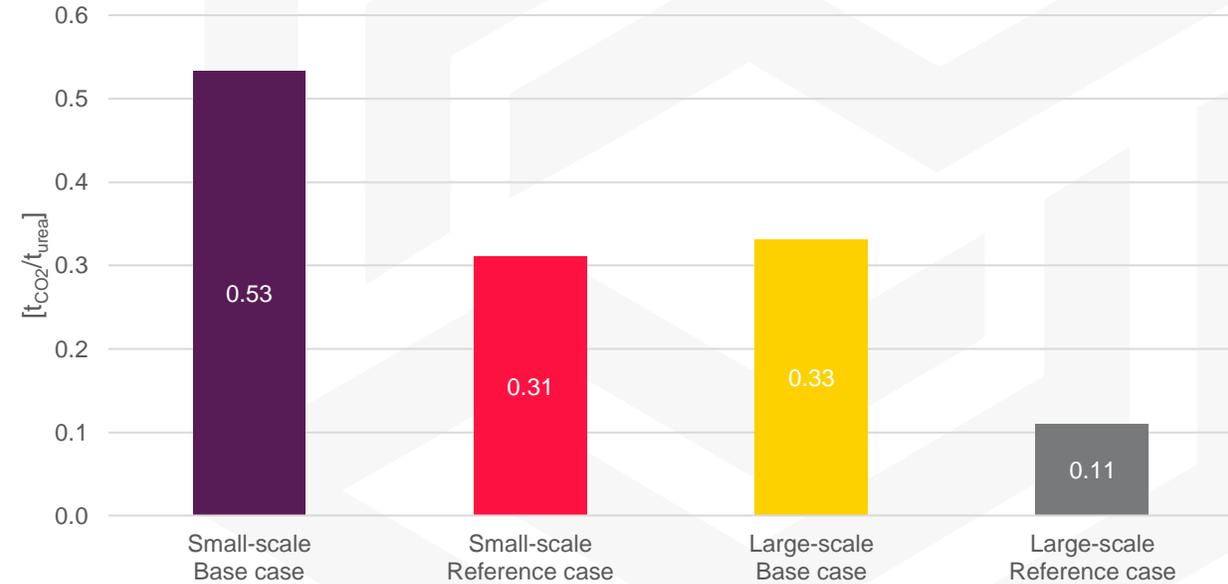|  |  | Small-scale | | Large-scale | |
|---|---|---|---|---|---|
|  |  | Base case | Ref. case | Base case | Ref. case |
| $LCO_{NH3}$ | [€/t_{NH3}] | 733 | 799 | 295 | 337 |

- The large-scale plants are more cost-effective than the small ones since the $LCO_{NH3}$ is much higher in the case of small-scale plants.
- Looking at the % composition of the $LCO_{NH3}$ it can be observed that capex are equal to 20% for large-scale plants and to 40% for small-scale plants. This is due to the scale effects.

# Results – Ammonia plants coupled with urea plants

## Primary energy consumption - Ammonia plants & urea plants



Legend:
- Specific natural gas feedstock (dark purple)
- Specific natural gas as fuel (red)
- Specific power imported from the grid (yellow)
- Specific steam input (gray)

Values by category:

| | Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|---|
| Specific steam input | 0.00 | 1.12 | 0.00 | 1.10 |
| Specific power imported from the grid | 6.59 | 6.86 | 0.36 | 0.60 |
| Specific natural gas as fuel | 5.66 | 5.66 | 5.51 | 5.51 |
| Specific natural gas feedstock | 14.22 | 14.22 | 13.93 | 13.93 |

| | | Small-scale | | Large-scale | |
|---|---|---|---|---|---|
| | | **Base case** | **Ref. case** | **Base case** | **Ref. case** |
| PEC | [GJ/t$_{urea}$] | 26.47 | 27.87 | 19.80 | 21.14 |
| CI | [t$_{CO2}$/t$_{urea}$] | 0.53 | 0.31 | 0.33 | 0.11 |

## Carbon intensity - Ammonia plants & urea plants



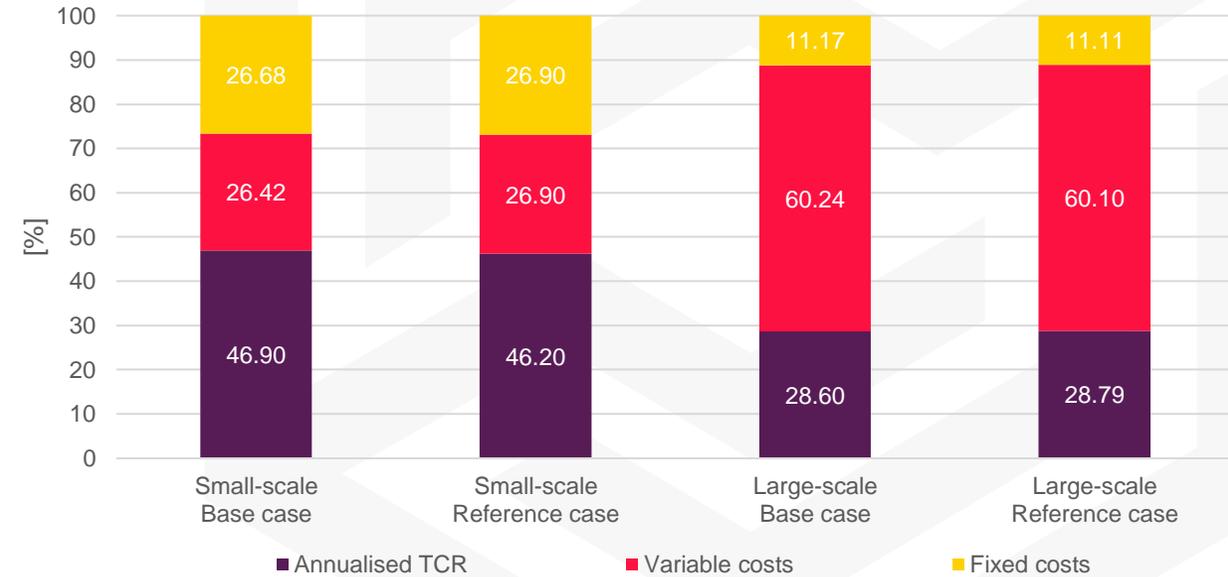| Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|
| 0.53 | 0.31 | 0.33 | 0.11 |

- Difference in primary energy consumption between small-scale plants and large-scale plants is principally due to higher import of electricity in the small-scale ammonia plants.
- Specific steam input of the large-scale urea plants is lower with respect to the small-scale urea plants. In any case, for the base case, the net steam input of the whole system (ammonia+urea plant) is equal to zero since the ammonia plant provides to the urea plant the necessary steam. Small-scale ammonia plants provide a high export of steam compared to the large-scale plants.
- Difference in CI is given by difference in CI of the ammonia plants since in urea plants there aren't any direct emissions of $CO_2$.

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# Results – Ammonia plants coupled with urea plants

## Levelized cost of urea



Bar chart (left) showing Levelized cost of urea [€/t_UREA]:

| | Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|---|
| Fixed costs | 166.48 | 176.71 | 22.85 | 24.92 |
| Variable costs | 164.84 | 176.69 | 123.27 | 134.75 |
| Annualised TCR | 292.59 | 303.52 | 58.52 | 64.56 |

Legend: ■ Annualised TCR ■ Variable costs ■ Fixed costs

## Levelized cost of urea



Bar chart (right) showing Levelized cost of urea [%]:

| | Small-scale Base case | Small-scale Reference case | Large-scale Base case | Large-scale Reference case |
|---|---|---|---|---|
| Fixed costs | 26.68 | 26.90 | 11.17 | 11.11 |
| Variable costs | 26.42 | 26.90 | 60.24 | 60.10 |
| Annualised TCR | 46.90 | 46.20 | 28.60 | 28.79 |

Legend: ■ Annualised TCR ■ Variable costs ■ Fixed costs

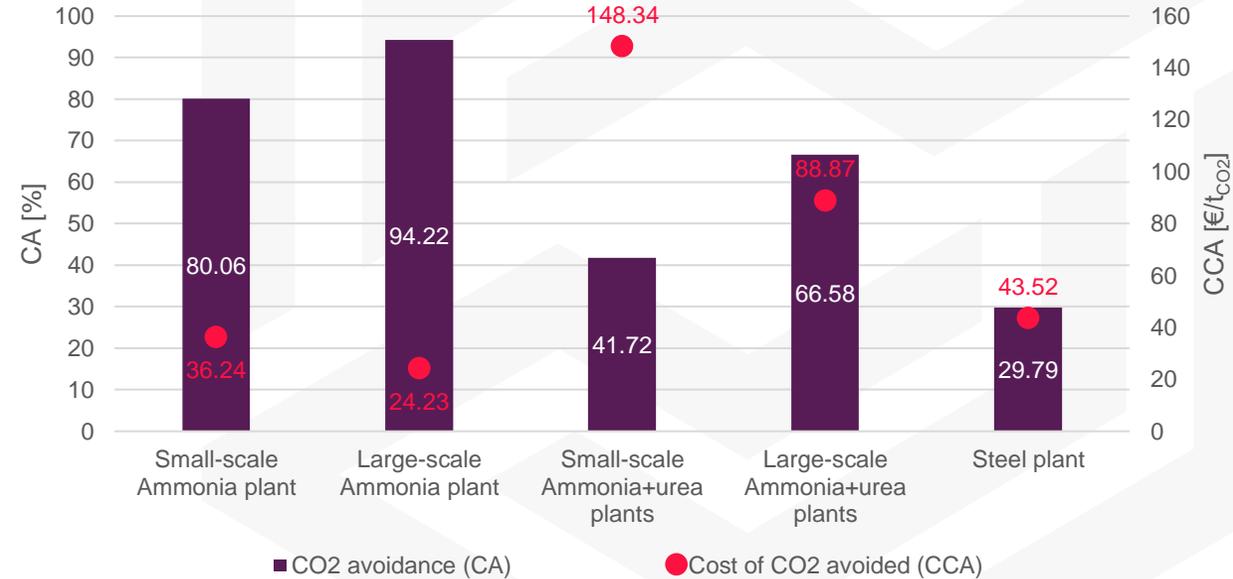| | | Small-scale | | Large-scale | |
|---|---|---|---|---|---|
| | | **Base case** | **Ref. case** | **Base case** | **Ref. case** |
| $LCO_{urea}$ | [€/t_{urea}] | 624 | 657 | 205 | 224 |

- The large-scale plants are more cost-effective than the small ones since the $LCO_{urea}$ is much higher in the case of small-scale plants.
- Looking at the % composition of the $LCO_{urea}$ it can be observed that capex are equal to 29% for large-scale plants and to 47% for small-scale plants. This is due to the scale effects.

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# KPIs comparison
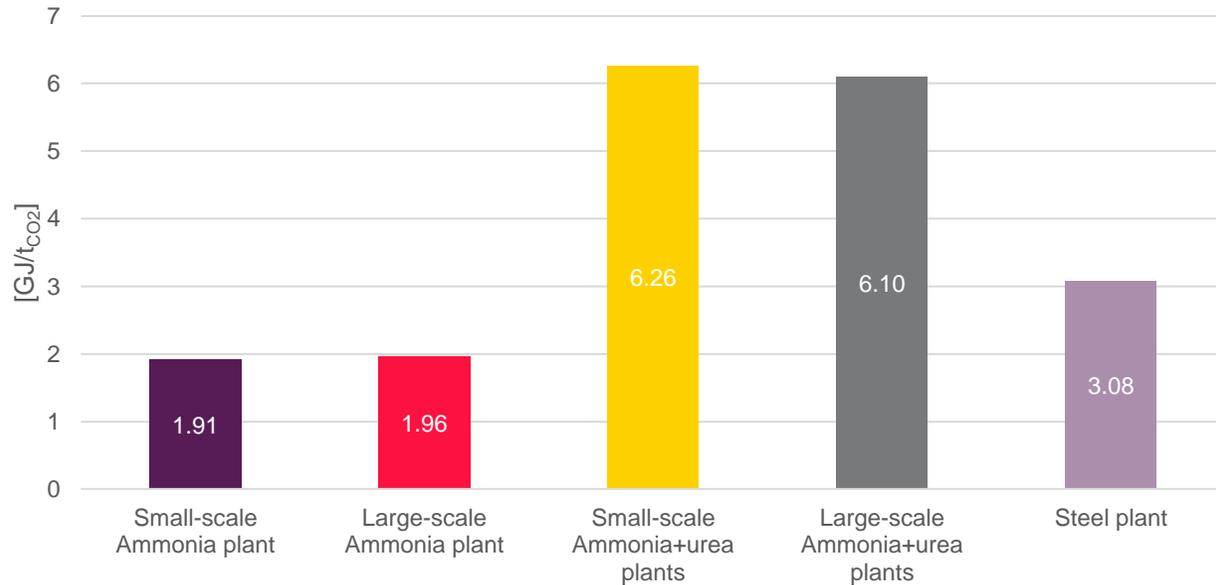


SPECCA



CA and CCA

- Regarding the SPECCA, no big differences arise between the small-scale and the large-scale plants considering analogous cases. Indeed, SPECCA of small-scale ammonia plant is very similar to the one of large-scale ammonia plant. The same can be inferred for the case of a coupling between an ammonia plant and a urea plant.
- $CO_2$ avoidance of large-scale plants is higher since the $CO_2$ emission related to the electricity import in the small-scale ammonia plant cannot be avoided. Consequently, the CCA is higher for small-scale plants.
- CA decreases when ammonia plants are coupled with urea plants since the $CO_2$ from clean-up section in the ammonia plant is not sent to storage (as happens for stand-alone ammonia plants), but it is used to produce urea.

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# Thank you!

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