The Role of Green Hydrogen in a Solar powered World: Case studies & business models

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Agenda

➢ Determining the role of hydrogen in renewable systems
➢ Use cases, from single systems to whole countries
➢ The economics of Swiss H₂ solar fuels
➢ Take-home messages
Determining the role of hydrogen in renewable systems

Use cases, from single systems to whole countries

The economics of Swiss H2 solar fuels

Take-home messages
Determining the role of hydrogen

The global optimality problem

➢ The energy system of tomorrow will be more complex than today
  ▪ A greater number of involved technologies
  ▪ A greater number of stakeholders

➢ But it still will have to be (at least) as performant as today
  ▪ As reliable
  ▪ As cost-effective

➢ How can such a system be properly designed?
  ▪ When every single parameter influences all the others
  ▪ Taking care of the details while always keeping the bigger picture in mind

➢ We have developed our own design method: the Grid New Deal tool
Determining the role of hydrogen

Our approach

- Economic **optimization** under technical constraints
  - Minimization of LCOE
  - Complying with the technological requirements of the considered new technologies

- Developing our own solution allows us to
  - Taylor our tool to our **customers’ needs**
  - Ensure a complete **mastery** of the underlying hypothesis
➢ Determining the optimal hybrid renewable system

➢ Use cases, from single systems to whole countries

➢ The economics of Swiss H2 solar fuels

➢ Take-home messages
Use cases

Single system – a remote installation in the Swiss mountain

➢ Customer’s issues
  ▪ Supplying a load with **high availability requirements** in a remote location
  ▪ Building a MV-line is expensive and has a huge impact on the environment
  ▪ **Consumption only during 3 months** per year (winter)

➢ Our proposition:
  ▪ Transform a yearly PV production into a winter ribbon thanks to an **hybrid system**

![Image of Swiss mountain](image)

![Graph of PV production](image)

![Graph of load consumption](image)
Use cases

Single system – a remote installation in the Swiss mountain

➢ Comparison of 3 different scenarios

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.68 CHF/kWh</td>
<td>2.05 CHF/kWh</td>
<td>1.48 CHF/kWh</td>
</tr>
</tbody>
</table>

➢ Hybridization is the path to reducing energy costs

Cheaper than building a new line!
Use cases

Single system – a remote installation in the Swiss mountain

Scenarios Modelling Optimization Analyze

Normalized monotonous power curves of hydrogen-linked elements

Only 4% of PV peak capacity
Use cases

Reduced scale territory – the island of Rapa Nui

➢ How to optimally decarbonize the island electricity production?

➢ Study conducted alongside Swiss Federal Institute of Technologies (EPFL)

➢ Published in Frontiers Energy Research
  ▪ “Benefits of a diversified energy mix for remote areas: the case of Easter Island”
Use cases

Reduced scale territory – the island of Rapa Nui

- Here again, **hybridization with H₂ is the key to:**
  - Cost efficiency
    - CAPEX reduction of 50%
    - LCOE reduction of 42%
  - Energy efficiency
    - Losses divided by 5.5!

**Figure 2.** Summary of annual energy fluxes between energy sources, storage systems and uses. Energy sources include photovoltaic (PV), wind turbines (W) and Pyrolysis (P); storage systems include lithium-ion batteries (B) and hydrogen-based storage (H); and uses include consumption (C) and losses (L).
Use cases

A whole country – Switzerland energy transition

➢ Switzerland problematic
  ▪ Reduction of local production
    o Nuclear power plants are being phase out (35% in 2019)
  ▪ Increase of local consumption
    o Electrification of mobility and building heating

➢ How to ensure security of supply without increase dependency to neighbouring countries?

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![Graph showing monthly distribution of estimated final consumption and annual breakdown of estimated final consumption](image)

- **Final cons. 2018**
- **Est. heating**
- **Est. e-mob.**

- Monthly distribution graph
- Annual breakdown pie chart

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![Pie chart showing annual breakdown of estimated final consumption](image)

- **Final cons. 2018**: 20%
- **Est. Heating**: 7%
- **Est. e-mob.**: 73%
### Use cases

#### A whole country – Switzerland energy transition

- Different scenarios depending on sun, wind and storage development
  - **A.** Solar and battery
  - **B.** Solar, battery and hydrogen storage to control imports
  - **C.** Solar, battery, hydrogen storage and wind to control imports

<table>
<thead>
<tr>
<th></th>
<th>Scenario A</th>
<th>Scenario B</th>
<th>Scenario C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final consumption</td>
<td>84.7 TWh</td>
<td>61.9 TWh</td>
<td>61.9 TWh</td>
</tr>
<tr>
<td>Installed PV power</td>
<td>50 GWp</td>
<td>67 GWp</td>
<td>50 GWp</td>
</tr>
<tr>
<td>Installed Wind Power</td>
<td>0</td>
<td>0</td>
<td>5.3 GW</td>
</tr>
<tr>
<td>Daily storage capacity (battery)</td>
<td>100 GWh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolyser</td>
<td>38 GW</td>
<td>22 GW</td>
<td></td>
</tr>
<tr>
<td>Additionnal seasonal storage (H₂)</td>
<td>0</td>
<td>26 TWh</td>
<td>19.9 TWh</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>8.8 GW</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td><strong>Raw Energy import</strong></td>
<td><strong>19.6 TWh</strong></td>
<td><strong>7 TWh</strong></td>
<td><strong>7 TWh</strong></td>
</tr>
</tbody>
</table>
Use cases

A whole country – Switzerland energy transition

➢ A **diverse renewable production** (sun and wind) and **seasonal storage** are the keys to achieve the transition without increasing dependency toward neighbouring countries.

https://gridview.gridnewdeal.com/cockpit/demo/?case=3#results
A whole country – Switzerland energy transition

➢ **A diverse renewable production** (sun and wind) and **seasonal storage** are the keys to achieve the transition without increasing dependency toward neighbouring countries.
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The capital role of storage costs

- We run full CAPEX/OPEX evaluation based on each component price.
- The costs of seasonal storage are of the utmost importance.

<table>
<thead>
<tr>
<th></th>
<th>Gazeous H₂</th>
<th>Liquid carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td>24 kCHF/MWh</td>
<td>2 kCHF/MWh</td>
</tr>
<tr>
<td><strong>OPEX</strong></td>
<td>0.2 kCHF/MWh/y</td>
<td>0.02 kCHF/MWh/y</td>
</tr>
<tr>
<td><strong>Full system price (Capex)</strong></td>
<td>615-806 BCHF</td>
<td>97-128 BCHF</td>
</tr>
<tr>
<td><strong>National LCOE range</strong> (depending on scenarios)</td>
<td>0.42 – 0.57 CHF/kWh</td>
<td>0.10 – 0.14 CHF/kWh</td>
</tr>
</tbody>
</table>

- Only cheap hydrogen storage can lead to a cost competitive transition.
  - Use Switzerland 14 million m³ of oil storage for liquid hydrogen carrier.
Choice of liquid carrier

Case Study: Liquid Organic Hydrogen Carriers

LOHC storage and transport concept ($H_2$LOHC: unloaded LOHC, $H_n$LOHC: loaded LOHC).

<table>
<thead>
<tr>
<th>LOHC</th>
<th>Reason for consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$-Ethylcarbazole (NEC)</td>
<td>Well-studied nitrogenous LOHC</td>
</tr>
<tr>
<td>Dibenzyltoluene (DBT)</td>
<td>Already existing application as a LOHC; safe and convenient handling</td>
</tr>
<tr>
<td>1,2-Dihydro-1,2-azaborine (AB)</td>
<td>Unique characteristics through integration of boron and nitrogen</td>
</tr>
<tr>
<td>Formic acid (FA)</td>
<td>Safe and convenient handling</td>
</tr>
<tr>
<td>Methanol (MET)</td>
<td>Very high storage density</td>
</tr>
<tr>
<td>Naphthalene (NAP)</td>
<td>Well-studied cycloalkane; high storage density</td>
</tr>
<tr>
<td>Toluene (TOL)</td>
<td>Well-studied cycloalkane; planned application as a LOHC</td>
</tr>
</tbody>
</table>

For our Case-Study: Dibenzyltoluene has been used in the calculation

- Existing promising development in Germany
- Easy to transport, lower toxicity, not flammable
Seasonal storage of solar fuel with $\text{H}_2$

**Case Study: Liquid Organic Hydrogen Carriers**

- **Concept**
  - Use of the existing infrastructure (Pipeline and oil tank storage) of an decommissionned Raffinery
  - Storage of hydrogen with Liquid Organic Hydrogen Carriers (ca. 1 TWh potential $\text{H}_2$ storage with BDT & 2 TWh with Methanol)
  - Close to a waste incinerator (Availability of heat and potential $\text{CO}_2$ source)
Seasonal storage scenario

- Open: Centralized H₂ production in the raffinery or decentralized H₂ production in industries where heat can be used, for industrial processes
- Storage in the existing oil tank (ca. 500’000 m³)
- Electricity production with a high temperature fuel cell, creating high temperature losses using the breaking the liquid LOHC to H₂
- Potential cost of hydrogen stored in the raffinery with summer surplus of electricity: 3-4 CHF/kg H₂
- Cost of winter electricity (150 MW renewable flexible generation in Winter): 30 cts/kWh (short term), 15 Rp/kWh (mid term): it is possible!
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Diversifying production and storage technologies is the key for the transition toward a decarbonized energy system.

Only a massive deployment of renewable energy production will make storage and green H\textsubscript{2} cost competitive.

With a system view of seasonal H\textsubscript{2} storage, the full load hours of electrolyser is not the main issue, H\textsubscript{2} storage cost is by far more central.

Policies and market designs must be adapted to this new paradigm to provide right signals to the investors and correctly remunerate the value of hybridization: \textbf{IEA PVPS Task 1 and 14 are addressing this need.}

Only a global approach, involving in depth technical, economic and regulatory understandings is able to provide appropriate answers to these challenges.
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