# Deep decarbonisation of the EU industry - A model-based assessment of alternative pathways

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# AGENDA

1. Background: Industry decarbonisation and innovations
2. Alternative scenarios for deep decarbonisation
3. A Paris-compatible industry sector: 95% reduction scenario
4. Conclusions

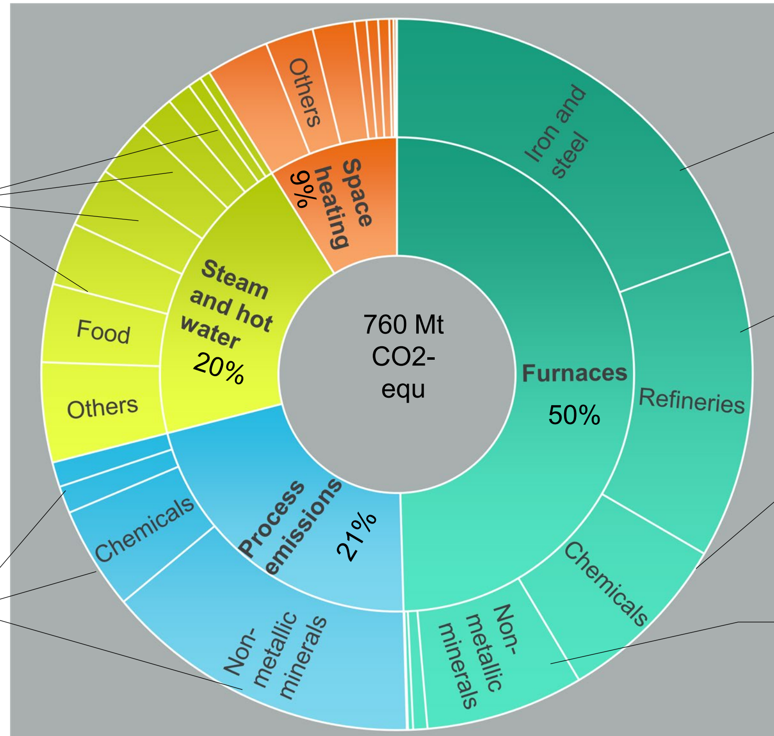
# Background: Industry decarbonisation & innovations

# Today's available technologies are not sufficient for decarbonisation

| Decarbonisation challenges | Emission sources 2015, EU | Decarbonisation challenges |
|---|---|---|

Strong reliance on natural gas, mostly high temperature

Process emissions chemically linked to production




Coke technically required in blast furnace

Strong reliance on refinery gas

Strong reliance on natural gas (also as feedstock)

High temperature limits use of renewables

- Deep decarbonisation not possible via BAT energy efficiency and traditional fuel switch
- Innovative low-carbon technologies are needed



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# Many process innovations are under development

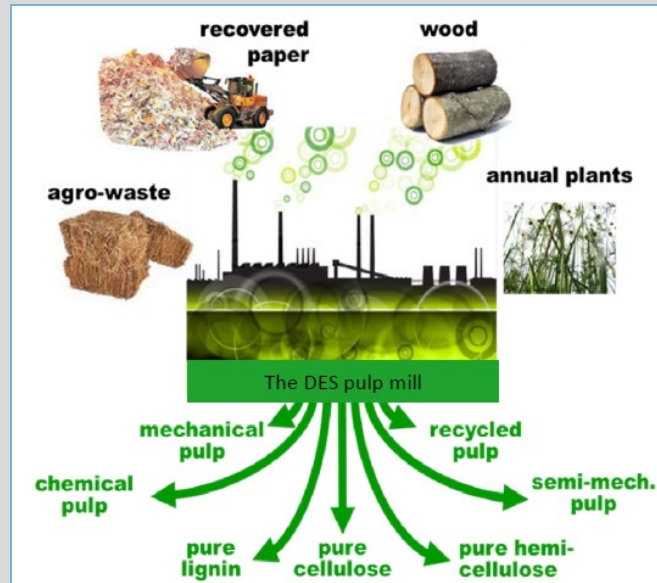
**Grass paper (Creapaper)**

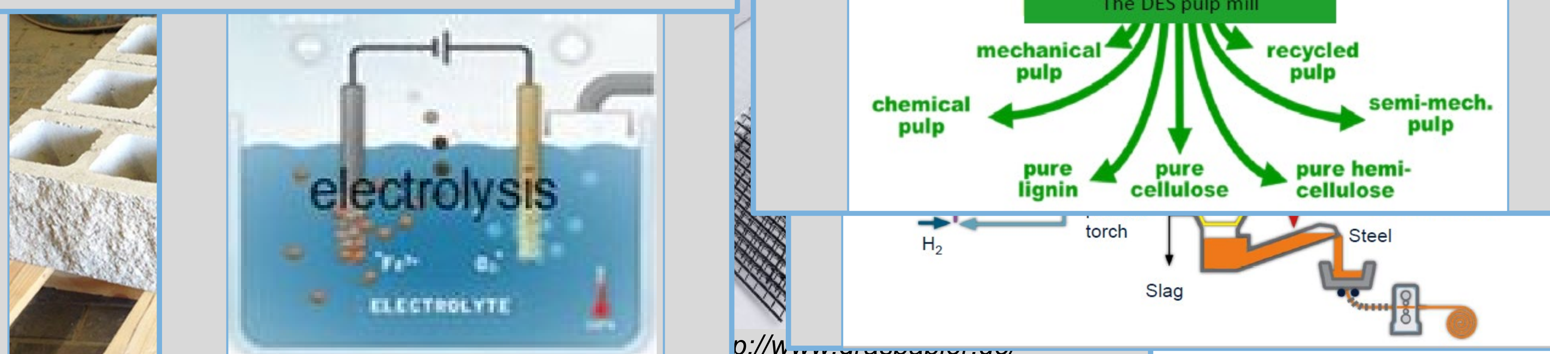
*Grass based fibres replacing wood fibres*

*Source: http://www.graspapier.de/*

**Deep Eutectic Solvents (Provides)**

*Dissolving ligno-cellulose raw material as used for paper production*




*Source: Towards the EU ETS Innovation fund workshops (online available)*

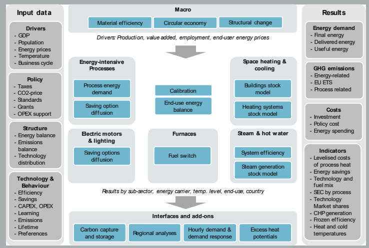
# Alternative industry sector decarbonisation scenarios

# 8 Scenarios are defined and simulated

| | Scenario name | Main scenario philosophy |
|---|---|---|
| no inno-vations | 1) Ref | **Current trends & policies** |
| | 2) BAT | **Today's best available technologies** |
| GHG reduction >80%. (ref. 1990) Including innovations with TRL >4 | 3a) CCS | **~ -80% GHG, focus on CCS** |
| | 3b) Clean gas | **~ -80% GHG, focus on renewable hydrogen and synthetic methane** |
| | 3c) Bioeconomy & circular economy | **~ -80% GHG, focus on biomass as fuel and feedstock and circular economy.** |
| | 3d) Electrification | **~ -80% GHG, focus on direct use of electricity** |
| | 4a) „Balanced mix“ -80% | **~ -80% GHG, balanced mix** informed by costs and potentials |
| | 4b) „Balanced mix“ -95% | **~ -95% GHG, Balanced mix** informed by costs and potentials |

## Simulation

FORECAST
FORecasting Energy Consumption Analysis and Simulation Tool



- Bottom-up simulation
- High technology detail
- Country level
- Policy instruments



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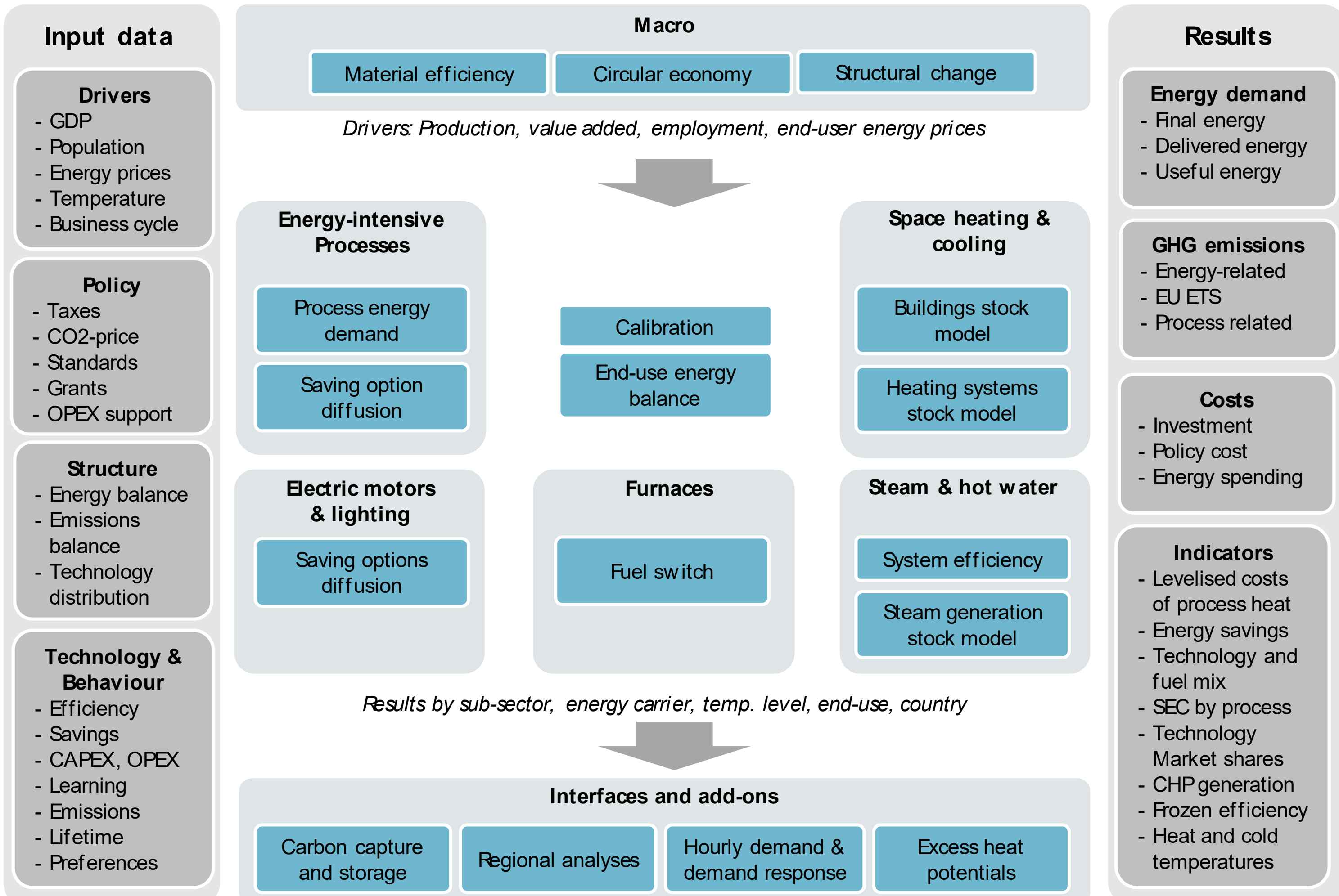
# The FORECAST model combines 6 sub-modules

[More information: https://www.forecast-model.eu/](https://www.forecast-model.eu/)

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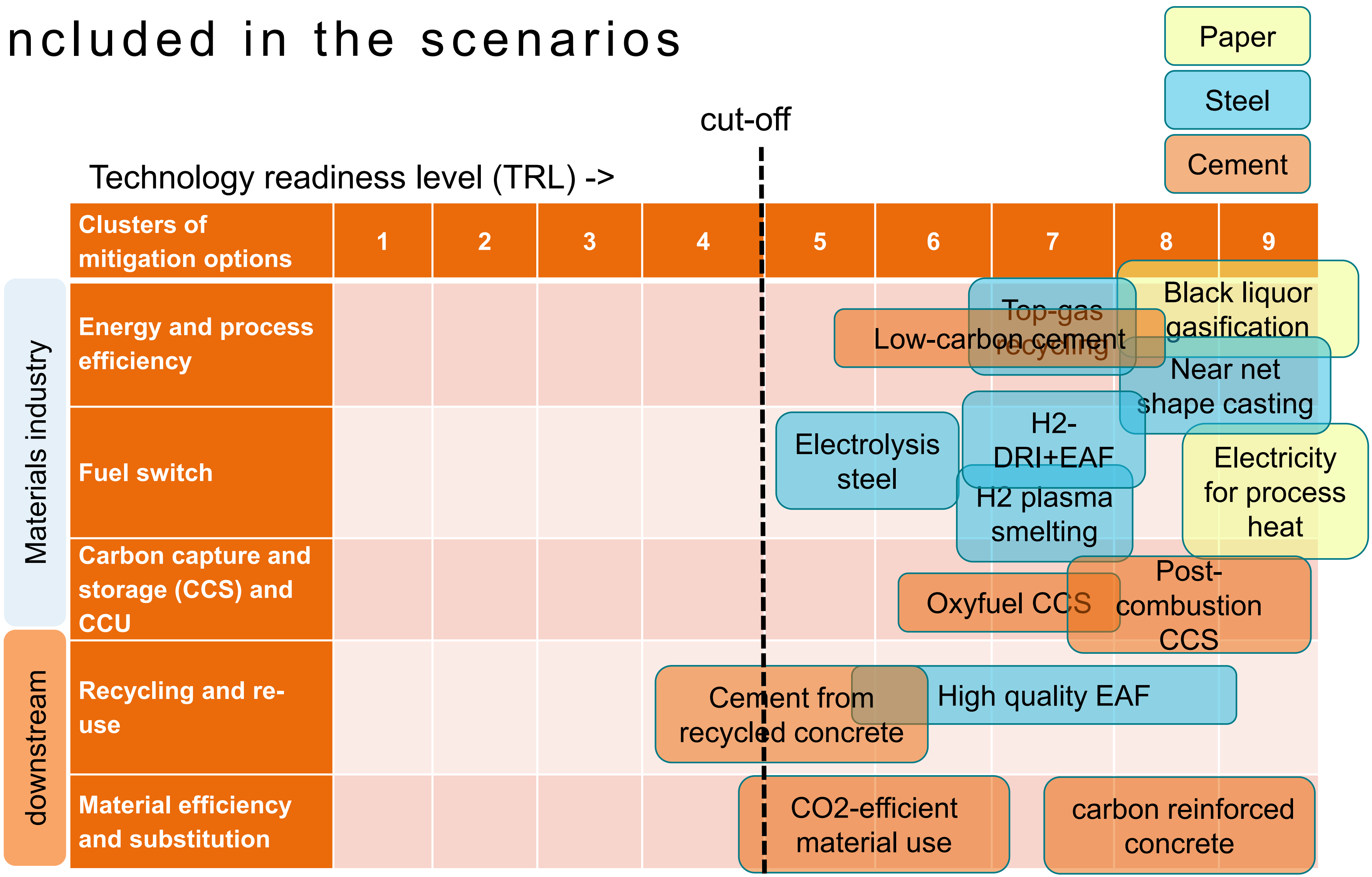
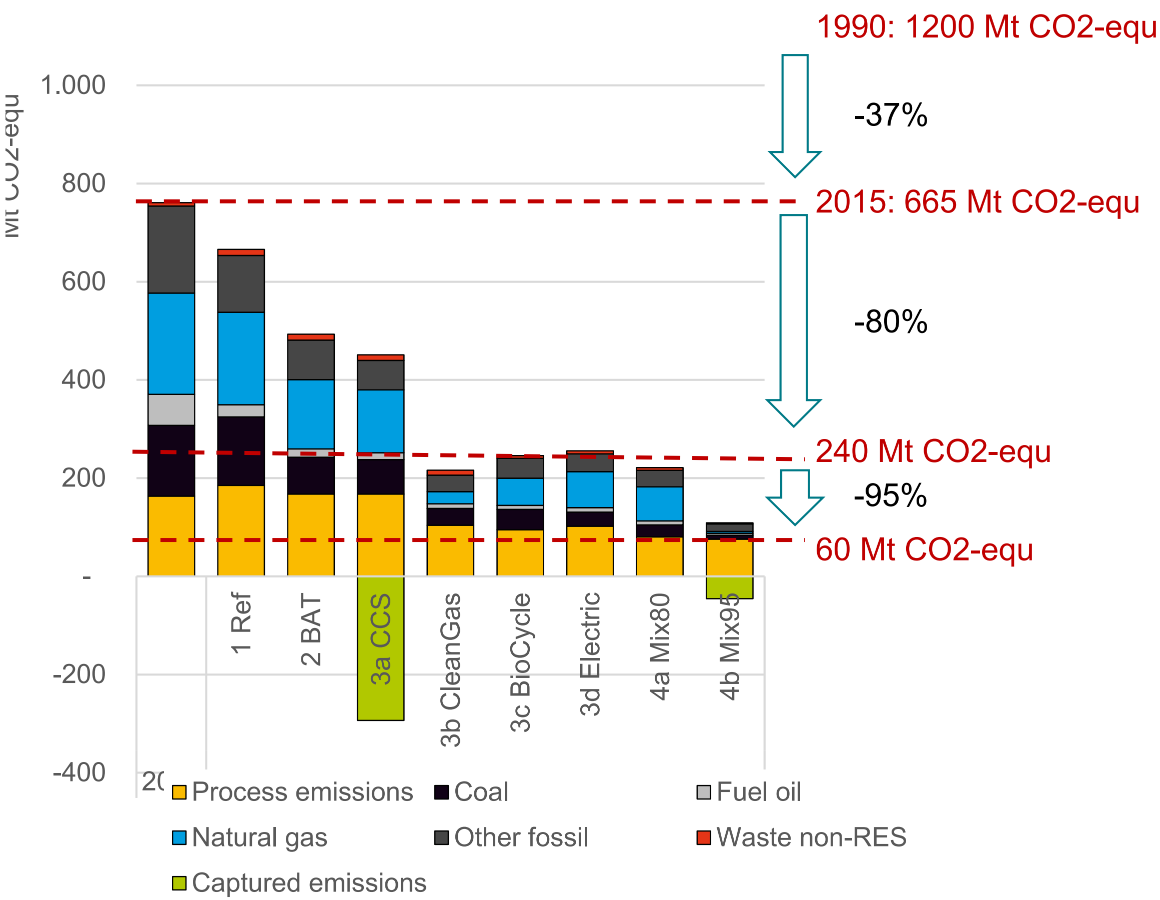
# Low-carbon innovations with TRL > 4 are included in the scenarios



# Major remaining emission sources are coal, process emissions and gas

GHG emissions by scenario and source EU28

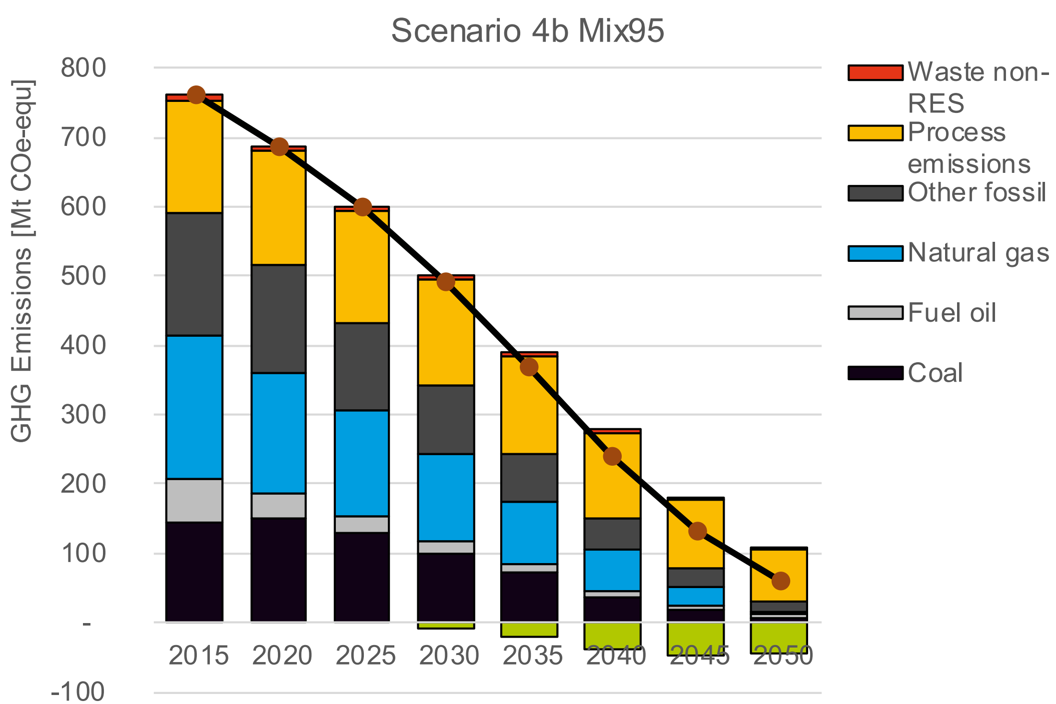



- Coal and fuel oil are substantially reduced in most decarbonisation scenarios
- Process emissions, natural gas and to less extent coal are remaining emission sources in 2050

# A 95% reduction scenario for the EU industry sector

# 95% GHG reduction possible with mix of measures

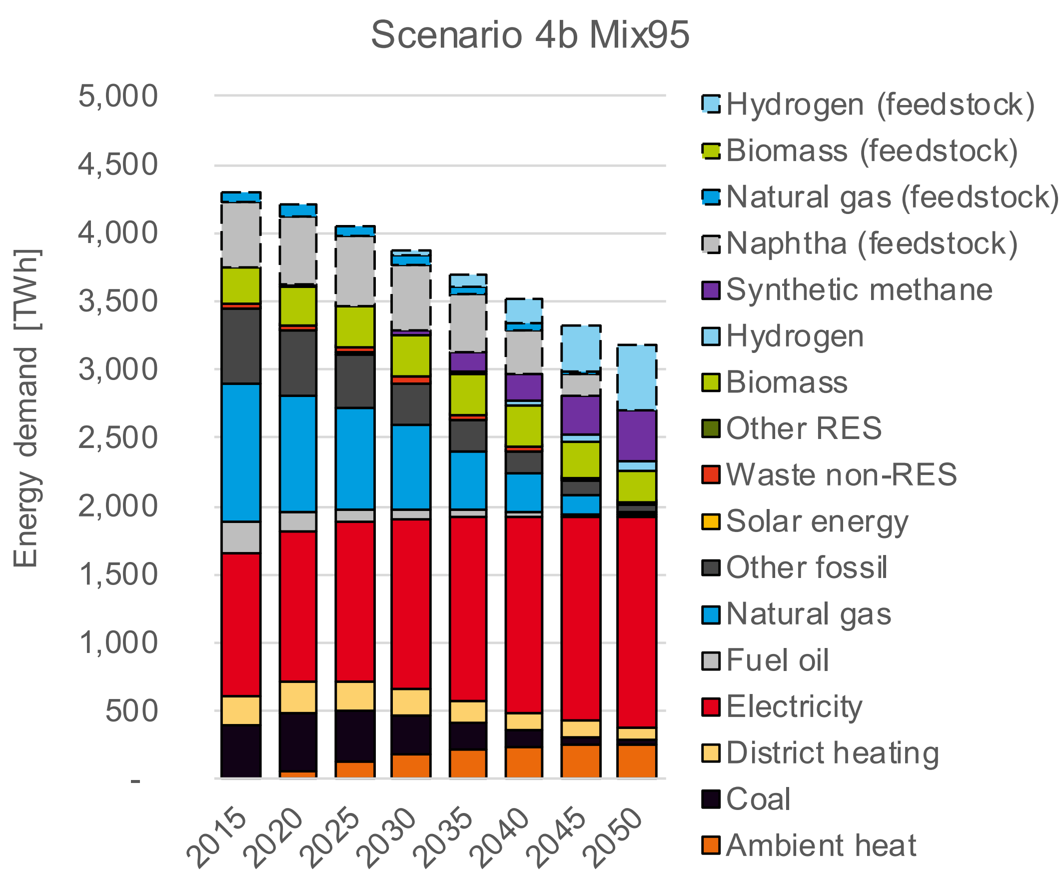
Scenario 4b Mix95- GHG emissions by source, EU28




- GHG reduction of 95% (vs 1990) and 92% (vs 2015)
- Remaining emissions mainly in processes
- CCS in cement and lime enters in 2030

# A fossil-free final energy demand in 2050

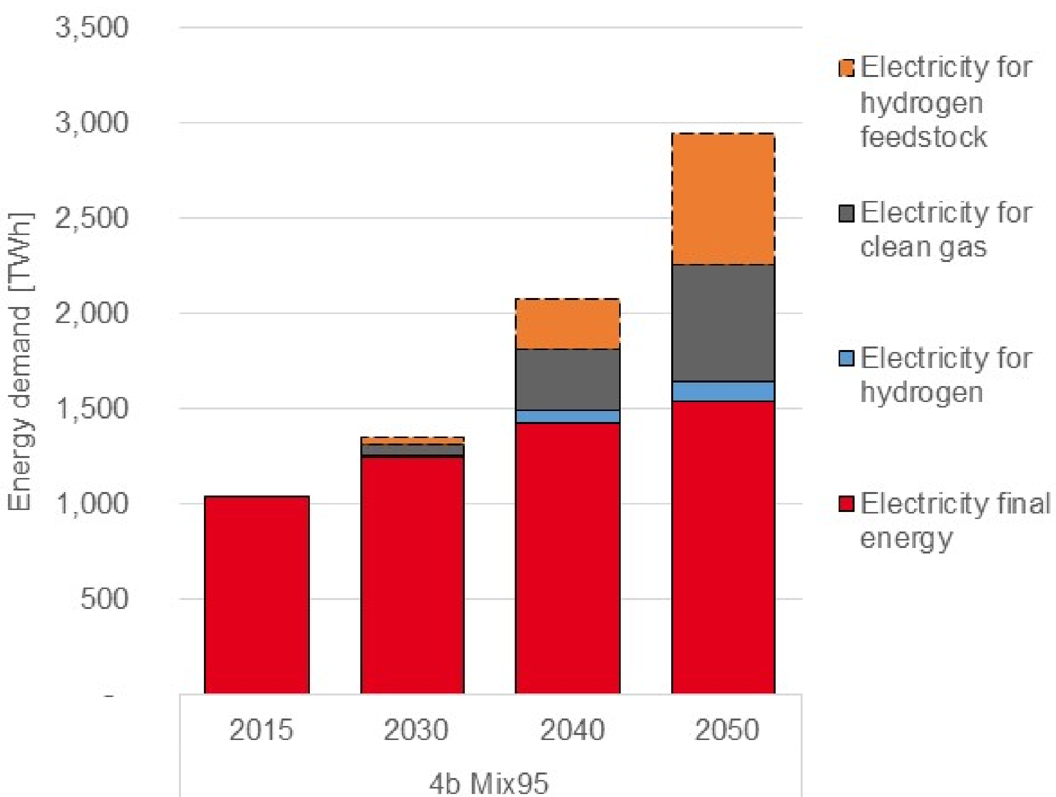
Scenario 4b Mix95 – final energy demand, EU28




- **349 TWh** demand for **synthethic methane** and **700 TWh for H2** in 2050
- **Direct electricity demand increases** from 1041 TWh in 2015 to 1550 TWh in 2050
- **Hydrogen** (480 TWh) and **synthetic methane** (370 TWh) gain high shares
- **Fossil fuels** are (nearly) completely **phased out**

# (Renewable) Electricity demand is tripling

Electricity incl. generation of e-fuels, EU28



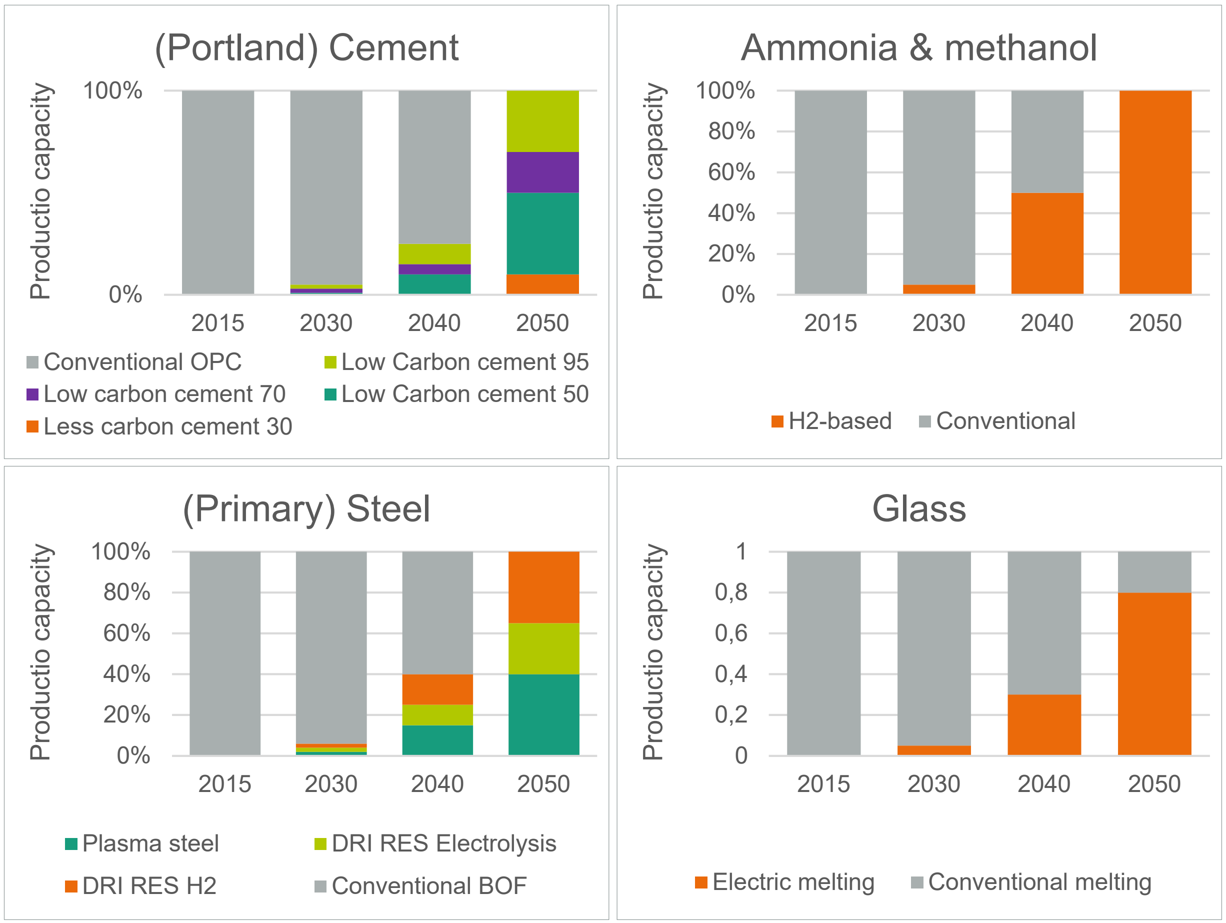

- **Electricity demand triples** (1041 -> 3102 TWh)
- **Hydrogen**:
  - Steel industry with H2-DR replacing oxygen steel
  - Chemical industry (ammonia, methanol and ethylene)
- **Synthetic methane / clean gas** in all sectors fed into gas grid
- **Electric process heating**, e.g.
  - Glass melting
  - Indirect fired clinker furnace
  - Electric boilers for steam
  - Heat pumps

# MAIN CHANGES BY SECTOR BY 2050

| Mitigation option / Sector | Integrated process improvement | Fuel switch | CCS | Recycling and re-use | Material efficiency and substitution |
|---|---|---|---|---|---|
| **Iron and steel** | BAT + Near Net shape casting | H-DR, plasma, electroysis steel 100% replace BOF-steel | - | Scrap-based EAF (40->77%) for new products | Substitution by wood; Higher material efficiency; Reinforced steel |
| **Basic chemicals** | BAT + Chlorine oxygene depolarized cathode<br>Selective membranes | Electric boilers, clean gas; H2 for ethylene, ammonia, methanol (100%) | - | Ambitious Plastics recycling | Plastics replaced by bio-based materials, reduced fertilizer demand |
| **Cement and lime** | BAT + Low-carbon cements 100% replace OPC; minimum clinker use | Clean gas co-firing | CCS for lime and clinker | Concrete recycling and re-use | Efficient concrete use, concrete substitutes, use of low-clinker concretes |
| **Glass and ceramics** | BAT + Oxy fuel, excess heat use | Electric melting (80%), clean gas | - | More re-use, inccrease in flat glass recycling | More efficient glass use |
| **Pulp and paper** | BAT + Innovative paper drying, enzymes, black liequor gasification | Electric boilers, biomass, clean gas? | - | Maximum paper recycling and re-use | Improved material efficiency |
| **Refineries** | BAT | Electricity, clean gas | CCS | - | Demand-side driven |

# 95% scenario requires fast and complete diffusion of low-carbon process innovations

Share of production routes by product capacity (EU28)




## Assumptions

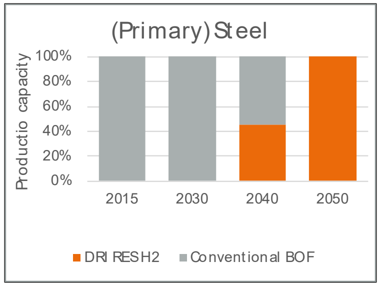
- Market entry in ~2030
- Reaching saturation in 2050
- Requires replacement of entire capital stock within only 20 years
- Technologies need to be ready for fast market introduction by 2030

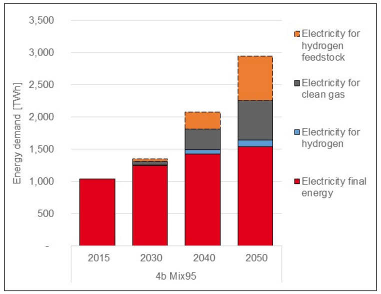
# Summary: Innovations facilitate decarbonisation of EU industry

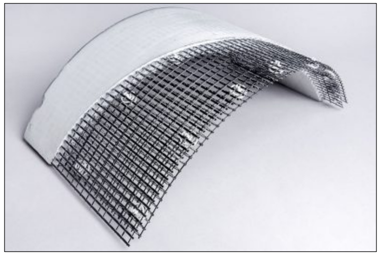
| Agenda | Results |
| --- | --- |
| 1 Introduction | ■ Available technologies not sufficient for decarbonisation of EU industry |
| 2 Innovations | ■ Many low-carbon process innovations are at pilot or demo scale (TRL > 4) |
| 3 Scenarios | ■ >80% decarbonisation is possible if innovations at least at pilot scale (TRL5) are included,<br>■ If CCS and biomass are excluded, electricity plays a major role |
| 4 95% scenario | ■ 95% reduction is possible with innovations, CCS, hydrogen, synthetic methane, electrification, circularity and material efficiency<br>■ In short: A fundamental change of the industrial production system |
| 5 Conclusion | ■ While major changes occur after 2030, technologies will need to be developed, tested and enter the market at industrial scale before |

# Is the EU ETS sufficient to achieve deep decarbonisation of industry?

- Phase 4 needs to make the process innovations ready for large-scale **market entry in 2030** latest
- The EU ETS needs to make new solutions **cost-effective**, e.g. technologies with high operational costs due to hydrogen or electricity use
- The ETS needs to generate sufficient trust to allows for **billion euros investments** to take place
- Innovations in material efficiency and circular economy require effective **price signals along the entire value chain**



Contact: Tobias.Fleiter@isi.fhg.de

# Thank you for your attention!

Download report and data:

Fleiter, T.; Herbst, A.; Rehfeldt, M.; Arens, M. (2019): **Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 2: Scenario analysis and pathways to deep decarbonisation**. ICF and Fraunhofer ISI. https://www.isi.fraunhofer.de/de/competence-center/energietechnologien-energiesysteme/projekte/pathways.html#tabpanel-3

# The methodology combines multiple data sources

**Technology data**
(task 1 results)

- GHG savings
- Energy savings
- CAPEX and OPEX
- Lifetime (economic/ technical)
- TRL
- Market entry data
- Diffusion boundaries

**Scenario definition**

1. Incremental improvement
2. BAT deployment
3. Decarbonisation scenarios technology focus (3 a-d)
4. Decarbonisation scenarios “Balanced mix” (4 a-b)

**Framework data until 2050**
Industrial production

- Value added
- Energy and CO2 prices
- …

**+ Sensitivities**

**FORECAST**

**Bottom-up model**

**Model database**

- Process data
- Energy balances
- BAT technologies
- Behavioral parameters

**8 Scenarios**

**Results**:

- GHG emissions until 2050 by source, sub-sector and country in 10-year steps
- Energy demand by energy carrier
- Investment and energy expenditures

# Example scenario definition **Iron and steel**

| Mitigation option / Scenario name | Integrated process improvement | Fuel switch | CCS | Recycling and re-use | Material efficiency and substitution |
|---|---|---|---|---|---|
| **1) REF** | Incremental efficiency improvements | Fuel switch driven by prices | No CCS | Slow increase according to current trends | No substantial improvement |
| **2) BAT** | Fast deployment of BAT efficiency | Fuel switch driven by prices | No CCS | Faster increase EAF: Used for construction steel, others | = 1) |
| **3a) CCS** | Energy efficiency innovations > TRL4<br>• Near Net shape casting<br>• Top-gas recycling | Fuel switch driven by prices | Post-combustion CCS | = 2) | =1) |
| **3b) CleanGas** | | Hydrogen based direct reduction (H-DR) (80%), clean gas | No CCS | | |
| **3c) BioCycle (Bioeconomy & circular economy)** | | Biomass co-firing | No CCS | High quality EAF allows higher shares for e.g. flat steel products | Steel substitution by biomass-based products; Higher material efficiency, Reinforced steel |
| **3d) Electric** | | Electrolysis steel (80%) | No CCS | = 2) | =1) |
| **4a) Mix 80%** | | H-DR, plasma, electrolysis steel (80%) | No CCS | = 3c | = 3c |
| **4b) Mix 95%** | | H-DR, plasma, electrolysis steel (100%) | No CCS | = 3c | = 3c |



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# 3 scenarios are simulated with bottom-up model FORECAST

## Scenario definition

| Mitigation options | REF | TRANS-CCS | TRANS-IPT |
|---|---|---|---|
| **Energy efficiency** | According to current policy framework and historical trends. | Faster diffusion of **incremental process improvements** (BAT & INNOV ≥TRL 5). | = TRANS-CCS + selected **radical process innovations** (INNOV ≥TRL 5) |
| **Fuel switch** | Fuel switching driven by energy and $CO_2$-prices | Financial support for **Fuel switching to biomass and PtH** | = TRANS-CCS + Higher financial support for biomass and PtH |
| **CCS** | - | **CCS** for major processes | - |
| **Recycling and re-use** | Slow increase in recycling rates based on **historical trends**. | Faster **increase in recycling** (e.g. steel, aluminium, paper). | = TRANS-CCS |
| **Material efficiency and substitution** | Based on historic trends. | **Increase in material efficiency & substitution.** | = TRANS-CCS |

## Simulation

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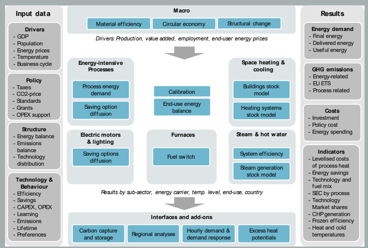

- Bottom-up simulation
- High technology detail
- Country level
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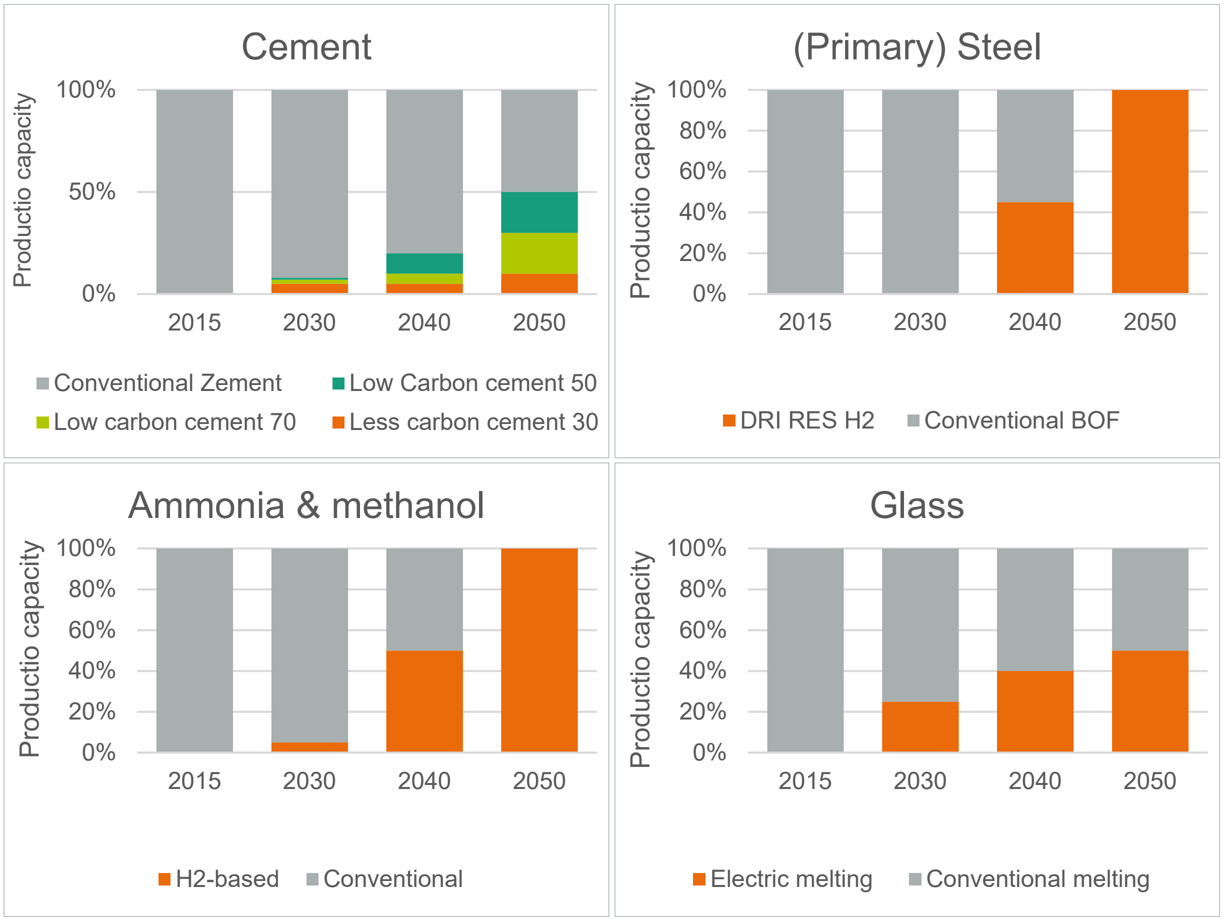
# Scenario TRANS-IPT requires fundamental change in process technologies




## Assumptions

- Market entry in 2030
- Reaching saturation in 2050
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- Technologies need to be ready for fast market introduction by 2030



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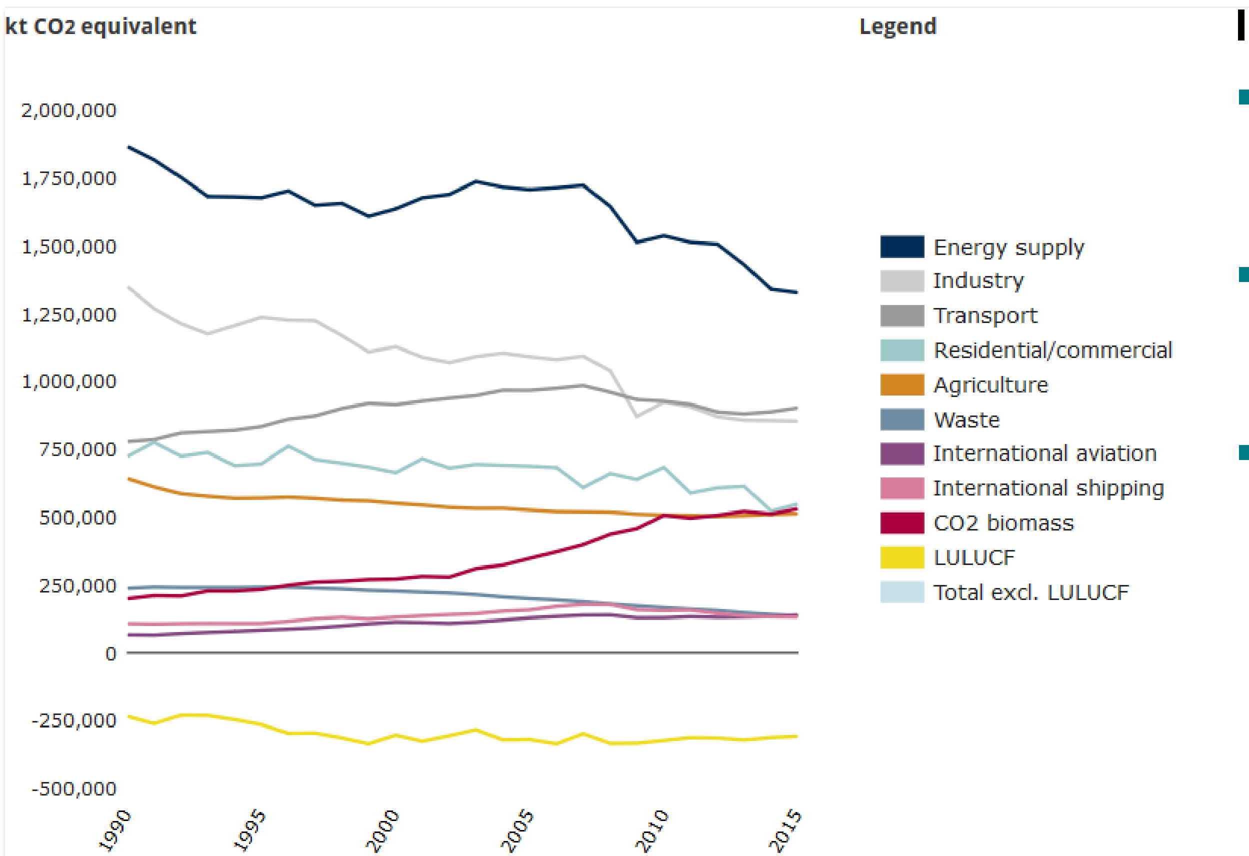
# Industry GHG emissions about 19% of EU total in 2015




Source: EEA

## Industry sector:

- Industry in 2015 about **19 % of total GHG** emissions
- **37% reduction** from 1990 to 2015 in industry sector
- **EU Low-Carbon Roadmap** from 2011 requires emission **reduction of 83-87%** by 2050 for all sectors

# Comparison: Relevance of technologies varies across studies for Germany

## Comparison of selected industry decarbonisation studies for Germany

| Scenario | GHG reduction | Energy efficiency | Biomass | PtH | PtG | CCS | New processes | Circular economy | Material efficiency & substitution |
|---|---|---|---|---|---|---|---|---|---|
| BMUB KS95 | -99% | | | | | | | | |
| UBA THGND | -95% | | | | | | | | |
| BDI 95%Pfad | -95% | | | | | | | | |
| BMWi Langfrist | -84% | | | | | | | | |
| BMUB KS80 | -75% | | | | | | | | |
| BDI 80%Pfad | -65% | | | | | | | | |



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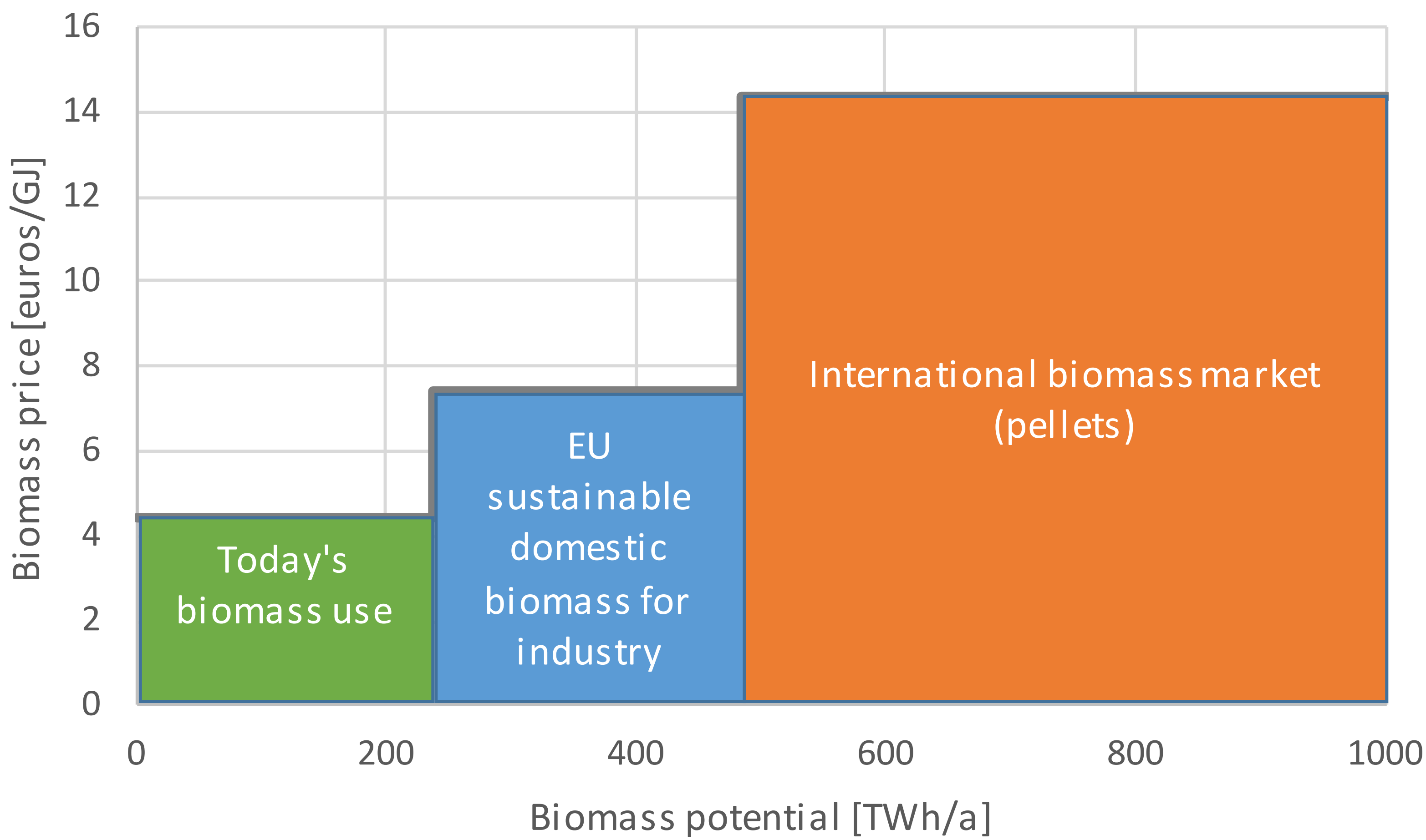
# Overview policy assumptions

# Assumptions: Biomass cost-potential curve



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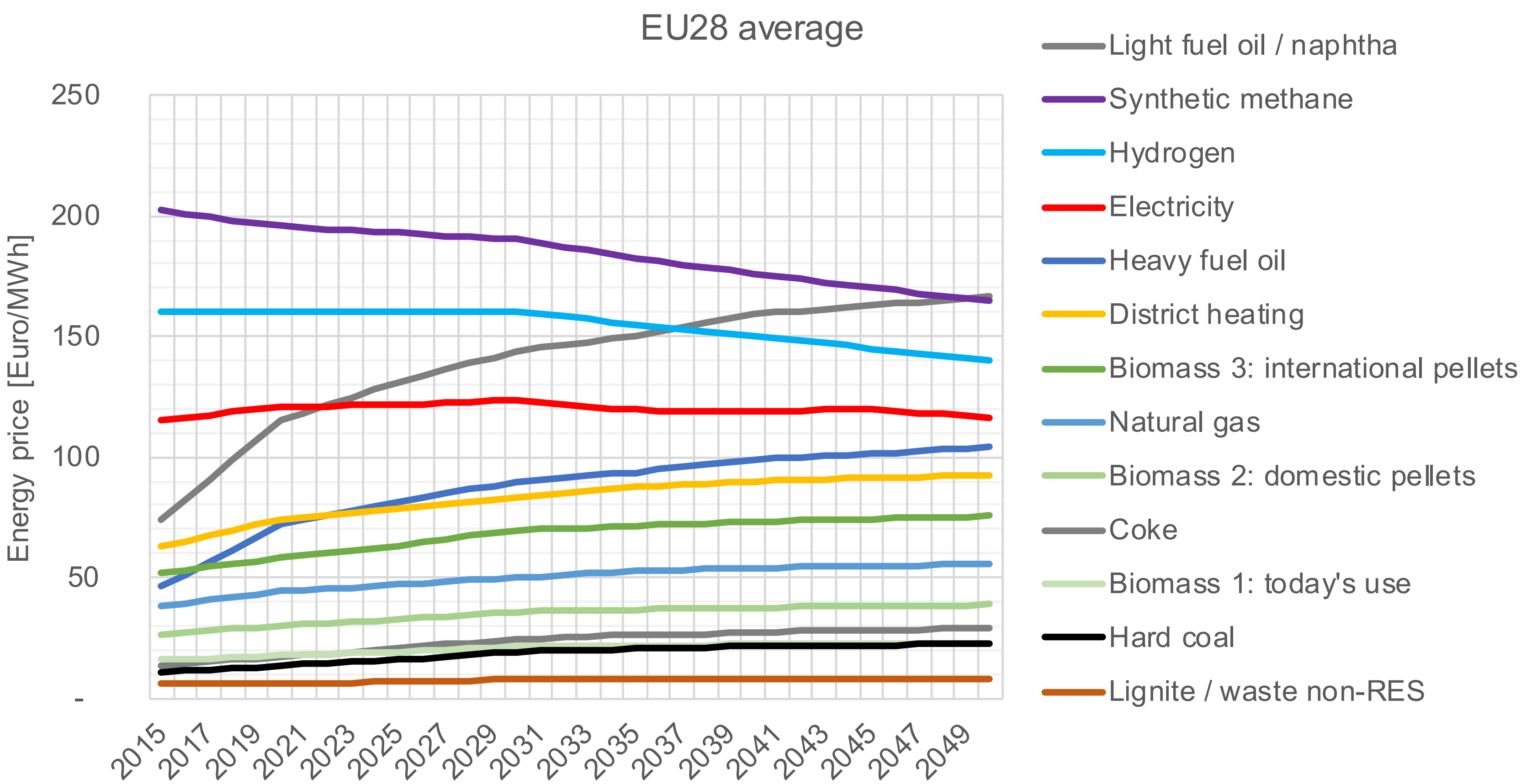
# Assumptions: Energy carrier prices EU28 average (incl. taxes and levies, excl. EUAs)



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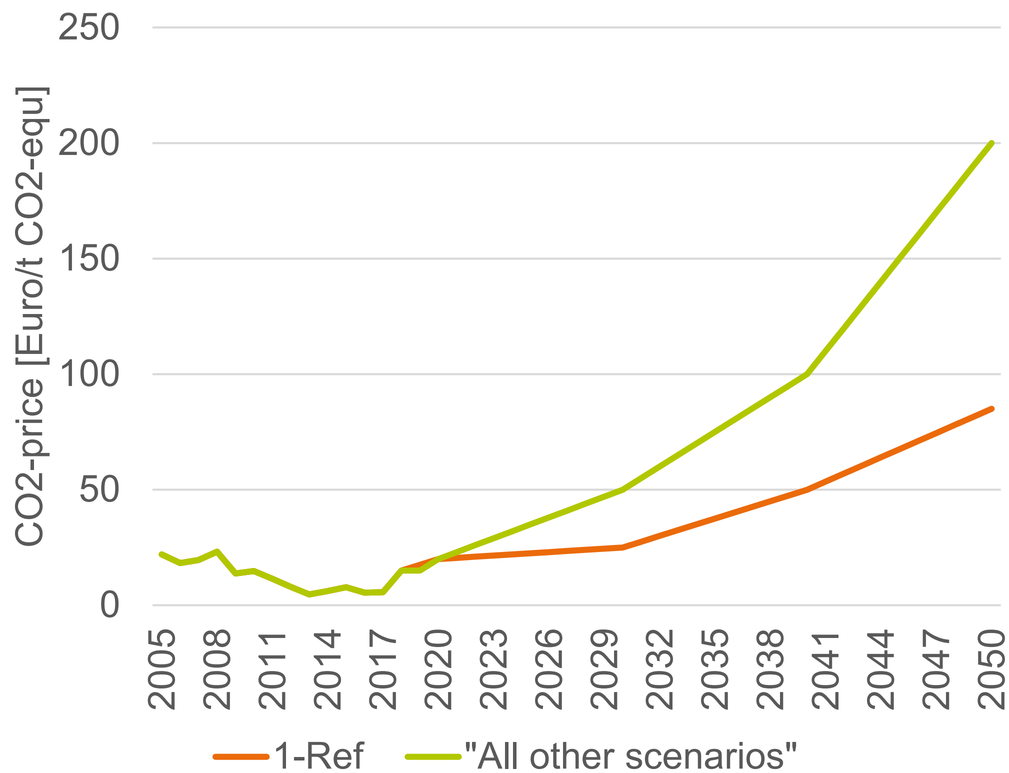
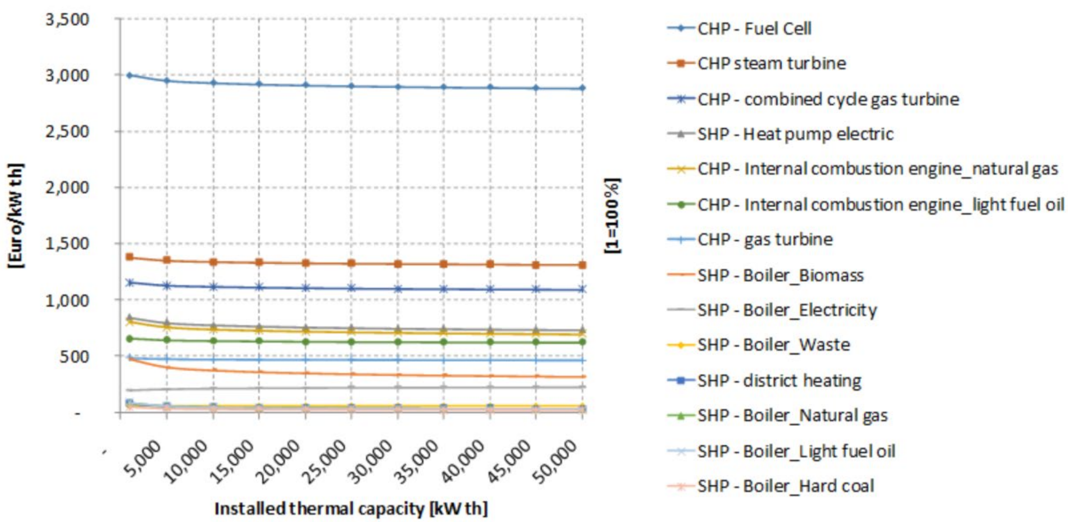
# Assumptions: CO2 price

- Scenario 1-Ref:
  - EUA price according to EU Reference Scenario 2016
- Other scenarios
  - Higher EUA price
  - Same CO2-price for non-ETS
- Scenario 4b Mix95
  - Price anticipation 10 years ahead



# Steam generation costs included in detailed stock model

Specific CAPEX for steam generation technologies in Germany as a function of installed capacity [Eiuro/kWth]




- techno-economic data considered for steam generation technologies includes CAPEX, OPEX, Efficiency (thermal and electric), lifetime
- CAPEX is a function of technology, installed capacity thermal, country and year



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# Investment needs are accounted as „additional“ compared to a reference

## Additional investment needs by innovative process

| Sector | Process | Reference process | CAPEX [euro/t product] compared to reference process | | | |
|---|---|---|---|---|---|---|
| | | | 2020 | 2030 | 2040 | 2050 |
| Iron and steel | Plasma steel (H2)* | BOF route | 438 | 377 | 324 | 278 |
| | DR electrolysis | BOF route | 198 | 170 | 146 | 126 |
| | DR RES H2 + EAF* | BOF route | 0 | 0 | 0 | 0 |
| Chemicals | Methanol H2* | Methanol | -14 | -14 | -14 | -14 |
| | Ammonia H2* | Ammonia | -222 | -222 | -222 | -222 |
| | Ethylene methanol-based* | Ethylene naphtha based | 0 | 0 | 0 | 0 |
| | Ethylene ethanol-based | Ethylene naphtha based | 0 | 0 | 0 | 0 |
| Non-metallic minerals | Less-carbon cement - 30% | Ordinary Portland Cement | 20 | 17 | 15 | 13 |
| | Low-carbon cement - 50% (recarbonating) | Ordinary Portland Cement | 50 | 43 | 37 | 32 |
| | Low-carbon cement - 70% | Ordinary Portland Cement | 80 | 69 | 59 | 51 |
| | Low-carbon cement - 95% (recycled concrete) | Ordinary Portland Cement | 150 | 129 | 111 | 95 |
| | Clinker electric kiln | Clinker conventional rotary kiln | 50 | 43 | 37 | 32 |
| | Container glass electric furnace | Container glass gas furnace | 129 | 111 | 95 | 82 |
| | Flat glass electric furnace | Flat glass gas furnace | 129 | 111 | 95 | 82 |

- Investments are accounted as additional investment needed for the innovative process compared to a reference process
- We assume regular re-investment cycles and no „early replacement“

# Clean gas production costs included as energy carrier price

| Assumptions | Clean gas production | Resulting energy carrier price |
|---|---|---|
| Renewable Electricity: ~100 Euros/MWh | Electrolysis | **Hydrogen**: 140-160 Euros/MWh |
| CO2: 0 Euros/MWh | Electrolysis Methanisation | **Synthetic methane**: 220-240 Euros/MWh |
| CAPEX electrolyser: 500-700 euros/kWel (Literature: 350-900) | | |
| Fullload hours: 4000 | | |

# Investment needs for CCS include entire process chain

| Process | Sector | Capture CAPEX [euro/t CO2 a] | | Transport & storage [euro/ t CO2 a] | | OPEX [% of CAPEX] |
|---|---|---|---|---|---|---|
| | | 2030 | 2050 | 2030 | 2050 | |
| Ammonia | Chemicals | 40 | 30 | 140 | 113 | 7% |
| Methanol | | 60 | 44 | 140 | 113 | 7% |
| Ethylene | | 180 | 133 | 140 | 113 | 10% |
| Integrated steelworks | Iron and steel | 90 | 67 | 140 | 113 | 5% |
| Clinker | Non-metallic minerals | 150 | 111 | 140 | 113 | 12% |
| Lime | | 150 | 111 | 140 | 113 | 5% |
| Container glass | | 400 | 296 | 140 | 113 | 7% |
| Flat glass | | 400 | 296 | 140 | 113 | 7% |
| Fibre glass | | 400 | 296 | 140 | 113 | 7% |
| Other glass | | 400 | 296 | 140 | 113 | 7% |
| Integrated paper mill | Pulp and paper | 400 | 296 | 140 | 113 | 7% |
| Refinery basic | Refineries | 200 | 148 | 140 | 113 | 10% |
| Refinery gasoline focused | | 200 | 148 | 140 | 113 | 10% |
| Refinery diesel focused | | 200 | 148 | 140 | 113 | 10% |
| Refinery flexible | | 200 | 148 | 140 | 113 | 10% |

- Capture costs are differentiated by process and differ according to CO2 concentration in flue gas, emission quantity, purity of CO2-stream, etc.
- Assumptions are in line with a broad range given in the literature
- The specific location and regional specificities of individual sites are not considered
- Underlying assumption: Large-scale CO2 transport infrastructure available