Hydrogen storage and transport using liquid organic hydrogen carriers

MARANDA seminar, 9.10.2017
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Towards clean energy?

Ref. Peter Lund, Energy challenges and technology breakthroughs towards 2050. in Future fuels for engine power plants seminar (FCEP WP4), November 22.11.2011.
What is needed in the revolution to renewables

Timing and regions of the production and consumption of solar and wind energy do not match.

Large-scale transportation and storage of renewable energy essential!

- Long-distance transportation of renewable energy, also between continents.
- **Storages of renewable energy** in different size classes and over various time periods, also in remote locations.
- For the industry, energy and transport. E.g. marine sector needs alternative energy sources.

The threat of climate change may end era of fossil energy before the reserves deplete.
Existing technologies are not sufficient for large-scale use of renewable energy

Batteries, compressed air and pumped hydro: **limited duration of discharge.** Electricity only within the grid. Pumped hydro and compressed air are **inflexible and not suitable for all locations.**

Hydrogen could be a **solution** for long-term and large-scale energy transportation and storage.
“Hydrogen is a flexible energy carrier that can be produced from any regionally prevalent primary energy source. …can be transformed into any form of energy.” “As a storehouse of low-carbon energy, it offers a means to integrate high shares of variable renewable electricity into the energy system.”

Energy system today and in the future

Technology Roadmap
Hydrogen and Fuel Cells
© OECD/IEA, 2015
International Energy Agency

Steam methane reforming, Coal gasification, By-product hydrogen, Hydrogen-rich gas, Wind/PV renewable energy, Biomass, Hydropower
Using the renewable energy directly, via battery and via hydrogen storage pathways.

- Compressed or liquid H2 not for large-scale/long-term storing, or long-distance transport.
- Solid materials are not mature, infrastructure missing, harsh conditions for hydrogenation/dehydrogenation.
- “Circular” H2 carriers, MeOH and CH₄, are easy to use and their energy contents are high. Challenges in manufacturing from atm. CO₂. Every batch re-produced.
- LOHC liquids are compatible with the existing infra. Suitable for large scale/long-term storing. Safe. Reversible (structures converse).

The desired characteristics of the H2 carriers depend on the applications. For the transport and domestic use, energy density, kinetics and safety are important.
LOHC cycle

Industrial hydrogen
- By-product hydrogen
- Methane reforming
- Gasification (syngas)

Carbon-free hydrogen
- Wind and solar
- Biomass
- Hydropower

New products for loading/releasing hydrogen
Catalysts and components

LOHC transport
- Safe (non ADR)
- Efficient
- Existing infra

LOHC use
- Industry
- Electricity
- Mobility, machines
- Residential

LOHC transport
- Safe (non ADR)
- Efficient
- Existing infra

LOHC = Liquid organic hydrogen carriers
Energy density

LOHCs = Safe and efficient liquid

Liquid hydrogen:
- boil-off in truck transport 1-3% daily
- Boil-off for a tanker 0.3% daily.
- Risks for leaks.

LOHCs don’t lose hydrogen even in the long-term storage. H2 storage density e.g. 6.2 wt%.
LOHC concept

Dibenzyl toluene (DBT) and toluene concepts in Germany and Japan.

Hydrogenious GmbH concept based on low-cost, heat-transfer fluids: hydrogen capacity 6.2 wt%.

Circular H2 carriers

Methanol from geothermal CO$_2$ and renewable hydrogen in Iceland.
- Note: DBT today 3-4 €/kg. Could be <1 €/kg in large-scale production. Toluene <1€/kg.
Safe and efficient transport of H2 with LOHC

1 m³ of DBT LOHC stores
57 kg hydrogen (624 Nm³, 1.9 MWh)
Comparison of alternatives for marine use

ScandiNAOS AB

<table>
<thead>
<tr>
<th>Storage 1 GWh (mech energy)</th>
<th>Net weight (ton)</th>
<th>Gross weight (ton)</th>
<th>Net Volume (m³)</th>
<th>Gross Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME MGO</td>
<td>187</td>
<td>200</td>
<td>208</td>
<td>300</td>
</tr>
<tr>
<td>ME MeOH</td>
<td>402</td>
<td>450</td>
<td>508</td>
<td>550</td>
</tr>
<tr>
<td>ME LNG</td>
<td>174</td>
<td>300</td>
<td>414</td>
<td>900</td>
</tr>
</tbody>
</table>

1 GWh with LOHC: Gross weight **680 tonnes** (37.4 tonnes H2), gross volume **654 m³**.
LOHCs are promising

**PROS**
- Extensive range of storage times and capacities.
- Compatible with the existing infra.
- No pressurisation needed.
- No low temperatures needed.
- No losses in storing.
- Safe storing and handling.
- Competitive storage weight and volume with other alternatives.
- Suitability for many end-use sectors anticipated.

**CONS**
- Dehydrogenation challenges (T >300 °C, pressure 1-3 bar)
- Better catalysts for improved kinetics and reaction conditions?
- Cleanliness of hydrogen released?
- Durability, number of cycles, maintenance?
- Total efficiency of LOHC pathway?
- Costs.
- Overall development of technology.
Hydrogen stored in a form of liquid “batteries” enables efficient and large scale storage of renewable energy.

Liquid hydrogen “batteries” for storing renewable energy, LOHCNESS

Tekes Smart, green&sustainable Call
Tekes grant on 11.5.2017
LOHCNESS project structure

WP1 LOHC feasibility screening
VTT, Fortum, St1, Voikoski, Leppäkosken sähkö, Aino Energia

WP2 Catalyst development
Task 1. Catalyst screening/development
Task 2. Catalyst preparation and validation
Task 3. New catalyst/reactor system
UH, VTT

Cooperation
- Hydrogenious GmbH
- Sasol Germany

VTT's research infra

WP3 LOHC demonstration
Task 1. Commercial concept: demonstration
Task 2. New reactor: proof-of-concept
VTT

WP4 Cooperation, dissemination and exploitation
VTT, UH

NEW PRODUCTS
SME: new catalysts and components

2nd Phase option:
Demonstrations in larger scale, e.g. on-board a vessel
Possible EU project

SOLETAIR (Tekes)
Arctic Seas

Hydrogen Council January 2017
LOHCNESS project 5/2017-4/2019

Companies
- Fortum, St1, Woikoski, Leppäkosken Sähkö, Aino Energia

Research partners
- VTT
- Helsingin yliopisto

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http://www.vtt.fi/sites/lohcness
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