A feasibility study on bioenergy uptake in the industrial sector

Sara Budinis*, Ivan Garcia Kerdan, Julia Sachs, Sara Giarola and Adam Hawkes

Sustainable Gas Institute - Imperial College London

*s.budinis11@imperial.ac.uk
Overview

The industrial sector is currently energy and emission intensive*:
• 36% TFEC (154 EJ) and 24% of global CO₂ emissions (8.3 GtCO₂)
• 69% of industrial energy use into 5 energy intensive subsectors

IEA targets:
• Current growth (2010-2014) energy consumption: 1.5% annual; expected growth for IEA 2DS target: 1.2%

Therefore there is a need for decarbonising the industrial sector!

Options include:
• Energy efficiency
• Fuel switching (e.g. from coal to gas; from fossil to renewable sources)
• Carbon Capture and Storage (CCS)

Use of bioenergy:
• On its own or combined with CCS (BECCS) to give negative emissions
• Sustainability: food versus energy?

Aims/goals of this study:
• Review if/where bioenergy can be used within the industrial sector
• Quantify the potential of bioenergy uptake for industrial decarbonisation
• Compare the effect of static vs dynamic supply curves on industrial decarbonisation

*www.iea.org/etp/
- Definition and use of bioenergy
- MUSE model
- Supply of bioenergy
- Demand of bioenergy: focus on industrial sector
- Scenarios
- Results
- Conclusions
Definition and use of bioenergy

Use within the industrial sector*:

- Mainly solid and gaseous biofuels
- More frequent in sectors producing bio waste (e.g. pulp and paper) but common practice in other sectors as well (e.g. cement)
- Use: combustion for heat, electricity and co-generation
- Bioenergy can be used for the generation of low, medium and high temperature heat

MUSE model

MUSE - ModUlar energy system Simulation Environment:
- Highly disaggregated
- Global scale with regional disaggregation (28 regions)
- Simulation with time horizon 2010 to 2100
- Modular
- Engineering-led and technology-rich (bottom-up)
- Microeconomic foundations
- Partial equilibrium
- Policy instruments modelled (e.g. carbon price, subsidies)

Industry Sector Module (ISM):
- 5 main subsectors (modelled: iron and steel; cement; chemicals; pulp and paper; aluminium)
- Industrial “others” (projections of energy consumption and emissions based on IEA – baseline vs decarbonisation profiles)
- 200 technologies:
  - Alternative productions routes
  - Option to switch fuel
  - Option to adopt post-combustion CCS
Supply of bioenergy

MUSE Energy Commodities

<table>
<thead>
<tr>
<th>Fossil</th>
<th>Bio-based</th>
<th>Electricity</th>
<th>Waste</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>LPG</td>
<td>Electricity</td>
<td>Agricultural residues</td>
<td>Heat</td>
</tr>
<tr>
<td>Gas</td>
<td>Methanol</td>
<td></td>
<td>Animal residues</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Gasoline</td>
<td>Naphtha</td>
<td>Hydropower</td>
<td>Forest residues</td>
<td>Uranium</td>
</tr>
<tr>
<td>Hard-coal</td>
<td>NGL</td>
<td>Solar</td>
<td>Industrial Waste</td>
<td></td>
</tr>
<tr>
<td>Heavy-fuel</td>
<td>Oil</td>
<td>Wind</td>
<td>MSW</td>
<td></td>
</tr>
<tr>
<td>Jetfuel-kerosene</td>
<td>Processed-coal</td>
<td>Geothermal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jetfuel-naphtha</td>
<td>Processed-gas</td>
<td>Ocean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignite</td>
<td>Refined-gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG</td>
<td>Solid-fuels</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Static supply curves:
Source: IIASA. Global Energy Assessment*, Chapter 7: Energy Resources and Potentials
- Algae
- Energy crops
- Waste

Dynamic supply curves:
Methodology: based on land use availability

*www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/Chapter7.en.html
Supply of bioenergy

Dynamic supply curves:

Dynamic supply curves are calculated for every iteration and every time period until convergence is reached.
1. Exogenous prices:
   - Zero carbon price
   - Carbon price according to the IEA 2DS*

Sensitivity analysis around key parameters:
- Years when bio-based technologies become available
- Growth rate
- CAPEX and fixed OPEX
- Price of bioenergy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base case</th>
<th>Range for sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2030</td>
<td>2020, 2050</td>
</tr>
<tr>
<td>Growth rate</td>
<td>20%</td>
<td>5, 10, 15%</td>
</tr>
<tr>
<td>CAPEX and OPEX</td>
<td>-</td>
<td>±20%</td>
</tr>
<tr>
<td>Bioenergy price</td>
<td>-</td>
<td>33, 300%</td>
</tr>
</tbody>
</table>

2. Endogenous prices: static versus dynamic supply curves

Exogenous prices
Results: zero carbon price - 1

- No investment in CCS
- Existing CCS plants get decommissioned

<table>
<thead>
<tr>
<th>Subsector (Mt)</th>
<th>2010</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals + CCS</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chemicals</td>
<td>775</td>
<td>1130</td>
<td>1272</td>
</tr>
<tr>
<td>Iron &amp; steel + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Iron &amp; steel</td>
<td>2318</td>
<td>3782</td>
<td>3505</td>
</tr>
<tr>
<td>Cement + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cement</td>
<td>3677</td>
<td>4861</td>
<td>3978</td>
</tr>
<tr>
<td>Aluminium + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>44</td>
<td>52</td>
<td>42</td>
</tr>
<tr>
<td>Pulp &amp; paper + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pulp &amp; paper</td>
<td>212</td>
<td>240</td>
<td>237</td>
</tr>
</tbody>
</table>
Results: zero carbon price - 2

- Fossil fuels maintain a relevant share
- Share of electricity increases over time, mainly due to non-energy intensive subsectors ("others")
- Limited role of solid biomass
• Carbon price consistent with the IEA 2DS (about US$/t 1900 by 2100)
• Growth rate: 20%
• **Heavy investment in CCS: iron and steel and cement “fully” decarbonised by 2050**

<table>
<thead>
<tr>
<th>Subsector (Mt)</th>
<th>2010</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>775</td>
<td>762</td>
<td>391</td>
</tr>
<tr>
<td>Chemicals + CCS</td>
<td>10</td>
<td>368</td>
<td>881</td>
</tr>
<tr>
<td>Iron &amp; steel</td>
<td>2318</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>Iron &amp; steel + CCS</td>
<td>0</td>
<td>3743</td>
<td>3505</td>
</tr>
<tr>
<td>Cement</td>
<td>3677</td>
<td>2</td>
<td>0</td>
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<tr>
<td>Cement + CCS</td>
<td>0</td>
<td>4858</td>
<td>3978</td>
</tr>
<tr>
<td>Aluminium</td>
<td>44</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>Aluminium + CCS</td>
<td>0</td>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>Pulp &amp; paper</td>
<td>212</td>
<td>161</td>
<td>4</td>
</tr>
<tr>
<td>Pulp &amp; paper + CCS</td>
<td>0</td>
<td>79</td>
<td>233</td>
</tr>
</tbody>
</table>
- Fossil fuel have a limited role
- Electricity and biomass take most of the market by 2100
Parameters:
- Years when bio-based technologies become available
- Growth rate
- CAPEX and fixed OPEX
- Price of bioenergy

Results:
- Both solid and gaseous biofuels are affected
- Gaseous biofuels enter the market in 2040
- Solid biofuels’ share starts growing substantially in 2020
- Total bioenergy consumption converges by 2060 (year), 2080 (price) or 2100 (growth rate)
Endogenous prices
Results:
static vs dynamic supply curves
Conclusions

Aims/goals of this study:
1. Review if/where bioenergy can be used within the industrial sector
2. Quantify the potential of bioenergy uptake for industrial decarbonisation
3. Compare the effect of static vs dynamic supply curves on industrial decarbonisation

Findings:
- Bioenergy can be used in the industrial sector: high potential for all temperatures (low/medium/high) heat and all sectors
  - Without carbon price:
    - Share of bio: 8% (2010) to 12% (2050) to 2% (2100)
    - Dominant technologies: based on fossil fuels
  - With carbon price:
    - Share of bio: 8% (2010) to 49% (2050) to 39% (2100)
    - Dominant technologies: based on biofuels, CCS
- Dynamic supply curves model land use competition and result in higher bioenergy prices

Future development:
- Including additional policy aspects e.g. subsidies for CCS
- Including supply chain and infrastructure bottlenecks (for CO₂ transport and storage)
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Thank you for your attention