AIDRES
Advancing industrial decarbonisation by assessing the future use of renewable energies in industrial processes (ENER-2020-OP-0011)

Project Results – Energy Future in Industry
Gothenburg (S), 9-11 May 2023
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“Advancing Industrial Decarbonization by assessing the future use of Renewable Energies in industrial processes”
The project team
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The real experts

<table>
<thead>
<tr>
<th>AIDRES Sector</th>
<th>Sector federation and companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>ESTEP, ArcelorMittal</td>
</tr>
<tr>
<td>Glass</td>
<td>GLASS FOR EUROPE, VUB BRUSSEL</td>
</tr>
<tr>
<td>Cement</td>
<td>FEBELGEM, EMBUREAU, CEMEX, VUB BRUSSEL</td>
</tr>
<tr>
<td>Chemical</td>
<td>INEOS, cefic, essenscia, DECHEMA</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>YARA, VUB BRUSSEL, DECHEMA</td>
</tr>
<tr>
<td>Refineries</td>
<td>Concave, INEOS</td>
</tr>
</tbody>
</table>
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A bit more concrete...

- Essential database to create a sharper picture of potential pathways for EII.
- Renewable energy demand, CO2 emissions, cost
- For all member states and regions of the EU.

INDUSTRY

- Energy efficiency
- Process integration
- Electrification of heat
- Electrification of processes
- Use of hydrogen
- CCU-S
- Use of biomass
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### Energy intensive industries and products in scope

<table>
<thead>
<tr>
<th>SECTOR</th>
<th>PRODUCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Primary and secondary steel</td>
</tr>
<tr>
<td></td>
<td>Excl. steel finishing sites</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>Ammonia, urea, nitric acid</td>
</tr>
<tr>
<td>Chemical</td>
<td>Olefins, polymers and organic synthesis</td>
</tr>
<tr>
<td></td>
<td>Excl. other basic chemicals and downstream products</td>
</tr>
<tr>
<td>Glass</td>
<td>Flat, container, fibre glass</td>
</tr>
<tr>
<td>Cement</td>
<td>Portland Cement II, LC3</td>
</tr>
<tr>
<td>Refinery</td>
<td>Light liquid fuel</td>
</tr>
<tr>
<td></td>
<td>(63.8% of product out of crude oil)</td>
</tr>
<tr>
<td></td>
<td>Excl. naphtha, heavy fuel, other</td>
</tr>
</tbody>
</table>

Source: Port of Antwerp and Bruges
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Layered model approach, type of onion

Tender, EU Commission (DG ENERGY)

Process selection (key technology)

Process modelling of production routes

Process integration (routes-pareto opt)

Results per ton/product and selection of routes

Regional integration

Scaling at EU27 NUTS3 (=small region, part of a province).

Revisions based on association figures and reports (VUB, IRENA, IEA, EC, ...)

OSMOSE, objective selection (cost toward zero emissions), scenarios, parameters sensitivity.

ASPN, others

EPOS *industrial blueprints*, Sci articles, industrial references

Sectors, vectors, other project boundaries

NUTS 3 data base with energy profiles, CO₂ emissions, cost for different products and routes

*The model does not optimise over the full time horizon 2018-2050.*
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Industrial plants mapping approach: the big picture

Input: **EUTL 2020**

Sector classification of installations

Selection criteria relevant installations:
- Part of EU27 (excl. UK)
- Part of identified sector
- Actively reporting
=> 1758 installations

Aggregation production site

=> 1536 sites

Link to **NUTS3** region

Automatic mapping (Google API)

Verification & correction location
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**Industrial plants mapping approach: the production capacities hunt**

Result Task 1: AIDRES database with all EU27 production sites classified per sector

- **Public database approach**
  - Steel
  - Refineries

- **Pareto (80/20) approach**
  - Chemical
  - Fertilisers

- **Emission factor (ETS) approach**
  - Cement
  - Glass

Industrial parameters per site - public database available?
- yes
- no

#sites responsible for 80% verified emissions 2019?
- ≤50% of sites
- >50% of sites
A production site is the geographical unit that combines production installations from one sector and specific company in space. E.g., a chemical production site (BASF Ludwigshafen) can group more than 40 production installations from the chemical sector at one site.
Industrial plants mapping approach: a map versus words

<table>
<thead>
<tr>
<th>Sector</th>
<th>#Production sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>372</td>
</tr>
<tr>
<td>Refinery</td>
<td>112</td>
</tr>
<tr>
<td>Cement</td>
<td>436</td>
</tr>
<tr>
<td>Glass</td>
<td>319</td>
</tr>
<tr>
<td>Chemical</td>
<td>258</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>39</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1536</strong></td>
</tr>
</tbody>
</table>

A production site is the geographical unit that combines production installations from one sector and specific company in space.

E.g., a chemical production site (BASF Ludwigshafen) can group more than 40 production installations from the chemical sector at one site.

- Energy, feedstock, material, demand.
- Production rates, product and co-product flows
- Emission rates
- CAPEX/OPEX

BE211 - Antwerp
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Industrial plants mapping approach: database essentials

AIDRES DATABASE
Industrial site
- Sector
- Production capacity or rate [kt/y]

NUTS3
- Sector
- Scenario conditions
- Production routes
- 16 Final energy vectors
- TOTEX = OPEX + CAPEX [m€/y]
- Direct and indirect emissions [ktCO₂/y]
- Captured CO₂ [ktCO₂/y]

AIDRES: Blueprint methodology

DG ENER/JRC-EIGL: Publication and visualisation

Energy vectors [PJ/y]
- Electricity
- Hydrogen
- Natural gas
- Naphtha
- Methanol
- Biomass
- Biomass waste
- Coal
- Plastic mix
- Coke
- Crude oil
- Biodiesel
- Spent solvent mixture
- Solid recovered fuel
- Alternative fuel mixture
- Plastic mix
## Industrial production routes approach: scenarios

<table>
<thead>
<tr>
<th>Nr</th>
<th>Year</th>
<th>Description</th>
<th>€/t$_{CO_2}$</th>
<th>€/MWh electricity</th>
<th>kg$_{CO_2}$/MWh electricity</th>
<th>€/kg H$_2$</th>
<th>kg$_{CO_2}$/kg H$_2$</th>
<th>€/MWh NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2018</td>
<td>Reference</td>
<td>25</td>
<td>125</td>
<td>231</td>
<td>1.8</td>
<td>8.2</td>
<td>24.4</td>
</tr>
<tr>
<td>1</td>
<td>2030</td>
<td>low H$_2$ price</td>
<td>150</td>
<td>71</td>
<td>120</td>
<td>3</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>2030</td>
<td>low H$_2$ - high NG price</td>
<td>150</td>
<td>71</td>
<td>120</td>
<td>3</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>2030</td>
<td>high H$_2$ price</td>
<td>150</td>
<td>71</td>
<td>120</td>
<td>5</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>2030</td>
<td>high H$_2$ - high NG price</td>
<td>150</td>
<td>71</td>
<td>120</td>
<td>5</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>2050</td>
<td>low H$_2$ price</td>
<td>350</td>
<td>71</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>2050</td>
<td>low H$_2$ - high NG</td>
<td>350</td>
<td>71</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>2050</td>
<td>high H$_2$ price</td>
<td>350</td>
<td>71</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>2050</td>
<td>high H$_2$ - high NG price</td>
<td>350</td>
<td>71</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

*ETS, 150 €/tCO2 (2030), 350 €/tCO2 (2050) based on respective Fit for 55 MIX Scenario values. Natural gas (NG) prices 0.025 €/kWh (2030), 0.035 €/kWh (2050) based on respective Fit for 55 Scenario values.

Source: [https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12265-2030-Climate-Target-Plan_en](https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12265-2030-Climate-Target-Plan_en)

Electricity CO2 intensity, 0.12 tCO2/MWh (2030), ‘0’ tCO2/MWh (2050) based on respective Fit for 55 MIX Scenario values and as agreed with EC.

H2 prices Derived from range: 2.7-5.7 €/kg (2030), 1.2-2.9 €/kg (2050).

Own calculation based on technical parameters from EC Ref Scenario (07/2021)

Electricity price, 71 €/MWh based on Fit for 55 ‘Mix Scenario’ (2030) and EC Ref Scenario (2050); 40 €/MWh as sensitivity for regional and technology specific context.


H2 impact [kgCO2/kgH2] to be assumed ‘0’, as ‘green’ molecule.

H2 based on fossil fuels (SMR process) represented in AIDRES Blueprint model.
Direct O2 emission reduction targets for each sector by 2030 - 2050.

Targets based on the EU PRIMES mix reference Scenario in line with EU Fit for 55 and the Green Deal targets, aiming at 90-95% CO₂ emission reduction industry by 2050.

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Industrial production routes: emission reduction targets

- **Direct** CO₂ emissions target by sector, related to process and energy, based on EU PRIMES MIX scenario¹.
- Targets for 2030 and 2050 compared to yearly reported average 2015-2019.

<table>
<thead>
<tr>
<th>AIDRES Emission Reduction targets</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIDRES Sector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>21%</td>
<td>86.3%</td>
</tr>
<tr>
<td>Cement</td>
<td>13%</td>
<td>93.2%</td>
</tr>
<tr>
<td>Refineries</td>
<td>28%</td>
<td>85.4%</td>
</tr>
<tr>
<td>Glass</td>
<td>13%</td>
<td>93.2%</td>
</tr>
<tr>
<td>Fertilisers</td>
<td>29%</td>
<td>96.1%</td>
</tr>
<tr>
<td>Chemical</td>
<td>29%</td>
<td>96.1%</td>
</tr>
</tbody>
</table>

Selection of single production routes, to meet PRIMES EU Reference scenarios regarding CO₂ reduction targets.

- A balanced hypothetical alternative to represent values of energy and feedstock inputs.
- Low carbon emission pathway for the industrial sectors and products, represented on EU level.
- Account for the uncertainty of future production methods for each industrial plant.
- Inspired by sector reports and studies.
- An AIDRES mix route has been created for each product.

Source: Tales of the cocktail foundation
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Industrial mix production routes: sector results STEEL

- AIDRES EU mix primary steel production routes¹.
  - Hydrogen direct reduced Iron (H-DRI): 59%
  - Carbon capture based routes: 26%
  - Other technologies e.g. MOE: 5%

¹Sources:
https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189ea/Iron_and_Steel_Technology_Roadmap.pdf
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Industrial mix production routes: sector results CEMENT

- AIDRES EU mix cement production routes¹.
  - Fuel replacement to alternative fuels (AFM) biomass waste (BMW) in combination with carbon capture: 85%
  - Coal + carbon capture: 5%
  - Limestone Calcined Clay Cement (LC3): 5%

¹Sources:
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**Industrial mix production routes: sector results FERTILISER**

- AIDRES EU mix fertiliser production routes¹.
  - Green hydrogen: 70%
  - SMR route, partially coupled with carbon capture and pyrolysis: 25%
  - Role of biomass is limited, however could appear in selected regions: 5%

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Industrial mix production routes: sector results GLASS

- AIDRES EU mix 2030 and 2050 glass production routes
  - Electrification +/- CC: 13%
  - Green hydrogen +/- CC: 13%
  - Natural gas +/- CC: 73%

1Sources:
AIDRES Project

Industrial mix production routes: sector results REFINERY

- AIDRES EU mix light liquid fuel production routes \(^1\).
  - Refinery activities are heavily influenced by decreasing fossil fuel consumption in the transport sector, leading to a **reduction in output** of roughly 70% by 2050.
  - Efuels (27%), advanced biofuels (22%), fossil fuels, partly produced with green H\(_2\) (51%)

Industrial mix production routes: sector results CHEMICAL

- AIDRES EU mix chemical production routes¹:
  - Since olefins are linked to polymers, it is assumed the starting point for the products in the chemical sector.
  - Naphtha + CC: (8.1%), electrification of crackers (6%), methanol market (31.1%), methanol biomass (23.7%), methanol CO-electrolysis (31.1%)

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Industrial AIDRES EU mix production routes: EU27 by energy vector

Energy and feedstock inputs (TWh/yr, 2018)

Reduction in direct CO2 emissions by 2050
- 82 to 87.5%
- 87.5 to 90%
- 90 to 94%

Energy and feedstock inputs (TWh/yr, 2050)

Reduction in direct CO2 emissions by 2050
- 82 to 87.5%
- 87.5 to 90%
- 90 to 94%

Based on AIDRES EU Mix Reference and 2050 routes. Scales of Luxembourg, Estonia, Latvia and Slovenia x 3
Industrial AIDRES EU mix production routes: EU27 by sector

Based on AIDRES EU Mix Reference and 2050 routes. Scales of Luxembourg, Estonia, Latvia and Slovenia x 3
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Industrial AIDRES EU mix production routes on NUTS3

- Results will be published on the JRC-Energy and Industry Geography Lab (EIGL) online tool [https://energy-industry-geolab.jrc.ec.europa.eu/](https://energy-industry-geolab.jrc.ec.europa.eu/)
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Industrial Symbiosis key synergy matchmaking (report)

Key synergies:

- **Type 1: Mutualisation of infrastructure per region (scaling function)**
  - E.g.: CO₂ capture infrastructure, Electrolysers (H₂, O₂)

- **Type 2: Exchange of resources per region (input-output substitution)**
  - E.g.: CO₂, steel slag to cement, heat
  - No material exchange between blueprint (post-compute only)
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Industrial Symbiosis: Selected Clusters
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Key findings, AIDRES EU mix routes

- Decrease of 57% in overall energy and feedstock inputs between 2018 and 2050, mainly due to decreased refinery output.
- Sharp increase in renewable electricity demand by 2050, with an increase by a factor 3 by 2030.
- Biomass could have a significant role in the chemical and refinery sectors by 2050.
- The cement sector to rely on biomass waste and alternative fuel mixtures, along with carbon capture technologies such as oxy-fuel combustion and calcium looping.
- Green hydrogen to become an essential energy vector for steel, fertilizer and chemical sectors.
- Methanol to replace naphtha as vital feedstock for the chemical sector.
- Strong decline of coal and natural gas, however, they can still have a role in some sectors combined with carbon capture.
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Conclusions and discussion

- The EU-EII has various options to achieve the 90-95% CO2 emission reduction target by 2050, though it comes with challenges which require measures to de-risk.
  - Development of novel technologies, making them cost competitive,
  - Innovation towards energy efficiency and industrial symbiosis,
  - Availability of renewable energy supply,
  - Moving production of the energy-intensive part of semi-finished products outside the EU,
  - Concerted collaboration across (industrial) sectors and regions,
  - Open exchange of knowledge and data across the EU and globally.

- The AIDRES database and all supporting documents will become publicly available during the coming weeks on the European Commission, DG ENERGY’s website. 

I encourage everyone to make use of the AIDRES database and to share your findings and enhancements with the broader community.
Keep in touch!

Project Manager:  
**Joris Valee**  
Researcher & Project Manager, 
Energy & Climate Strategy  
VITO NV., Belgium  
Joris.Valee@vito.be  
AIDRESProject@vito.be

Project Officer:  
**Eric Lecomte**  
European Commission –  
Directorate General for Energy Unit B.5 – Innovation, Research, Digitalisation, Competitiveness  
Eric.LECOMTE@ec.europa.eu