Towards greener hydrogen production in China

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Hydrogen from fossil fuels
Hydrogen production routines in China

Hydrogen is not a full commodity at present

Hydrogen production route is highly dependent on locally rich sources
In China, the produced hydrogen is mainly for ammonia and refinery.
Hydrogen production from coal

<table>
<thead>
<tr>
<th>Resources</th>
<th>Cost of raw materials, RMB/t</th>
<th>H₂ price, RMB/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>760</td>
<td>1.07</td>
</tr>
<tr>
<td>Petroleum coke</td>
<td>950</td>
<td>1.12</td>
</tr>
<tr>
<td>Refinery gas</td>
<td>3000</td>
<td>1.40</td>
</tr>
<tr>
<td>Residue oil</td>
<td>4000</td>
<td>1.88</td>
</tr>
</tbody>
</table>

For 20MT/y refinery

Due to availability of coal and lower cost, hydrogen production from coal will continue mainly for ammonia synthesis.

Gasification processes is a key step to produce hydrogen.
Higher efficiency and less coal consumption for pulverized gasifier than coal-water slurry gasifier

If we have to choose coal gasification to produce hydrogen, use the pulverized gasifier as much as possible
### Hydrogen from methane reforming in China

<table>
<thead>
<tr>
<th>Product</th>
<th>Yearly prod. (mil. t/y)</th>
<th>Energy consumpt. (GJ/t)</th>
<th>Thermal LHV Practical (%)</th>
<th>Efficiency Ideal (%)</th>
<th>CO₂ (t/t)</th>
<th>Main technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>124</td>
<td>29</td>
<td>65</td>
<td>89</td>
<td>16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Syngas/synthesis</td>
</tr>
<tr>
<td>Ethylene</td>
<td>75</td>
<td>15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>62</td>
<td>93</td>
<td>0.65</td>
<td>Steam cracking C&lt;sub&gt;2&lt;/sub&gt;H&lt;sub&gt;6&lt;/sub&gt;</td>
</tr>
<tr>
<td>Propylene</td>
<td>53</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.28</td>
<td>Steam cracking C&lt;sub&gt;2&lt;/sub&gt;H&lt;sub&gt;6&lt;/sub&gt;</td>
</tr>
<tr>
<td>Methanol</td>
<td>32</td>
<td>28</td>
<td>72</td>
<td>84</td>
<td>0.9</td>
<td>Syngas/synthesis</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>20</td>
<td>12.6</td>
<td>84&lt;sup&gt;c&lt;/sup&gt;</td>
<td>92</td>
<td>0.9</td>
<td>Steam reforming</td>
</tr>
<tr>
<td>Synfuels</td>
<td>18&lt;sup&gt;d&lt;/sup&gt;</td>
<td>67</td>
<td>60</td>
<td>78</td>
<td>1.18</td>
<td>Syngas/synthesis</td>
</tr>
</tbody>
</table>

<sup>a</sup> incl. CO₂ converted into urea  
<sup>b</sup> data kindly provided by F. Dautzenberg, ABB Lummus, 2005  
<sup>c</sup> CH₄ used for reaction heat; no steam export  
<sup>d</sup> excl. 3 million tonnes per year under construction

- Currently, reforming process is mainly focus on using the tail gas, coke gas etc.
- Shale gas and unconventional gas reforming is expected to produce hydrogen in the future
## Catalysts, products and processes in steam reforming

<table>
<thead>
<tr>
<th>Design</th>
<th>$H_2O/CH_4$</th>
<th>$P$ (bar)</th>
<th>$T_{inlet}$ ($^\circ$C)</th>
<th>$T_{exit}$ ($^\circ$C)</th>
<th>$H_2$</th>
<th>CO</th>
<th>$CO_2$</th>
<th>$CH_4$</th>
<th>Process duty MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous</td>
<td>4.5</td>
<td>30</td>
<td>500</td>
<td>850</td>
<td>75.19</td>
<td>11.07</td>
<td>10.49</td>
<td>3.24</td>
<td>97.8</td>
</tr>
<tr>
<td>Modern</td>
<td>1.8</td>
<td>30</td>
<td>650</td>
<td>920</td>
<td>71.08</td>
<td>17.61</td>
<td>4.56</td>
<td>6.75</td>
<td>85.4</td>
</tr>
</tbody>
</table>

Production costs for hydrogen with/without CO$_2$ capture/storage.
Data from IEA 2005

<table>
<thead>
<tr>
<th></th>
<th>Large</th>
<th>Large with CCS</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_2$ pressure (bar)</td>
<td>78</td>
<td>78</td>
<td>Liq.</td>
</tr>
<tr>
<td>LHV efficiency (%)</td>
<td>73.2</td>
<td>61.1</td>
<td>46</td>
</tr>
<tr>
<td>Investment (USD/GJ/y)</td>
<td>9.4</td>
<td>11.9</td>
<td>21</td>
</tr>
<tr>
<td>$H_2$ costs (USD/GJ)</td>
<td>5.5</td>
<td>6.7</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.5</td>
</tr>
</tbody>
</table>
Hydrogen from non-fossil fuels
Routes to Harvest Photon Energy

**Ancient & nature routes**
- Plants
  - Cellulose
  - Protein
  - Hydrocarbons (coal, oil & gas)  
  - Efficiency < 1%

**Modern routes**
- Photons
  - Electrons
  - Hydrogen
  - HCs
  - Efficiency ~ 20%

**Near future: within 10 years?**
- PV
  - Wind
  - Wave

**Future routes > 50 years?**
- Photoelectrochem

- Abundant renewable energies will provide cheap electrons to produce H₂ via electrolysis and then HCs (such as FTS) will be highly sustainable.
- Direct hydrocarbon synthesis via photoelectrochemistry requires significant advances in science and technology.

**Current efficiency <5%**
What if electricity is abundant but non-balanced?

Estimated wind potential 70 TW (land only)

Theoretical $1.2 \times 10^5$ TW solar energy
What if electrolysis plays a central role?

Solar, wind & hydro-power

Biomass

Power Plant

Electrolysis/Fuel Cell

H₂ and O₂

H₂ Storage

Upgrading

CO₂

H₂

CO₂ hydrogenation

CH₄, CH₃OH...

Fuels

Consumer

Fuel storage

Fuels

Chemicals
Converting available carbon to fuels, not by-product CO₂

- No shift reaction: \( \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \)
- Effectively no CO₂ emissions
- Hybrid system uses 70% less coal
- Product fuel’s energy is 20% from nuclear

Coal: 4,400 tons/day

Gasifier: Small amount of CO₂

Gas Cleanup: H₂S

Synfuel: 25,000 barrels/day

Nuclear Plant

Electrolyzers

Fischer-Tropsch Synthesis

Product Upgrade

Synfuel Product

Sulfur Product
Energy content of fuels

Fill up the tank with gasoline!
20 l/min or 720MJ/min
Corresponds to 60,000A @ 200V
## Challenges in the Transport Sector

Probably electricity will be the major form of sustainable energy, but it is impractical to store (in particular in the transport sector—require long cables?). _Who much energy is used in the transport sector??_

<table>
<thead>
<tr>
<th>Bont Fuel Cells</th>
<th>Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Electrolyse 70%</td>
<td>• Distribution 90%</td>
</tr>
<tr>
<td>• Compression 90%</td>
<td>• Local transformation 90%</td>
</tr>
<tr>
<td>• Distribution 90%</td>
<td>• charging/decharging 80%</td>
</tr>
<tr>
<td>• Fuel cell 45%</td>
<td></td>
</tr>
<tr>
<td>• Can be improved</td>
<td></td>
</tr>
</tbody>
</table>

**Total efficiency**

\[
0.7 \times 0.9 \times 0.9 \times 0.45 = 25\%
\]

Hard to store Hydrogen

No Infrastructure

**Total effektivitet**

\[
0.9 \times 0.9 \times 0.8 = 65\%
\]

Capacitet is a problem

Charging is slow
Thank you very much!