CO$_2$ utilization
Outline

• AkzoNobel
• Sustainability
• Rethinking our raw materials
• Possibilities of using CO₂ as raw material
• Challenges of using CO₂ as raw material
• Conclusions
AkzoNobel key facts

2011
• Revenue €15.7 billion
• 57,240 employees
• EBITDA: €1.8 billion*
• Net income: €0.5 billion
• 40 percent of revenue from high growth markets
• A leader in sustainability

Revenue by business area

<table>
<thead>
<tr>
<th>Business Area</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Coatings</td>
<td>34%</td>
</tr>
<tr>
<td>Decorative Paints</td>
<td>33%</td>
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<td>Specialty Chemicals</td>
<td>33%</td>
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</tbody>
</table>

EBITDA* by business area

<table>
<thead>
<tr>
<th>Business Area</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Performance Coatings</td>
<td>46%</td>
</tr>
<tr>
<td>Decorative Paints</td>
<td>23%</td>
</tr>
<tr>
<td>Specialty Chemicals</td>
<td>31%</td>
</tr>
</tbody>
</table>

* Before incidentals
AkzoNobel brands
**AkzoNobel’s medium term strategic goals**

- **Value**
  - Accelerated growth
  - Grow to €20 billion revenues
  - Increase EBITDA each year, maintaining a 13-15% margin
  - Reduce OWC/revenues by 0.5 p.a. towards a 12% level
  - Pay a stable to rising dividend

- **Values**
  - Sustainable growth
  - Top quartile safety performance
  - Top 3 position in sustainability* 
  - Top quartile performance in diversity, employee engagement and talent development
  - Top quartile eco-efficiency improvement rates

* SAM annual benchmark
Sustainability & climate change

- Energy independence
- Preserve rainforests
- Sustainability
- Green jobs
- Livable cities
- Renewables
- Clean water, air
- Healthy children
- Etc., etc.

Global warming is a complete myth! So just keep on walking...

But stay away from the edge

Bad news, we're running out of ice.
Carbon footprint: sum of all direct and indirect emissions

The product life cycle

- Extraction
- Raw materials
- Production
- Use
- End of life

Scope 1
Scope 2
Scope 3 upstream
Scope 3 downstream

Cradle-to-gate (scope 1, 2 & 3 up)

Life Cycle: Cradle-to-grave (all scopes)
Rethinking our raw materials

Shift to non-conventional raw materials and conversion processes for the energy and chemical industry
Chemical conversion of carbon dioxide

H. Arakawa et al, Chemical Reviews (2001), 101, 953
Sense and sensibility of carbon dioxide conversion

Chemical upcycling analogous to “Waste = Food” concept

Green Chemistry, Sustainable Chemistry, Cradle-to-Cradle….

Next generation C\textsubscript{1} feedstock?

Nature’s favorite raw material

Current and future availability high

Quality-cost-ratio will increase significantly (CCS)

Mild and safe reagent (GRAS status)

» Utilizing CO\textsubscript{2} is thermodynamically challenging!
The challenge of chemical carbon dioxide conversion

\[ \Delta G > 0 \text{ for standard conditions} \]

\[
\begin{align*}
\text{CO}_2 + 2\text{NH}_3 & \rightleftharpoons \text{urea} + \text{H}_2\text{O} \\
\text{CO}_2 + 3\text{H}_2 & \rightleftharpoons \text{MeOH} + \text{H}_2\text{O} \\
\text{CO}_2 + \text{H}_2 & \rightleftharpoons \text{CO} + \text{H}_2\text{O} \\
\text{CO}_2 + 2\text{MeOH} & \rightleftharpoons \text{DMC} + \text{H}_2\text{O}
\end{align*}
\]
Urea

- Production of 160,000,000 ton per year
- Process carried out at high pressure
- Recycle loop in process
- Steam consumption: 1.0 ton/ton urea
Methanol from CO₂

- High pressure and recycle needed
- Methanol from CO₂ not economical due to high H₂ price
- Methanol synthesis from syngas is believed to occur via CO₂:
  50,000,000 ton/year

CO₂ + 3H₂ ⇌ MeOH + H₂O

CO₂ + H₂ ⇌ CO + H₂O

Goehna et al., CHEMTECH 1994, 36
DMC from CO\textsubscript{2}

- CO\textsubscript{2} + 2MeOH $\rightleftharpoons$ DMC + H\textsubscript{2}O
- Even at high pressures the equilibrium is limited to 1-2%
- Not possible to design a process without excessive energy consumption due to large recycle
The disadvantages of current CO\textsubscript{2} processes

- High energy consumption related to separation/cooling/compressors
- High investment costs due to compressors, heat exchangers and thick piping
- Very large plants are built to minimize effect of high investment costs on production costs (economies of scale)
Conclusions

• CO₂ can potentially be applied to make many different chemicals

• Reason for AkzoNobel to be interested in CO₂ utilization is to obtain access to renewable and preferably cheaper raw materials

• Due to equilibrium limitations CO₂ processes require high pressures and recycle loops ➞ high investment costs and energy consumption

• Membranes can potentially help to reduce energy consumption by eliminating recycle loops and working at lower pressures
George Olah: the methanol economy