Today’s presentation

- Status subtask A
- Status subtask B
- Preliminary results subtask C
IEA Annex XVI – Subtask A

Large-scale integrated hydrogen production for power generation PCDC (Precombustion Decarbonisation)
Basic PCDC Process Scheme

Fuel → Syngas generation → Water-gas shift → CO2 removal → H₂

Air → Air Separation → O₂ → CO₂ removal

H₂O → H₂O → H₂, CO → H₂, CO₂ → CO₂

O₂ → N₂
Subtask A: Plan and Organisation

- Subtask leader: IEA GHG Programme
- CCP main contributor and funder of step 1-3
- Scope: Step 1-3 of phase 1
  1. Concept assessment based on previous work
  2. Concept selection
  3. Main study with focus on standardisation issues
     - Modularisation
     - Repeat design
Results from Step 1 and 2

- Screening based on 5 studies
  - Hydro: Hydrokraft and Naturkraft
  - CCP: Foster-Wheeler (FW) study
  - IEA GHG Programme: FW and Flour Daniel Study

- Objectives
  - Comparison of cost, efficiency and CO2 capture
  - List of potential technology suppliers
  - Recommend concept for standardisation
Step 3 – Scope of work

- Define CCGT un-controlled case
- Define base case CCGT with CO2 capture
- Market study
- Cost Reduction Study
  - Modularisation
  - Standardisation and repetitive design
  - Optimisation
Status and Way forward

- Step 1 and 2 work done (Hydro)
- Step 3 work done (Jacobs Engineering)
  - Funded 50% by CCP and 50% by Kclimatek.
  - Report finalised in Q1 2004
  - Ownership of results is placed at CCP1 members

- Next step
  - Step 1 and 2 results will be reported to IEA for publication before termination of subtask (Draft June 2005)
  - Step 3 will be based on a summary of the Jacobs study
    - CCP1 have accepted dissemination of the Jacobs Study for IEA (2004)
    - CCP1 must approve the final report before it is released to IEA (Draft June)
Biomass to hydrogen
Subtask B – Biomass to Hydrogen

- Member situation
  - 10 members from 8 countries:
    - France, Italy, Netherlands, Belgium, Denmark, Norway, Singapore, Switzerland

- Meetings, incl. planned 1st half 2005
  - Brussels April 12
  - Stockholm May 20
  - Montpellier July 5
Subtask B – Final report - approach

- Overview and description of biomass to hydrogen process routes
- Scenarios for biomass to hydrogen pathways. Related to
  - Production scale/location
  - Practical approach to availability and properties
  - End-use
  - Co-processing opportunities
- Identification of useful pathways

- Novel pathways
  - Mixing biomass with coal for hydrogen production
  - Using glycerine (currently a by-product of RME biodiesel production) as feedstock
  - Imports of pyrolysis oil as feedstock, produced in e.g. Asia, for further processing in Europe

Fig.: Scenarios

- Small scale*
  - Local case
  - 2-10 t/h
  - Some overlap with subtask C

- Large scale
  - Distribution
  - Pretreatment e.g. Biooil, charcoal or densification
  - Biomass collection - by sea?
  - Co-processing
  - Some overlap with subtask A

*Can also be anaerobic digesters + small reformers

H2 local/regional distribution
Subtask B – Final report focus for R&D Needs and Recommendations

- R&D needs - arise from all parts of the value chain. Special focus on
  - Feed preparation
  - Feed homogenisation
  - Processing
  - Cleaning

- Recommendations - these can be related to
  - Pathways
  - Prioritised R&D
  - Potential EC proposals
  - Potential IEA follow-up ideas for new tasks
Small stationary reformers for distributed hydrogen production - Preliminary results
About Subtask C

- 15 members representing 10 countries
  - 11 industrial companies

- 9 Technical meetings and one upcoming concluding event on June 15, 2005 in Oslo

<table>
<thead>
<tr>
<th>Participant</th>
<th>Country</th>
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<tbody>
<tr>
<td>Hydro</td>
<td>N</td>
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<tr>
<td>Haldor Topsøe</td>
<td>DK</td>
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<td>Engineering Advancement Association of Japan</td>
<td>Japan</td>
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<td>Osaka Gas</td>
<td>Japan</td>
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<td>Mitsubishi Kakoki Kaisha Ltd</td>
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<td>Gastec</td>
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<td>IFE</td>
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<td>Gaz de France</td>
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<td>BP</td>
<td>UK</td>
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<td>Intelligent Energy</td>
<td>UK (USA)</td>
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<td>Mahler</td>
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<td>Hyradix</td>
<td>USA</td>
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<td>Gas Natural</td>
<td>Spain</td>
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<td>Swedish Gas Technology Centre</td>
<td>Sweden</td>
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<td>iESE</td>
<td>Singapore</td>
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Key stakeholders represented

- The customers
  - BP, Gas Natural, Gaz de France, Intelligent Energy and Hydro

- The suppliers
  - Haldor Topsøe, Hyradix, IGS Mahler, Mistshubishi and Osaka Gas

- The researchers and the authorities
  - Gastec, IFE, ENAA, SGC

BP – public station with hydrogen in Singapore - 2004
Tasks and activities

- The task was divided in four activities:

1. State of the art – technology status
2. Transport Fuel Market Adaptation
3. Minimising of CO₂ Emissions
4. Hydrogen Demand in Stationary Markets, e.g. combined heat and power
Main objective

- Main objective: find system solutions for initial markets

Approach
- Evaluate experiences from plants in operation
- Consider customer requirements
- Consider opportunities offered by this technology
Customer requirements – technology status

Top five customer requirements
- Foot print and height
- Cost
- Efficiency
- Reliability and durability
- Hydrogen gas quality

Harmonised system for initial/short term markets
- 100 – 300 Nm³/hour
- Containerised
- Service, training and maintenance programme

Hyserve – 100, Example of best available reformer technology in 2005
Reformer supplier results

Major technology achievements 2002 – 2005
- Foot-print and height of small-scale reformers is reduced significantly
- Efficiency improved
- Start-up time reduced
- Cost reduced

Gap analyses
- Customer requirements – performance
  - Improvement of complete system (i.e. compressor and storage), on footprint and cost
  - Documentation of reliability and durability through testing
  - Operational costs
- Market and stakeholder development
  - Market and stakeholders need more dissemination. More knowledge
Results: Best Available Technology - 2005

- Capacity: 100 Nm³/h
- Footprint: 3.8 m X 2.6 m
- Volume: 28 m³
- Efficiency (HHV): 70%
- Operating range: 40 to 100%
- Electricity: 20 kW
- Cold start-up time: 4 hours
- Start-up from standby: 1 hour
- Operating pressure: 0.8 MPa
- Catalyst replacement: 40,000 operating hours
- Reformer tube replacement: 100,000 operating hours
- PSA valves replacement: every 2 years
- Inspection: every year
- Capital costs: about 450,000 €
Current technology and installations
Long term priorities – adapt to refuelling

Long Term priorities
- Target cost in 2020 are 0.13$/Nm³
- Underground station design – only dispenser on ground
- Capacity 500 – 700 Nm³/hour dependent on the storage capacity
- Automatic and remote operation
<table>
<thead>
<tr>
<th>FINAL REPORT - Main Chapters</th>
<th>Input base</th>
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<tbody>
<tr>
<td>1. Purpose of the technology</td>
<td>SSR – the storyline</td>
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<td>Technology study, Phase 1 and Phase 2</td>
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<td>Matrix on feedstock and technology</td>
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<td>2. Fuel market requirements</td>
<td>Report on customer requirements – input from, BP, IE, Hydro, Gas Natural and Technology study (Gastec)</td>
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<td>3. Minimising of CO₂ and other emissions</td>
<td>Reports from IFE (iESE)</td>
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<td>4. Experiences from fuelling stations in operation</td>
<td>Memos and presentation based on operational data at meetings</td>
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<td>5. Small-scale reformers in CHPs</td>
<td>Gaz de France study – input/contribution from Haldor Topsøe, IE</td>
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<tr>
<td>6. Recommendations for small-scale reformers in a market introduction phase.</td>
<td>Will be based on the work of and input from the Subtask C – members</td>
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</table>
More networking needed

More network efforts:
- Harmonise system design
- Develop experience base and exchange data
- Methodology for monitoring and testing of reformer performance
- Develop systems harmonised to fuel station requirements

Concluding event in Oslo (June 15-17)
- Closed seminar for reformer stakeholders
- Present and discuss results
- Discuss common challenges and tasks for further networking
- Propose new IEA – HIA Task
CO$_2$ – removal from reformers possible

- Technology exists, today’s commercial solutions are too expensive
- Will add cost and footprint to the hydrogen production units
- Extensive research and development are ongoing world wide, aiming at cost competitive solutions with high-energy efficiency

Schematic drawing of a SMR-based fuel processor with CO$_2$ capture and removal (source IFE)
Hydrogen for micro CHP – possible synergies with transport market

Large scale reformer

With CO2 Sequestration Potential

Long term vision: centralised production
With H2 transmission and distribution

Small scale Reformer

Local H2 distribution network

H2 Storage tank

H2 back-up inlet

PEM FC

PEM FC

PEM FC

PEM FC

Pressure regulators

Stora tank

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Summary of results

- Current technologies are Auto Thermal Reforming (ATR) and Steam reforming (SMR)
- The reformer technology is fuel flexible
- The current Best Available Technologies can compete with electrolysis on compactness and cost
- The medium term requirements on foot-print are within reach – challenges related to documented reliability and costs
- Cost targets are still challenging
- The long term requirements on system design and underground construction needs more research, development and harmonised effort
- CO2 – sequestration technically possible – major cost and design implications
- Reformers in the CHP-market linked to use of PEM – can be feasible if synergies with fuel market can be obtained