Deep decarbonisation of the Dutch heavy industry through electrification of the production of basic materials and transportation fuels

Toon van Harmelen, Clemens Schneider, Yvonne van Delft, Robert de Kler, Mathieu Baas, Vincent Kamphuis
Key Findings

• Three what-if electrification scenarios demonstrate that reduction of life cycle CO₂ emissions to near 0 in 2050 is technically possible;
• Required renewable electricity potentials are large: 1,5 – 2,5 times the Dutch North sea wind energy potential;
• Life cycle CO₂ emissions of heavy industry and transport are comparable to total Dutch GHG emissions (219 Mt CO₂ eq);
• Two scenarios, All electric and Big on hydrogen, show possibilities for fossil fuel independence. The Competition scenario shows the possibilities while relying partly on conventional technology with CCS;
• Each scenario needs its own infrastructure with its challenges;
• A favourable scenario is likely a combination.
Content

• Objective
• Approach & model set-up
• Methodology & assumptions
• Three what-if electrification scenarios
• Results
• Conclusions & recommendations
Objective

To explore deep decarbonisation scenarios for the demand of the Dutch heavy industry in 2050, through electrification of the production of basic materials and transportation fuels

- identify the technical feasibility,
- required feedstock and energy potentials and
- pros and cons of different electrification pathways
Approach

- Inventory of current and future situation
- Inventory of options
- Design of scenarios
- Model calculations
- Iterative discussions
- Reporting
Model set-up

Input
• Production levels of basic materials, fuels, food and paper (2010, 2050)
• Production technology (2010, 2050)
• Energy mix (2010, 2050)
• Carbon resources
• Renewable energy potential

Calculation model

Output
• Energy demand of production process (electricity, H₂, syngas/FT-naphta)
• Feedstock demand (carbon and fuel) of production process (H₂, CO₂, syngas/FT-naphta)
• Direct CO₂
• Indirect CO₂

Parameters
• Energy/production [TWh/Mton]
• Feedstock/production [TWh/Mton]
• Direct CO₂/production [Mton/Mton]
• Indirect CO₂/production (energy, carbon feedstock, combustion of fuels, end-of-life) [Mton CO₂-eq/Mton]

Based upon: Decarbonising the energy intensive basic materials industry through electrification - Implications for future EU electricity demand, Stefan Lechtenböhmer et al (2015, Wuppertal Institute & Univ of Lund)
Methodology & assumptions

• Life cycle CO₂ to 0: direct fossil based CO₂ emissions at production, use phase, end-of-life of products (also of exports)
• What-if electrification scenarios sketching three distinct technology based pathways
• Modest volume growth, no structural changes (“High growth” scenario from Prosperity & environment, CPB/PBL 2015)
• Using North Sea wind power potentials, incl. 23% battery storage losses for maintaining security of supply:
  – NL: 34 GW ~ 130 TWh (PBL, 2011)
  – North Sea: 250 GW ~ 1000 TWh (Energy Odyssey)
  – 90% one-way battery efficiency (projected battery efficiency, TNO 2018)
Domestic use and export

• Currently, refineries and chemical industry produce approximately \( \frac{1}{4} \) for the domestic and \( \frac{3}{4} \) for foreign markets;
• In scenarios for 2050, the chemical industry is assumed to maintain its production of mainly plastics for the foreign market;
• In scenarios for 2050, transport fuel for export and international bunkers (navigation and aviation) is assumed to be disappeared (electricity, hydrogen or biomass is not supplied from the Netherlands);
• For a clear analysis, the same assumption is applied for both the current situation as the 2050 scenarios.
Three what-if electrification scenarios
### Scenarios: leading indicators

<table>
<thead>
<tr>
<th>Low political driver</th>
<th>High political driver</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>“competitive transition”</strong></td>
<td><strong>“revolutionary transition”</strong></td>
</tr>
<tr>
<td>A lot of debate on climate and GHG emissions</td>
<td>Climate and GHG link is accepted</td>
</tr>
<tr>
<td>Renewable and fossil technologies compete on a financial basis</td>
<td>Strong political actions: CO2-tax, fuel excise, car tax, subsidies for R&amp;D, Capex and write-off</td>
</tr>
<tr>
<td>Public opinion, NGO’s and visionary companies (big brands) drive the change</td>
<td>Governments lead the change</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low technical driver</th>
<th>High technical driver</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>“no transition”</strong></td>
<td><strong>“painful transition”</strong></td>
</tr>
<tr>
<td>Climate change and GHG reduction will be disputed</td>
<td>Climate change and need for CO2 reduction are not disputed</td>
</tr>
<tr>
<td>No carbon tax</td>
<td>There is carbon tax</td>
</tr>
<tr>
<td>Offshore wind projects will peter out</td>
<td>Offshore wind and solar projects will require subsidies</td>
</tr>
<tr>
<td>No investment in transnational grids</td>
<td>Energy expensive, economic growth suppressed, political struggles</td>
</tr>
<tr>
<td>Paris targets will not be met</td>
<td>Technology Investments driven by CO2-reduction per dollar invested</td>
</tr>
<tr>
<td>Fossil carbon will become scarce over time, prices will go up</td>
<td></td>
</tr>
</tbody>
</table>

Indicators give insight in the transition process towards electrification. Based on the TNO study “Electrification options for the Port of Rotterdam”, a case study for Smart Port by Robert de Kler et al. 2017
Current situation

Products
- Basic Chemicals
  - Olefins
  - Ammonia
  - Chlorine
- Metal
  - Iron & steel
  - Aluminum
- Food
- Minerals
  - Glass & ceramics
  - Cement
- Paper & pulp

Transport Fuels
- Road Transport
- Aviation
- Navigation
What-if scenarios A, B and C

**All Electric**
- Carbon source: bio, waste
- Energy source: wind
- Industry: factories
- Products & Markets: ships, planes, trucks

**Big on hydrogen**
- Carbon source: bio, waste
- Energy source: wind
- Industry: factories
- Products & Markets: ships, planes, trucks
- Hydrogen

**Competition**
- Carbon source: bio, fossil
- Energy source: wind
- Industry: factories
- Products & Markets: ships, planes, trucks
- CCS
# What-if scenarios:
Three distinct technological pathways

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Current situation</th>
<th>A. All-electric</th>
<th>B. Big-on-Hydrogen</th>
<th>C. Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short description</strong></td>
<td>Production is largely fossil based</td>
<td>Renewable electricity as energy carrier in industry and transport. Maximal direct electrification with storage issues. Refineries are closed</td>
<td>Hydrogen as final energy carrier for transportation and industry, produced with conversion losses by renewable electricity. Refineries are closed. Add H2 infrastructure</td>
<td>A mix of energy carriers, renewable electricity (indirect electrification, hydrogen), fossil fuels with CCS and bio(syn)fuels. Add CO2 infrastructure</td>
</tr>
<tr>
<td><strong>Carbon source and CO2 emissions</strong></td>
<td>Fossil based energy and feedstock, high CO2 emissions</td>
<td>Partly closed carbon cycle, waste &amp; bio (growth) used as feedstock (olefins), near zero CO2 emissions</td>
<td>Partly closed carbon cycle, waste &amp; bio (growth) used as feedstock (olefins), near zero CO2 emissions</td>
<td>Crude oil for olefins and coal for steel combined with CCS; scarce bio based synfuels used for transportation and small sectors, near zero CO2 emissions</td>
</tr>
<tr>
<td><strong>Leading stakeholders</strong></td>
<td>Gas and petrochemical industry</td>
<td>Power sector (DC grid)</td>
<td>Gas sector (H2 grid)</td>
<td>Petrochemical industry and others</td>
</tr>
<tr>
<td><strong>Demand projection</strong></td>
<td>Product and service demand projections are from the PBL scenario high growth, combined with assumed high energy efficiency improvements up to a factor 2</td>
<td></td>
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</tr>
</tbody>
</table>
# Technological options by subsector and scenario

<table>
<thead>
<tr>
<th>Subsector</th>
<th>Sector</th>
<th>Process (High Value Chemicals)</th>
<th>Current situation</th>
<th>A. All electric</th>
<th>B. Big on hydrogen</th>
<th>C. Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic chemicals</td>
<td>Olefins</td>
<td>Ethylene, propylene, other</td>
<td>Current crude oil based processes</td>
<td>Bio (for export) and waste (domestic) based MTO/MTA are used for olefin production</td>
<td>Bio (for export) and waste (domestic) based MTO/MTA are used for olefin production</td>
<td>Use crude oil refining and naphtha and gasoil steam cracking and residue gasification via MTO to produce olefins/aromatics (CCS waste incineration)</td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
<td>Current electrical process</td>
<td>Current electrical process</td>
<td>Current electrical process</td>
<td>Current electrical process</td>
</tr>
<tr>
<td>Ammonia</td>
<td></td>
<td></td>
<td>Current natural gas based processes</td>
<td>Direct electrical ammonia synthesis</td>
<td>Indirect electrical ammonia synthesis via H2</td>
<td>Current electrical process</td>
</tr>
<tr>
<td>Freight road</td>
<td></td>
<td></td>
<td>Combusion engines</td>
<td>Electric vehicles</td>
<td>H2 fuel cells</td>
<td>Current electrical process</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
<td>Combustion engines</td>
<td>Electric vehicles</td>
<td>H2 fuel cells</td>
<td>Biobased syncanol or OME</td>
</tr>
<tr>
<td>Passenger road</td>
<td>Gasoline, diesel, CNG and electricity</td>
<td>Combustion engines</td>
<td>Electric vehicles</td>
<td>H2 fuel cells</td>
<td>Biobased syncanol or OME</td>
<td></td>
</tr>
<tr>
<td>Aviation</td>
<td>Kerosene</td>
<td>Combustion engines</td>
<td>Electric airplanes</td>
<td>H2 fuel cells</td>
<td>Biobased kerosene</td>
<td></td>
</tr>
<tr>
<td>Oil refinery</td>
<td>Basic chemicals</td>
<td></td>
<td>Crude oil refining</td>
<td>None</td>
<td>None</td>
<td>Crude oil for feedstock</td>
</tr>
<tr>
<td>Basic chemicals</td>
<td>Fuel</td>
<td></td>
<td>Crude oil refining</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Iron &amp; steel:</td>
<td></td>
<td></td>
<td>Blast oxygen furnace</td>
<td>Electrowinning</td>
<td>Direct reduction H2 + EAF</td>
<td>HISARNA or TGR + Carbon Capture</td>
</tr>
<tr>
<td>Metal</td>
<td>Primary steel</td>
<td>EAF, Secondary steel from scrap</td>
<td>EAF, Secondary steel from scrap</td>
<td>EAF, Secondary steel from scrap</td>
<td>EAF, Secondary steel from scrap + CCS</td>
<td>Current process</td>
</tr>
<tr>
<td></td>
<td>Secondary steel</td>
<td>Current process</td>
<td>Current process</td>
<td>Current process</td>
<td>Current process</td>
<td>Current process</td>
</tr>
<tr>
<td></td>
<td>Aluminium</td>
<td></td>
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<tr>
<td></td>
<td>Glass</td>
<td>Container glass, flat glass, glass fibre</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Minerals</td>
<td>Cement</td>
<td>Current processes</td>
<td>ENCI</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lime</td>
<td></td>
<td>No lime production</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Food</td>
<td>Milk powder, potato &amp; sugar</td>
<td>Steam boilers</td>
<td>Heat pumps + compression + HT storage, breakthroughs</td>
<td>Heat pumps + compression + H2/fuel cells, fuel mix change</td>
<td>Heat pumps + compression + H2/fuel cells, fuel mix change</td>
<td>Biogas BAT, decarbon electricity</td>
</tr>
</tbody>
</table>
Results
Current domestic CO₂ emissions (2010)

Basic chemicals (incl. export) and transport (excl. export) are dominant
Current CO$_2$ of industrial life cycle are comparable to total Dutch GHG emission (219 Mton)
Current situation

Energy and feedstocks almost completely fossil based
2050 Scenario All electric

Direct electricity reduces energy demand with 20%; 2x NL North Sea wind, 25% total NS; completely fossil independent
Indirect electricity via hydrogen results in a more or less stable energy demand, completely fossil independent.
2050 Scenario Competition

Increase of energy demand with 30%; biomass potential ~ 2 x NL; same electricity potential; crude oil and CCS needed
2050 Primary energy demand

North Sea wind potentials needed up to 2,5x NL North Sea wind, 30% total NS; C fossil dependent, biomass potential 2x NL
Sweet spots: All electric based transport & steel, Big on hydrogen based basic chemicals
Conclusions & recommendations
Conclusions

• It is technically possible to reduce life cycle CO₂ emissions to near 0 in the what-if scenarios All electric, Big on hydrogen and Competition in 2050;
• Current life cycle CO₂ emissions of the Dutch energy intensive industry & transport are comparable to the current total of Dutch direct GHG emissions (219 Mton);
• Required renewable electricity potentials are large: 1.5 – 2.5 times the Dutch North sea wind energy potential, equalling 20% - 35% of the total North sea wind potential;
• Energy use is comparable to the current situation in scenario Big on hydrogen, 20% lower in All electric and 30% higher in Competition (mainly due to transport);
• Two scenarios, All electric and Big on hydrogen, show possibilities for fossil fuel independence. The Competition scenario shows the possibilities while relying partly on conventional technology with CCS;
• Carbon sourcing in scenario A & B requires limited biomass potentials (10% of the Netherlands area) for plastic production growth, while in scenario C required potentials are large for transport (biomass potentials of 2x the Netherlands area) and fossil fuels for plastics;
• Each scenario needs its own infrastructure and has its own challenges (storage, transport, safety);
• A favourable scenario is likely a combination of different scenario elements applied in different markets / sectors: A. direct electrification in transport, steel & minerals; B. hydrogen in basic chemicals; C. renewable alternatives in food & paper.
Recommendations for further work

Further investigate:

• How to prepare the next decade for potential long term scenarios – identify critical & no-regret technologies, in general and per sector & product;

• Economic impacts and feasibility – for value chain and Dutch society;

• Necessary governance to support desired developments;

• Dutch export position on future decarbonised energy carriers for transportation (aviation and navigation) - currently 3x the domestic use.