H-delivery WP 3 – Task 3.2: Characterisation of prospective technologies


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Introduction

This is a summary of the data generated from Round 1 of the “Sustainable Hydrogen Delphi Survey”.

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**Participant Information**

*Q1 – Please state which geographical region or country you are primarily considering when responding to these questions*

- UK: 16
- Rest of Europe: 11
- USA: 17
- Rest of World: 3
- Unspecified: 5

*Q2 – Please select your main job function:*

- Industrial Manufacture: 26
- Industrial Research: 6
- Lobbying: 13
- National Government: 1
- Non-industrial Research: 5
- Other: 1

*Q3 – What percentage of your job is involved primarily with hydrogen?*

- 0-25%: 17
- 26-50%: 11
- 51-75%: 5
- 75-100%: 21
Hydrogen Production

Q4 – Predict the worldwide hydrogen production used as an energy vector (standard tonnes) for 2020 to 2050:

The median response indicates that the worldwide hydrogen production as an energy vector will steadily rise from 2.5 million standard tonnes in 2020 to 50 million standard tonnes in 2050. However, the chart above shows that a significant number of people don’t expect more than 1000 standard tonnes of hydrogen to be available as an energy vector by 2050.

This question will be explored further in round 2 of the survey.
Q5 – The 2008 global final energy consumption was 8 428 Million tonnes of oil equivalent (Mtoe)*, this is equivalent to 2 922 million standard tonnes+ of hydrogen. What percentage of global energy requirement do you think hydrogen could be used to deliver in the time periods:

* Data from IEA (2010). Key World Energy Statistics
+ this is the same as 2.922 trillion gallons of gasoline equivalent (gge), 32.7 trillion cubic meters or 1 156 trillion cubic feet of hydrogen

The median response indicates that the percentage of energy demand met using hydrogen as a vector would rise from 2% in 2020 to 20% in 2050.

This question will be explored further in round 2 of the survey.
Q6 – What do you consider to be the key drivers for the development of a hydrogen economy?

The most frequently cited drivers for the development of a hydrogen economy related to concerns about future fossil fuel availability and cost, the requirement to reduce greenhouse gas emissions and other pollutants, the requirement for alternative transport fuels and the requirement for storage of electricity generated from renewable technologies along with increased energy efficiency. This will be assisted by the development hydrogen technologies, their increased cost effectiveness and the establishment of seed infrastructure.

This question will be explored further in round 2 of the survey.
Q7 – What do you consider to be the key barriers slowing or preventing the development of a hydrogen economy? Bullet points or text acceptable in answer

The most frequently cited barriers for the development of a hydrogen economy related to the cost and technical barriers of implementing the new technology as well as the existence of incumbent technology. It was considered that policy, lack of infrastructure, lack of investment and public perception were also significant barriers.

This question will be explored further in round 2 of the survey.
Q8 - Indicate the key developments in the hydrogen economy which you anticipate in the next 40 years:

<table>
<thead>
<tr>
<th>2010 - 2020</th>
<th>2020 - 2030</th>
<th>2030 - 2040</th>
<th>2040 - 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy to reduce carbon emissions intensifying</td>
<td>Increased R&amp;D for H₂ production and storage</td>
<td>Reduction in carbon-based energy production</td>
<td>Technology so common that goes unnoticed</td>
</tr>
<tr>
<td>Incentives to accelerate H₂ technology development</td>
<td>Increased renewable energy generation</td>
<td>Technology so common that goes unnoticed</td>
<td>Social acceptance of H₂ as a major energy vector</td>
</tr>
<tr>
<td>Public Perception</td>
<td>Increasing technical sophistication and refinement</td>
<td>Technology so common that goes unnoticed</td>
<td>Social acceptance of H₂ as a major energy vector</td>
</tr>
<tr>
<td>Technology</td>
<td>Cost reductions</td>
<td>Infrastructure continued infrastructure expansion</td>
<td></td>
</tr>
<tr>
<td>Improved capital lifetime</td>
<td>Seed/initial networks (key locations)</td>
<td>National (US) H₂ network with existing power networks</td>
<td></td>
</tr>
<tr>
<td>Overlapping networks enabling long-distance travel</td>
<td>Retail availability of H₂ (filling stations in initially populated areas)</td>
<td>Hydrogen infrastructure developing rapidly</td>
<td></td>
</tr>
<tr>
<td>Development of infrastructure including pipelines</td>
<td>Development of infrastructure completed using ship/oil terminals</td>
<td>H₂ filling stations (low cost)</td>
<td></td>
</tr>
</tbody>
</table>
2010 - 2020
- Niche H₂ and FC markets
  (replacing batteries)
- H₂ implementation with existing
to technologies
- H₂ becoming competitive with
other technologies

Petroleum too expensive to produce

2020 - 2030
- Niche market expansion
- Intermediate H₂ car market
- Spatial H₂ economy (outwards
  from big cities to isolated
  places)
- Reduced cost of FC /
electrolyzers (improved high
volume manufacturing)

Drastic oil price increase
benefits alternative energy
markets

2030 - 2040
- H₂ in transport/portable /
decentralised power

Alternative energies cheaper
than fossil fuels: transition
complete

DC superconducting
transmission lines

2040 - 2050
- Stable/mature H₂ car market
- OCH₂ significant energy
  source for power, transport,
  heating and chemicals
- Commercialisation of
  advanced technology
- Potential global economic
  shocks precludes development
  of other energy sources
- H₂ economy achieved
Hydrogen Production Technologies

Q9/10/16 – For each of the Hydrogen Production Technologies listed:

a) Indicate the scale of production to which the technology is best suited using a scale of 0 to 5 where:

0  <200kg H₂ pa
1   200-1 000 kg H₂ pa
2   1 000-10 000 kg H₂ pa
3   10 000-30 000 kg H₂ pa
4   30 000-100 000 kg H₂ pa
5   > 100 000 kg H₂ pa
The technologies which appear to be best suited for small scale production (<1 000 kg H₂ pa) are:
  • Microbial electrolysis

The technologies which appear to be best suited for medium scale production (1 000 – 30 000 kg H₂ pa) are:
  • Bioderived liquid reforming
  • Biomethane reforming
  • Plasma reforming
  • Photoelectrochemical
  • Photolytic (microbial)
  • Photosynthetic (bacterial)
  • Photolysis

The technologies which appear to be best suited for large scale production (>30 000 kg H₂ pa) are:
  • Autothermal reforming
  • Membrane reforming
  • Partial oxidation
  • Steam reforming
  • Sorbent enhanced reforming
  • High temperature electrolysis
  • Thermochemical Cycles
  • Gasification (coal and biomass)
  • Pyrolysis
  • Thermocatalytic Cracking

Low temperature electrolysis and dark fermentation appear to be suitable for a wide range of production scales.
Many hydrogen producing technologies have already reached technological capability. These include:

- Autothermal reforming
- Biomethane reforming
- Steam reforming
- Low temperature electrolysis including atmospheric and pressurised alkaline as well as PEM.
- Gasification (coal and biomass)

Those expected to reach technological capability by 2020 are:

- Bioderived liquid reforming
- Membrane reforming
- Partial oxidation
- Plasma reforming
- High temperature electrolysis
- Microbial electrolysis
- Photolysis
- Thermocatalytic cracking

Those expected to require more time include:

- Sorbent enhanced reforming
- Photoelectrochemical
- Photolytic (microbial)
- Photosynthetic (bacterial)
- Thermochemical cycles
- Dark fermentation
- Pyrolysis
c) Commercial Capability

Hydrogen producing technologies which have already reached technological capability include:
- Biomethane reforming
- Steam reforming
- Low temperature electrolysis including atmospheric and pressurised alkaline
- Gasification (coal)

Those expected to reach technological capability by 2020 are:
• Autothermal reforming
• Membrane reforming
• Partial oxidation
• PEM electrolysis
• High temperature electrolysis
• Photoelectrochemical
• Photolytic (microbial)
• Photolysis
• Gasification (biomass)

Those expected to require more time include:
• Bioderived liquid reforming
• Plasma reforming
• Sorbent enhanced reforming
• Microbial electrolysis
• Photosynthetic (bacterial)
• Thermochemical cycles
• Dark fermentation
• Pyrolysis
• Thermocatalytic cracking

In general, technologies are expected to move from technological to commercial capability within 5 to 10 years. However, microbial electrolysis, microbe photolysis and the use of photosynthetic bacterial are expected to take significantly longer (>20 years) to reach commercial capability.
d) Standardised production (>1 000 units per year)

The only hydrogen producing technologies which have already achieved standardised production are biomethane reforming and coal gasification.

Those expected to reach technological capability by 2020 are:
- Autothermal reforming
- Steam reforming
- Low temperature electrolysis including atmospheric and pressurised alkaline as well as PEM
• Gasification (biomass)

Those expected to require more time include:
• Membrane reforming
• Partial oxidation
• High temperature electrolysis
• Photoelectrochemical
• Photolytic (microbial)
• Photolysis
• Bioderived liquid reforming
• Plasma reforming
• Sorbent enhanced reforming
• Microbial electrolysis
• Photosynthetic (bacterial)
• Thermochemical cycles
• Dark fermentation
• Pyrolysis
• Thermocatalytic cracking

In general, technologies are expected to move from technological capability to standardised production within 30 years. However, pyrolysis and microbial electrolysis are expected to take significantly longer.
e) Greatest potential assets for commercialisation
f) Greatest potential barriers to commercialisation
A wide range of assets and barriers to commercialisation of hydrogen production technologies have been reported by the participants. Where the technologies affected have been indicated by more than three participants, it has been represented with bold text.

**g) potential of hydrogen production within an urban setting**

![Diagram showing potential for H2 production in an urban setting]

Low Temperature Electrolysis and Photoelectrochemical are the technologies most widely accepted as being suitable for hydrogen production within an urban setting.

**h) indicate the scale of production feasible within a forecourt situation (325m² or 3500ft²)**

Using a scale of 0 to 5 where:

- 0 < 200kg H₂ pa
- 1 200-1 000 kg H₂ pa
- 2 1 000-10 000 kg H₂ pa
- 3 10 000-30 000 kg H₂ pa
- 4 30 000-100 000 kg H₂ pa
- 5 > 100 000 kg H₂ pa

There were few responses to this question and some confusion as to the scale feasible in a forecourt situation.
i) Indicate the barriers foreseeable in an urban setting
j) indicate the frequency and skill level of maintenance required

There was a spread of opinions about the frequency and skill level required for maintenance. In general, most technologies required at least a general handyman with hydrogen specific training on a monthly basis.
**Electrolysis Production Priorities**

**Q11 – increased site surface area vs increased operating costs**
Choice of increasing site surface area to incorporate larger storage tanks or increasing operating costs due to lack of capacity to take advantage of off-peak electricity rates.

Larger Site Surface Area generally favoured.

**Q12 – increased use of solar / wind generated electricity vs reduced maintenance**
Choice of increasing use of solar / wind generated electricity or reducing maintenance by allowing electrolyser to run without interruption.

Increasing use of solar / wind generated electricity should not be an issue if appropriate control systems are used. Varying current is a problem, but on/off operation is not.

**Q13 – high electrolysis efficiency vs sellable oxygen production**
Choice of increasing electrolysis efficiency or producing sellable oxygen as a by-product.

Increased electrolysis efficiency generally favoured – potential exceptions to this would be a hospital with a local requirement for oxygen.

**Q14 – high electrolysis efficiency vs high hydrogen production rate**
Choice of increasing electrolysis efficiency by operating with a very low current density or increasing hydrogen production rate by increasing the current density.

This was considered to be application dependent with no clear bias to one option or the other.

**Q15 – high electrolysis efficiency vs higher capital/maintenance costs and restricted availability of high temperature process heat**
Choice of using more electricity for low temperature electrolysis or using high temperature electrolysis with higher capital/maintenance costs and restricted availability of high temperature process heat

This was considered to be application dependent with no clear bias to one option or the other.
Feedstock

Q17 – Specify the energy inputs/feedstock most likely to contribute to the bulk of hydrogen production in 2020-2050

Carbon based feedstocks are expected to decline, with biomass sources peaking in 2030 then declining, while nuclear and other renewable sources increasing.

Q18a – For hydrogen produced through electrolysis, what issues might arise with electricity provision in urban areas for transport refuelling locations?

Electricity availability for urban electrolysis

No of mentions
Q18b – What issues with industrial electricity rates might be faced?

Issues with industrial electricity rates

<table>
<thead>
<tr>
<th>Issue</th>
<th>No. of mentions</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>6</td>
</tr>
<tr>
<td>Not relevant to domestic producers</td>
<td>4</td>
</tr>
<tr>
<td>None if offpeak</td>
<td>2</td>
</tr>
<tr>
<td>Short term only</td>
<td>1</td>
</tr>
<tr>
<td>Yes</td>
<td>0</td>
</tr>
</tbody>
</table>
**Safety Risk and Public Perception**

**Q19 – What opportunities do you foresee to develop global standards and safety regulations for hydrogen production?**

General agreement that good progress has already been made.

**Q20 – What will be the key factors to cover insurance risk mitigation from 2020 to 2050?**

Initially standards/regulations and storage/transport methods need to be developed at the same time as demonstration projects are undertaken which will build up familiarity and experience.

**Q21 – Are there any safety issues which should be addressed when siting hydrogen production facilities near power plants (including nuclear) and high voltage lines?**

General consensus that common sense be followed and that hydrogen production would be no more dangerous in this scenario than other energy sources or chemical plants.
Q22 – What are the key factors to include in any scheme aimed at community education regarding hydrogen production?

![Graph showing factors with safety being the highest]

Q23 – What public acceptability barriers do you foresee for hydrogen production in fuelling stations?

![Graph showing barriers with safety being the highest]

Safety is considered to be the main public acceptability barrier and as such is the key factor to include in any scheme aimed at community education.
Sustainable Development and Hydrogen

Q24 – most important aspects of sustainability (environmental / economic / social)

Although fossil fuel based technologies are generally regarded as the least sustainable, renewable methods including biomass, PV/solar and wind are also mentioned in this category, despite also being considered as sustainable methods in Q25.