Contributions of hydrogen energy system analysis on finding clues for R&D prioritization

The Institute of Applied Energy
Dr. Yuki Ishimoto

24th November 2021
Contents

• Introduction: Generic description of hydrogen Energy systems analysis
• Example 1: Hydrogen production
• Example 2: Long distance hydrogen transport
• Summary
### Introduction: Generic description of hydrogen Energy systems analysis

#### General definition

- To understand the interactions between elements in the energy system to be analyzed, especially using mathematical tools.

#### Wide variety of outputs depending on objectives

- Technical (energy efficiency), Environmental (GHG, other aspects), Economic (levelized cost of hydrogen) performances

#### Can provide many clues for improvement

- Energy intensive, high CO₂ emission and/or most costly part(s)
- Sensitivity analysis of above also helps our understanding
- Note: we must use “correct” assumptions and methodologies to get good implications
  - The results totally depend on them and objective settings. Anything not considered in the model does not change the results.
Example 1 Hydrogen production: water electrolysis

- With a low utilization factors, hydrogen cost is relatively high. Especially with low electricity prices, this becomes significant.
- Variable cost does not largely change with a lower utilization factor. The total amount of annual fixed cost (investment, labor and maintenance) does not change, and this is allocated to a smaller amount of hydrogen.
- This is the reason why investment cost reduction of electrolyzers is considered in both relatively small PtG systems and large scale green hydrogen production.

Utilization factor dependence of hydrogen cost

Differences in cost breakdown with utilization factors of 30% and 90%
Example 1 Hydrogen production: water electrolysis

- Assumptions that have high sensitivity to hydrogen costs are electricity price and utilization factor.
- Other assumptions changed here have small effect on the results.

Cost breakdown and its sensitivity on assumptions tell us clues for improvement.
Example 2: hydrogen long distance transport

- System consists of large scale carrier conversion, long distance transport, delivery (pipeline, road, train, and ship).
- The scope is from hydrogen to hydrogen.
  - Input hydrogen is considered as feedstock.

LT: Loading terminal
RT: Receiving terminal

Carrier conversion
Loading terminal
Seaborne transport
Receiving terminal
Dehydrogenation/ Cracking
Delivery

**LH₂ chain**

- Liquefier
- LT: Seaborne transport
- Vaporizer
- Pipeline

**Tol-MCH chain**

- Hydrogenation
- MCH
- LT: Seaborne transport
- Dehydrogenation
- PSA
- Compressor
- Pipeline

**NH₃ chain**

- Compressor
- ASU
- NH₃ synthesis
- LT: Seaborne transport
- Cracking
- PSA
- Compressor
- Pipeline

**Scope of study**

- LH₂ chain
- Tol-MCH chain
- NH₃ chain

99.99% H₂

Common assumptions

<table>
<thead>
<tr>
<th>Case</th>
<th>Delivered hydrogen</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>2.5 billion Nm³/(y chain) (225 kt/y chain)</td>
<td>Baseline</td>
</tr>
<tr>
<td>Large scale (LS)</td>
<td>10 billion Nm³/(y chain) (900 kt/y chain)</td>
<td>Assumed the same technology level as baseline case</td>
</tr>
</tbody>
</table>

- Static and block flow diagram based analysis
- Energy carrier system
  - Utilization factor: 90%
  - Electricity for utility: supplied from the grid
  - Plant life time: 30 years
  - Transport distance: 10,000 km

Large scale chain can improve economic efficiency

- **LH₂**
  - Increase of turnover in the loading terminal storage reduces the cost.
  - Increased storage in the receiving terminal also reduces CAPEX per unit storage.

- **MCH and NH₃**
  - The same effects are expected but cost contribution from terminals are not large.
  - Heat integration with adjacent industry plants, demand without purification, direct use (only NH₃) can reduce the hydrogen cost.

**Major cost drivers**
- **LH₂ (CAPEX)**
  - LH₂ related technologies (liquefier and storage technologies)
- **MCH (OPEX)**
  - Dehydrogenation, especially reaction heat
- **NH₃ (OPEX)**
  - NH₃ synthesis and cracking

Competitiveness of hydrogen carriers also depends on demand technologies

---

The Institute of Applied Energy

Summary

• Energy systems analysis of hydrogen can provide a lot of useful clues for R&D prioritization.
  – Cost breakdown tells us which part should/can be cut

• Large scale chain can improve economic efficiency
  – Levelized cost of hydrogen using energy carrier are in similar range.
  – Competitiveness of hydrogen carriers also depends on demand technologies

• There are multiple directions of R&D for hydrogen deployment
  – Efficiency, large-scale facility, learning effect etc.