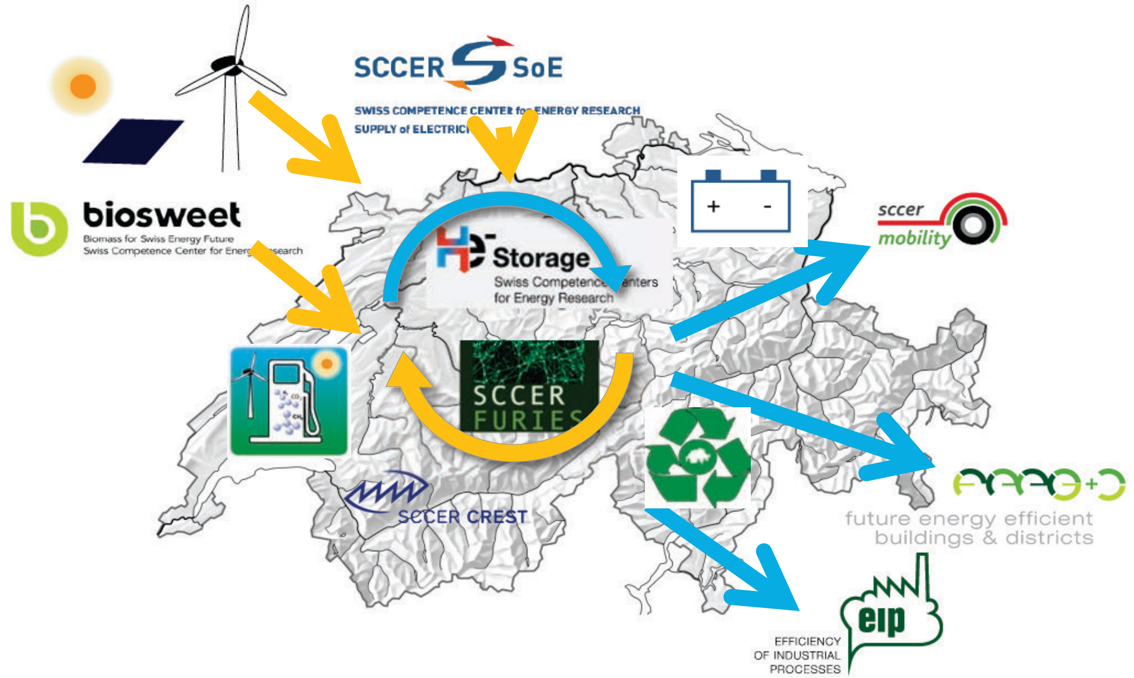


In cooperation with the CTI

Energy funding programme
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Swiss Competence Centers for Energy Research
<u>Mobility</u> and <u>Storage of Heat and Electricity</u>

Thomas J. Schmidt, Jörg Roth

The near Future?

Jules Vernes, 1875 (1874?)

- *Et qu'est-ce qu'on brûlera à la place du charbon?*
- *L'eau, répondit Cyrus Smith.*
- *L'eau, s'écria Pencroff, l'eau pour chauffer les bateaux à vapeur et les locomotives, l'eau pour chauffer l'eau !*

Top Level Target

H2 Storage
Swiss Competence Center for Energy Research

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

COP21

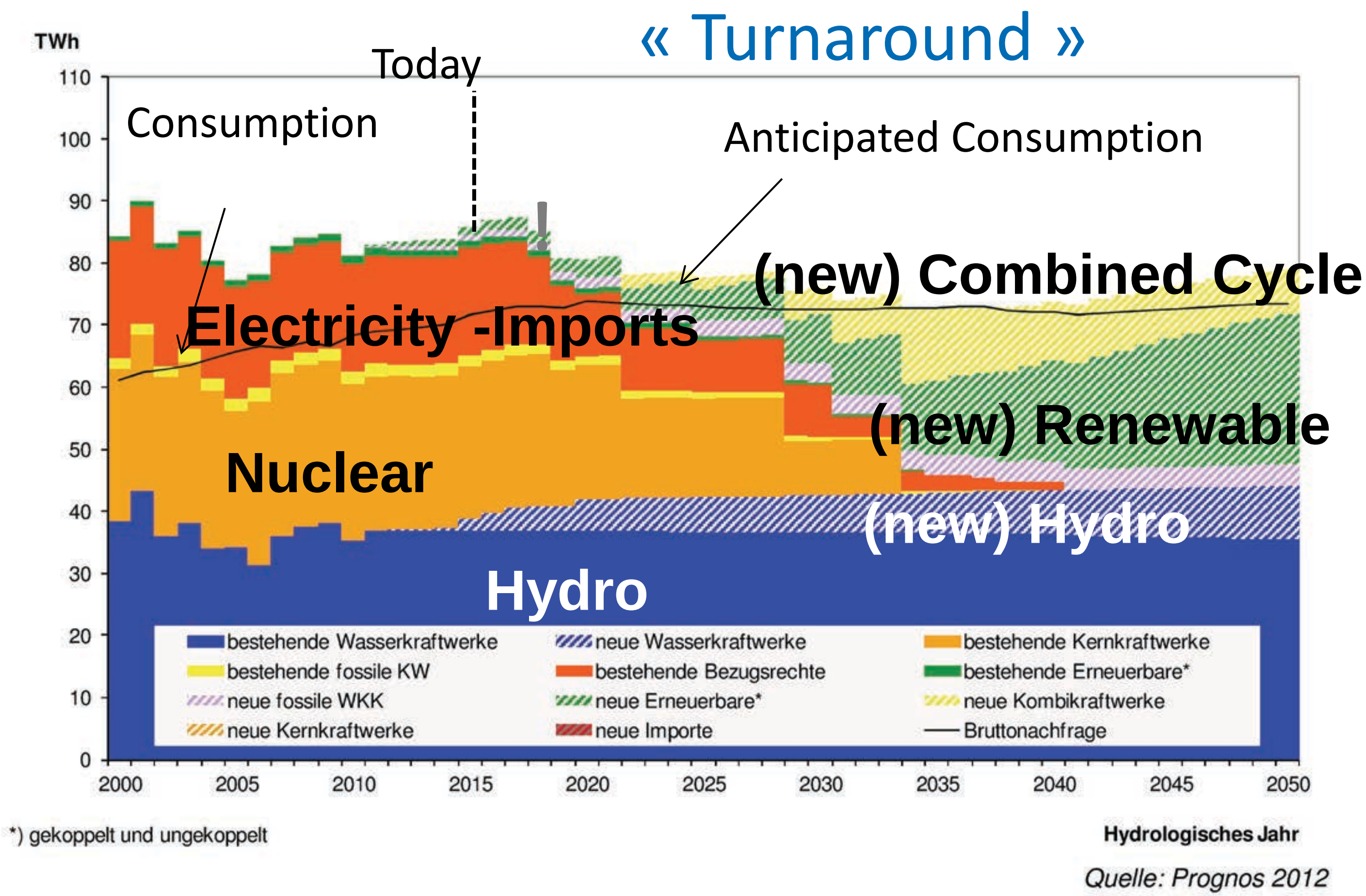
Swiss national target:

2030: Greenhouse gas emissions 37.6 Mio t CO_2eq.

(70% compared to 1990; 2014: 48.71 Mio t CO_2eq.)

15. 072 Botschaft zum Verfassungsartikel über ein Klima- und Energielenkungssystem vom 28. Oktober 2015

Energy Strategy 2050



Top Level Target

H2-Storage
Swiss Competence Center for Energy Research

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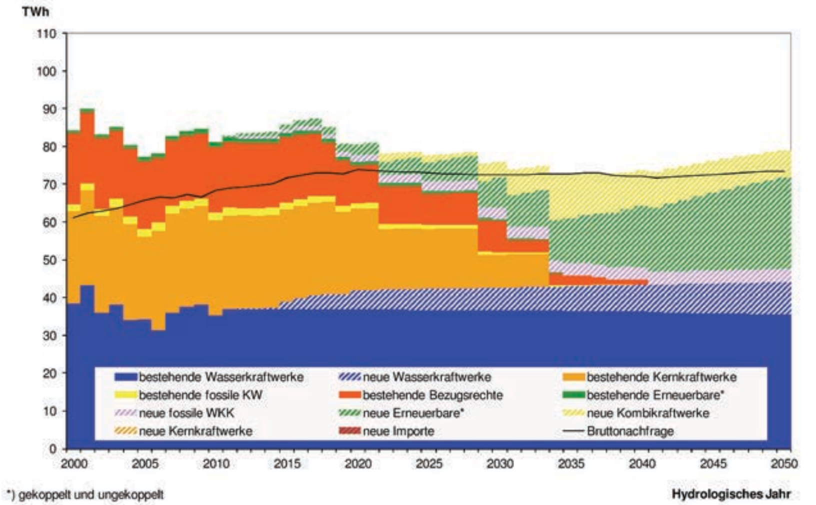
15. 072 Botschaft zum Verfassungsartikel über ein Klima- und Energielenkungssystem vom 28. Oktober 2015

ES 2050

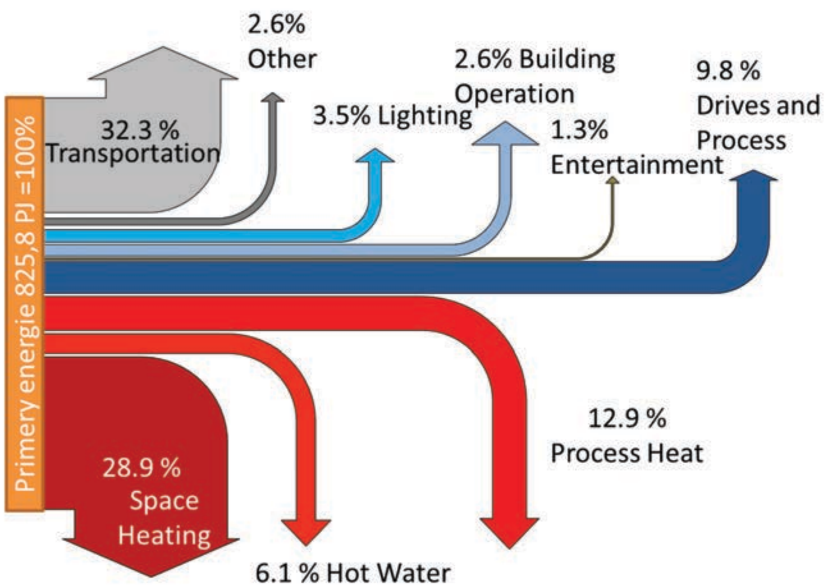
Security of Energy Supply

- No new nuclear power plants
- Increase efficiency
- Cap/reduce consumption
- **Ramp up Renewables**

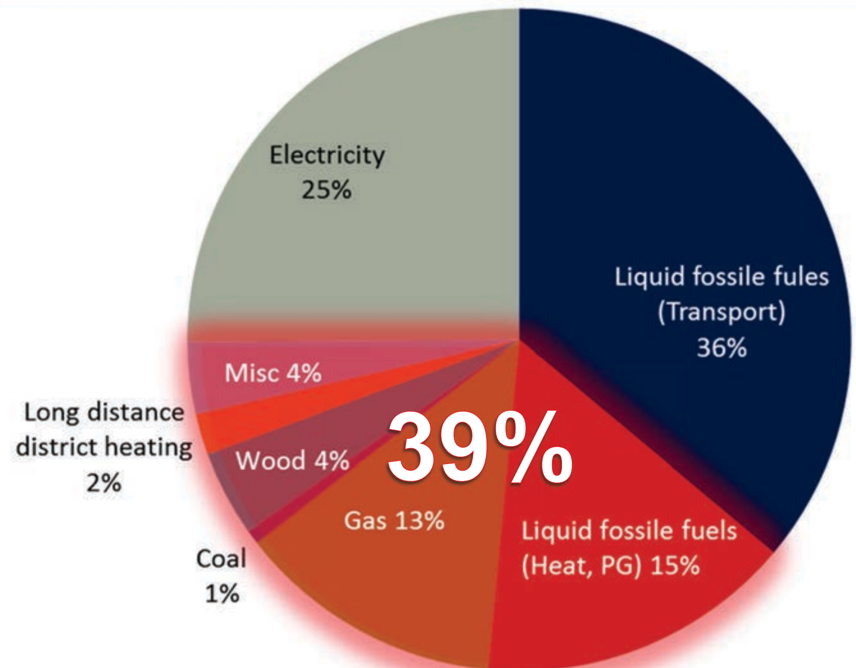


Quelle: Prognos 2012

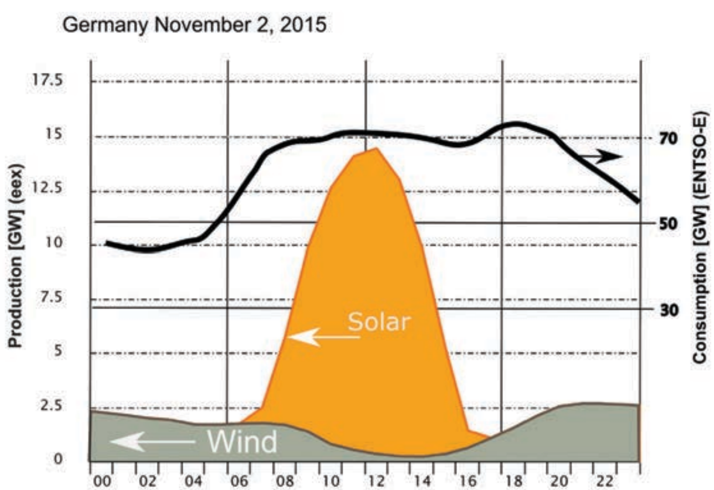
Motivation



Quelle:
Analyse des schweizerischen Energieverbrauchs 2000 - 2014 nach Verwendungszwecken BFE 2015 ; *Prognos, TEP, Infras 2015*



Schweizerische Gesamtenergiestatistik 2014



Key Messages

- Major applications: **Heat** generation (~50 %) and transportation.
- Major energy carriers: **Electricity** (~25%) and **transportation fuels**.

SCCER Heat & Electricity Storage

Power to X

Storage of thermal energy

Haselbacher
Haussener
Barbato
Rommel
Worlitschek
Baldini

Storage of electrical energy

Novak
Kovalenko
Fromm
Villevieille
Battaglia
Fuerst

H_2 Production & Storage

Züttel
Sivula
Girault
Laurenczy

Catalytic & Electrocatalytic CO_2 Reduction

Coperet
Dyson
Broekmann
Schmidt

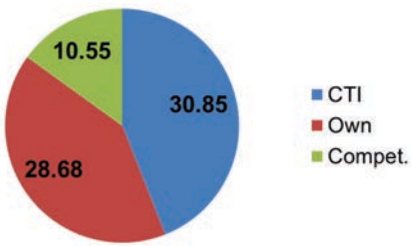
Assessment of Energy Storage

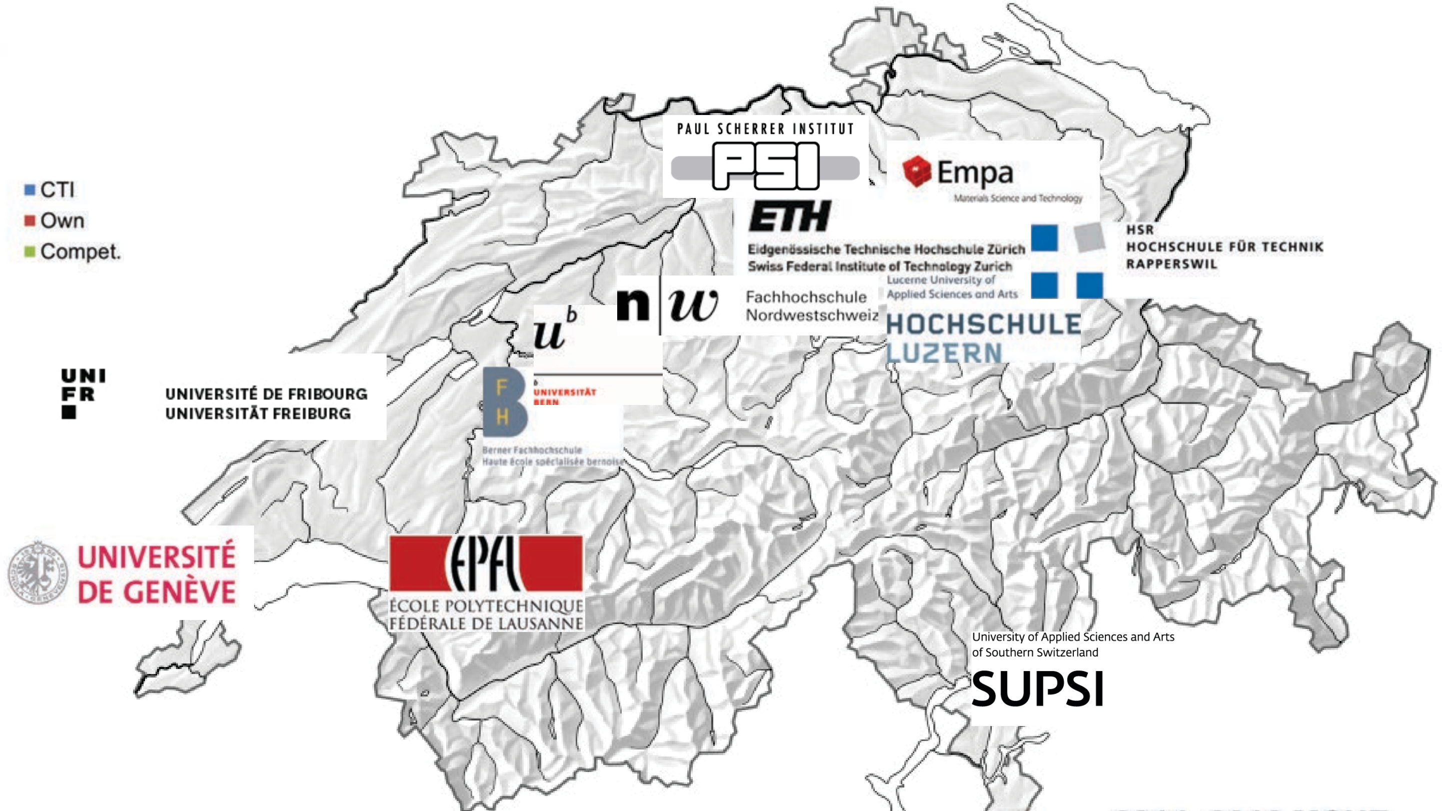
Patel
Worlitschek
Schmidt
Bauer
Girault
Friedl Jansohn
Züttel

What we are

Storage
Swiss Competence Center for Energy Research

2014-2016 FTE

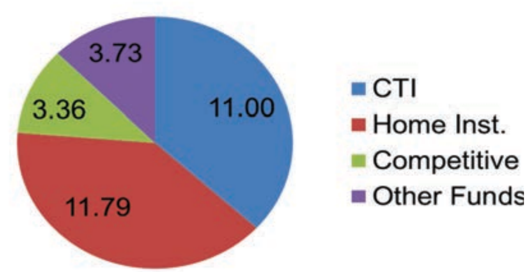




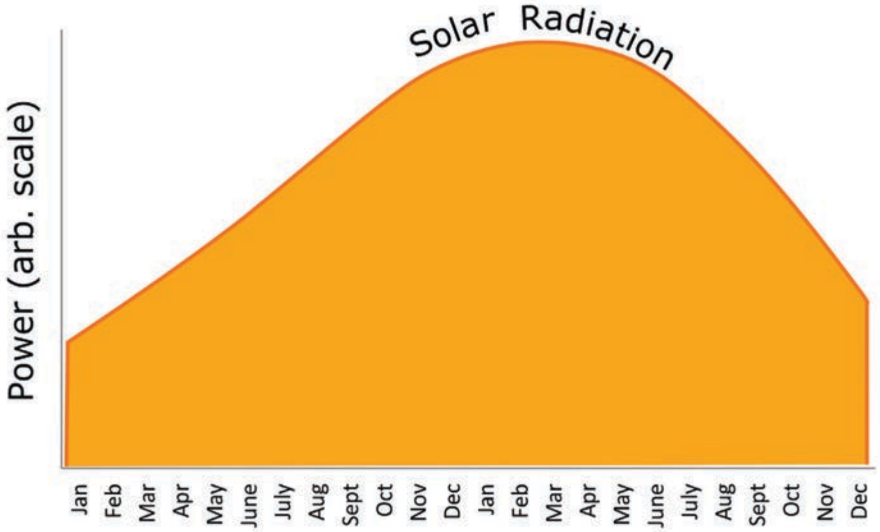
Key Messages

- Research network.
- Centralistic organized
- 130 People ~ 70 FTE.
- 30 M CHF worth of funding.

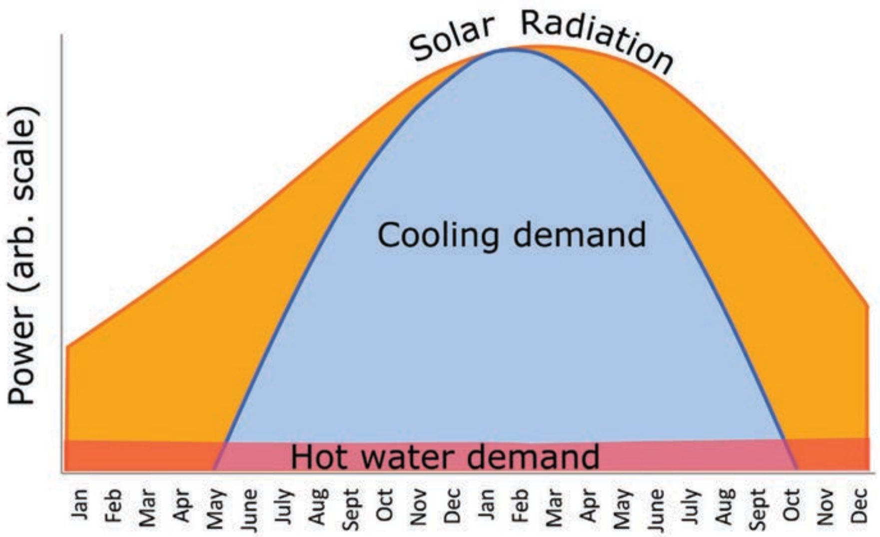
2014 -2016 MCHF



Timescales for Heat Storage



Timescales for Heat Storage



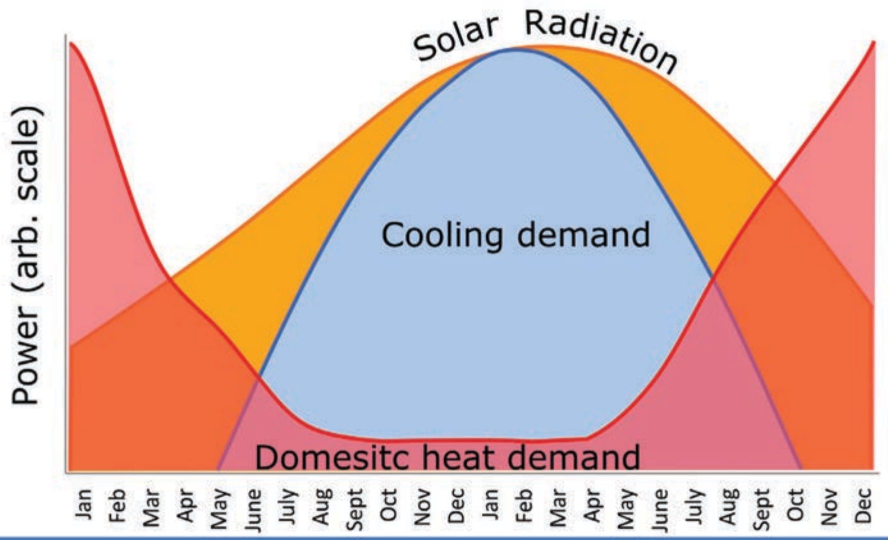
Key Messages

Renewable heat (domestic)

- Solar Thermal, Solar PV (Heat Pump)
- Colling and hot water demand matches energy supply profile

→ Short term heat storage (days)

Timescales for Heat Storage



Key Messages

Renewable Heat (domestic)

- Solar Thermal, Solar PV (Heat Pump)
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→ **Short term heat storage (days)**

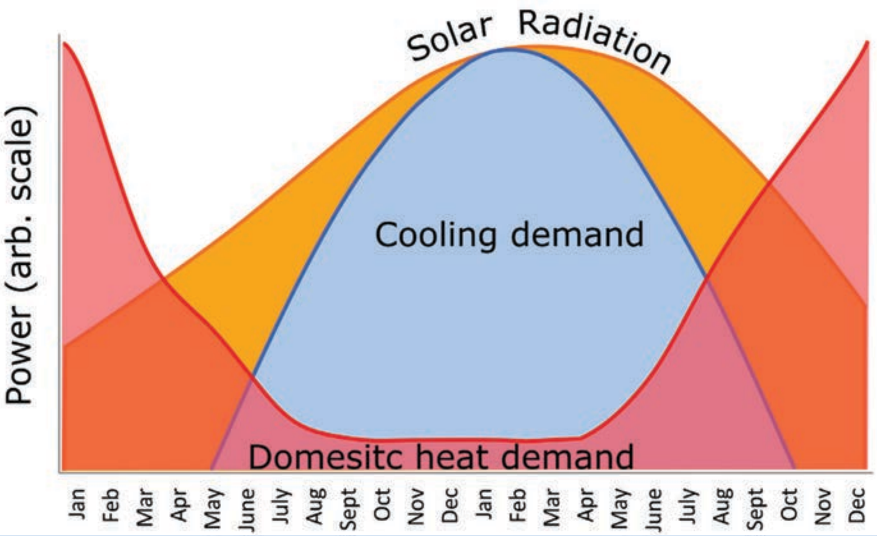
Space heat demand is anticyclic to energy supply!

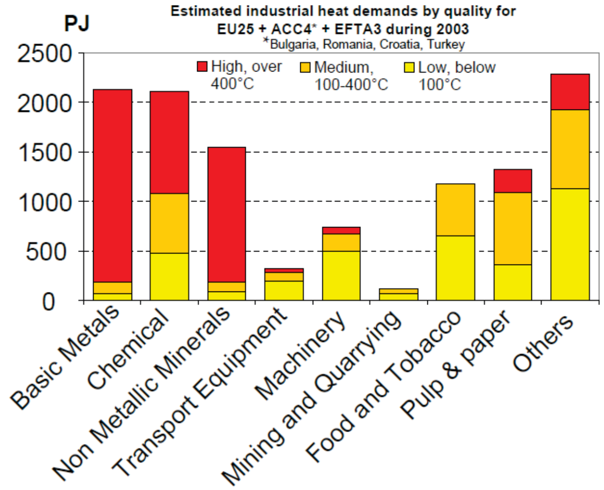
→**Long term heat storage ~6 month.**

35% of primary energy cut out the bill!

Timescales for Heat Storage

Storage
Swiss Competence Center for Energy Research





EcoheatCool The European Marktet Final Report 2005
https://www.euroheat.org/wp-content/uploads/2016/02/Ecoheatcool_WP1_Web.pdf

Space heating and hot water

Renewable heat (domestic)

- Solar Thermal, Solar PV (Heat Pump)
- Colling and hot water demand matches energy supply profile

→ **Short term heat storage (days)**

Space heat demand is anticyclic to energy supply!

→**Long term heat storage ~6 month.**

35% of primary energy cut out the bill!

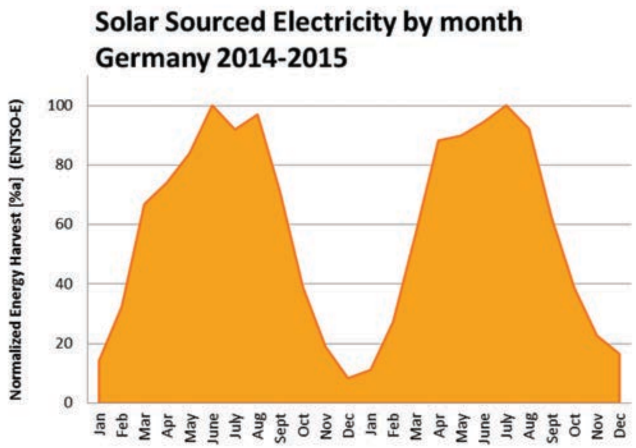
Industrial processes

For specific temperature levels

- Efficiency increase (recuperation).
- Peak shaving option to match energy supply profile.
- Enables AA-CAES.
- Increase utilization (Thermal Solar Power plant)

→ **Short term heat storage (hours to days)**

Timescales for Electricity Storage

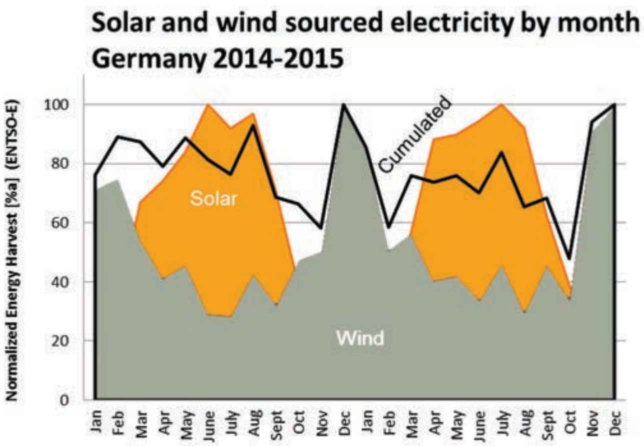


Key Messages

Long-term storage

- PV: April – Sep. -> Storage Oct. – April, 7 Month!

Timescales for Electricity Storage



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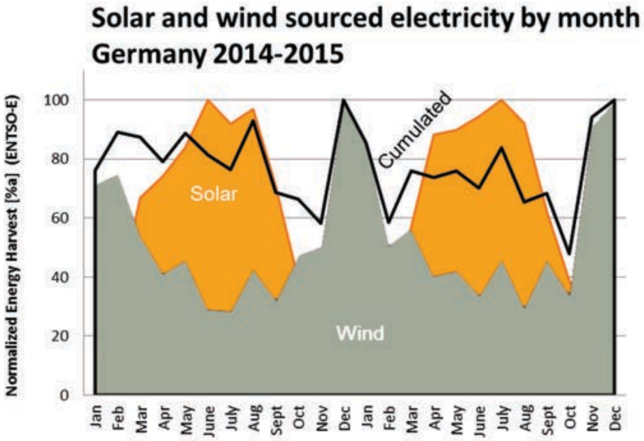
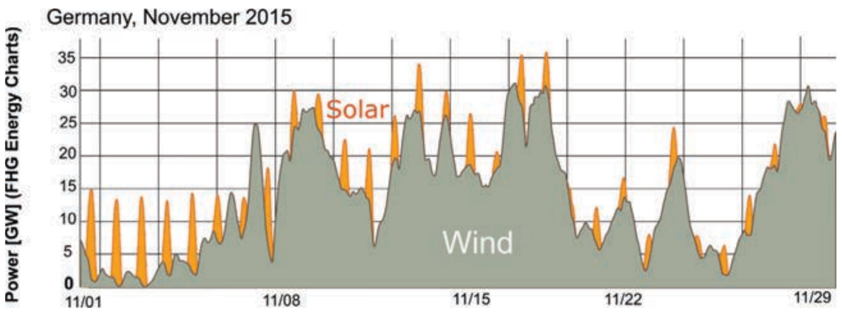
- PV+Wind: Bottleneck Oct-Nov, Feb-March, 2-4 Month

Timescales for Electricity Storage





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- Example Nov 2015: 2 out of 4 weeks fine,
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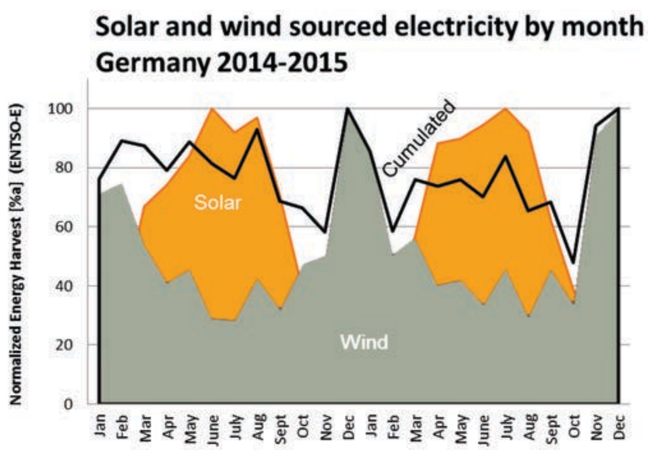
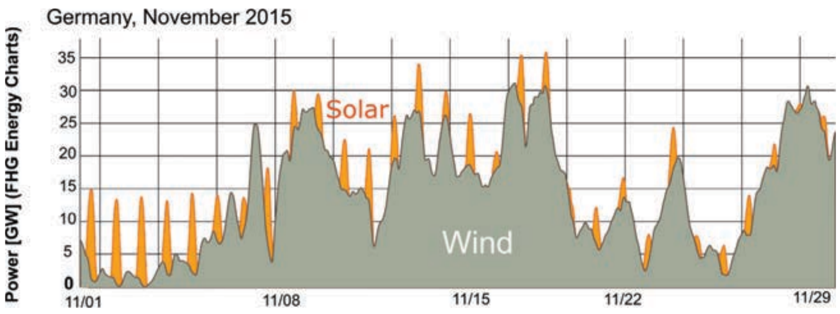
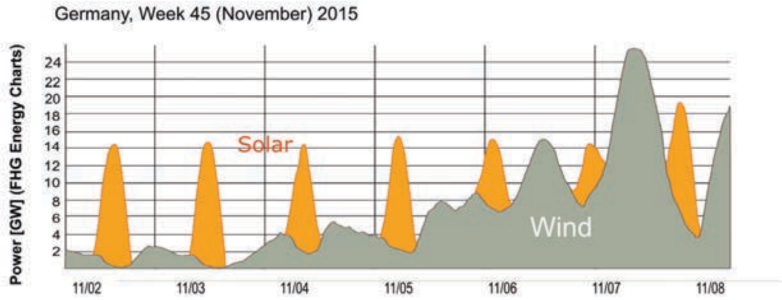
Timescales for Electricity Storage

Storage
Swiss Competence Center
for Energy Research







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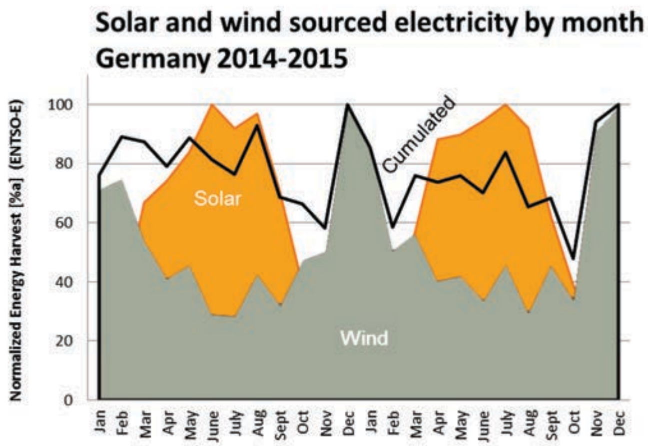
- Week 45, Nov 2015, 5 days low wind, low sun.
  →Long-term storage in the order of Weeks
  IF Wind AND PV are sourced in a good way.

Timescales for Electricity Storage



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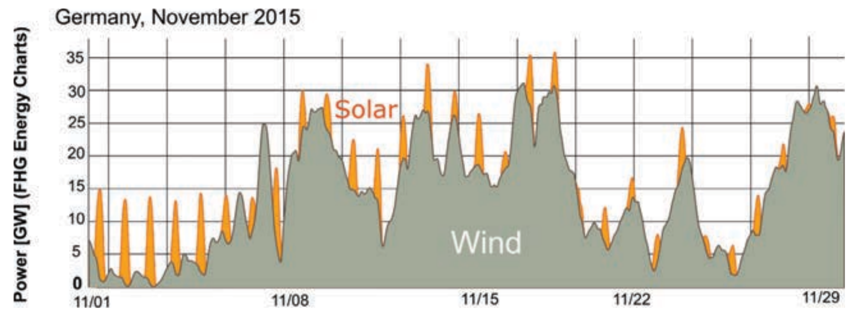
- Week 45, Nov 2015, 5 days low wind, low sun.

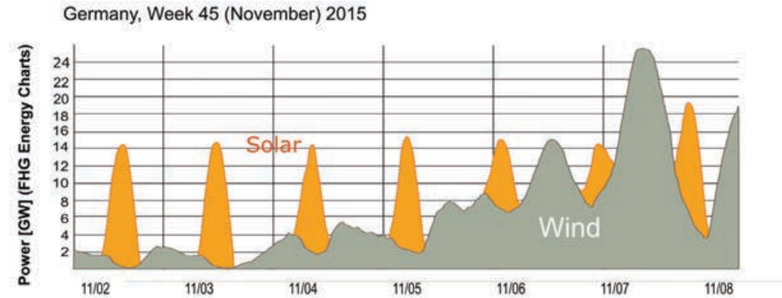
  → Long-term storage in the order of Weeks

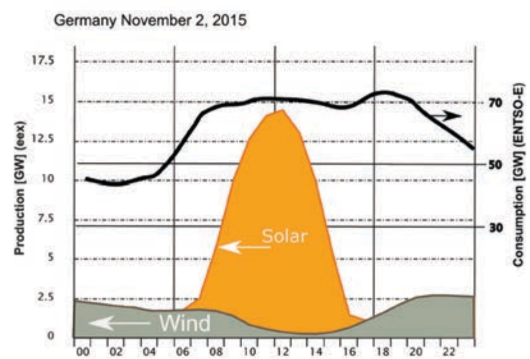
  IF Wind AND PV are sourced in a good way.

Short-term storage

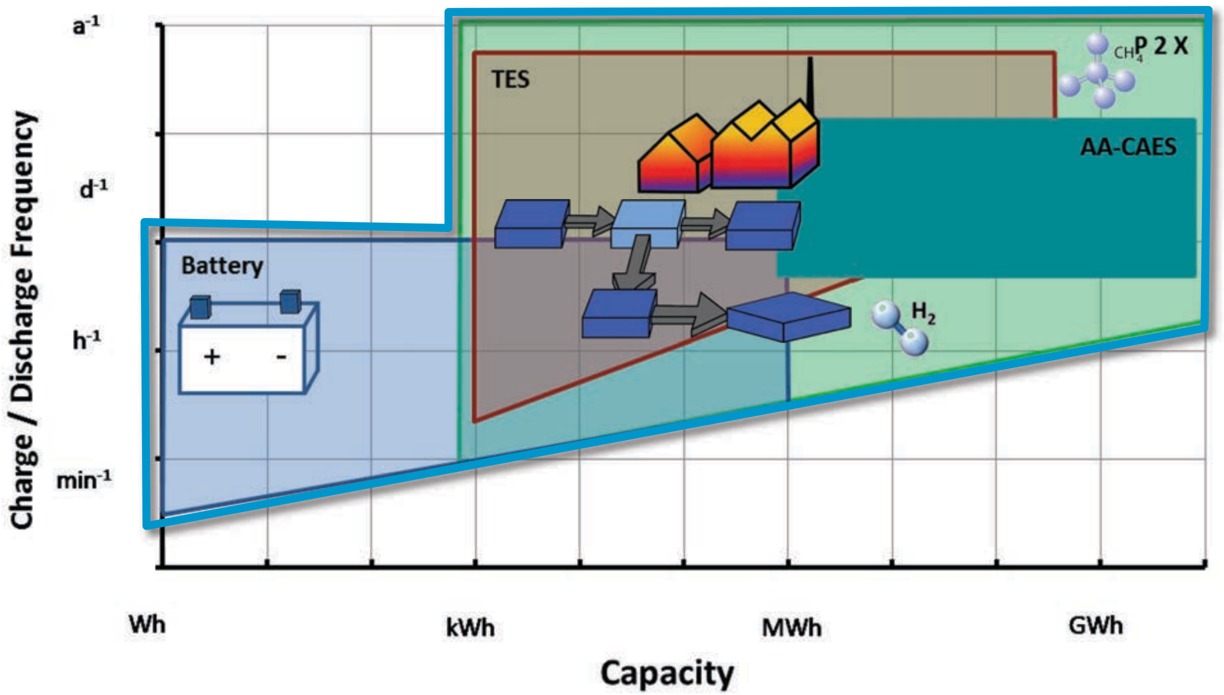
Peak shaving e.g. with battery storage.





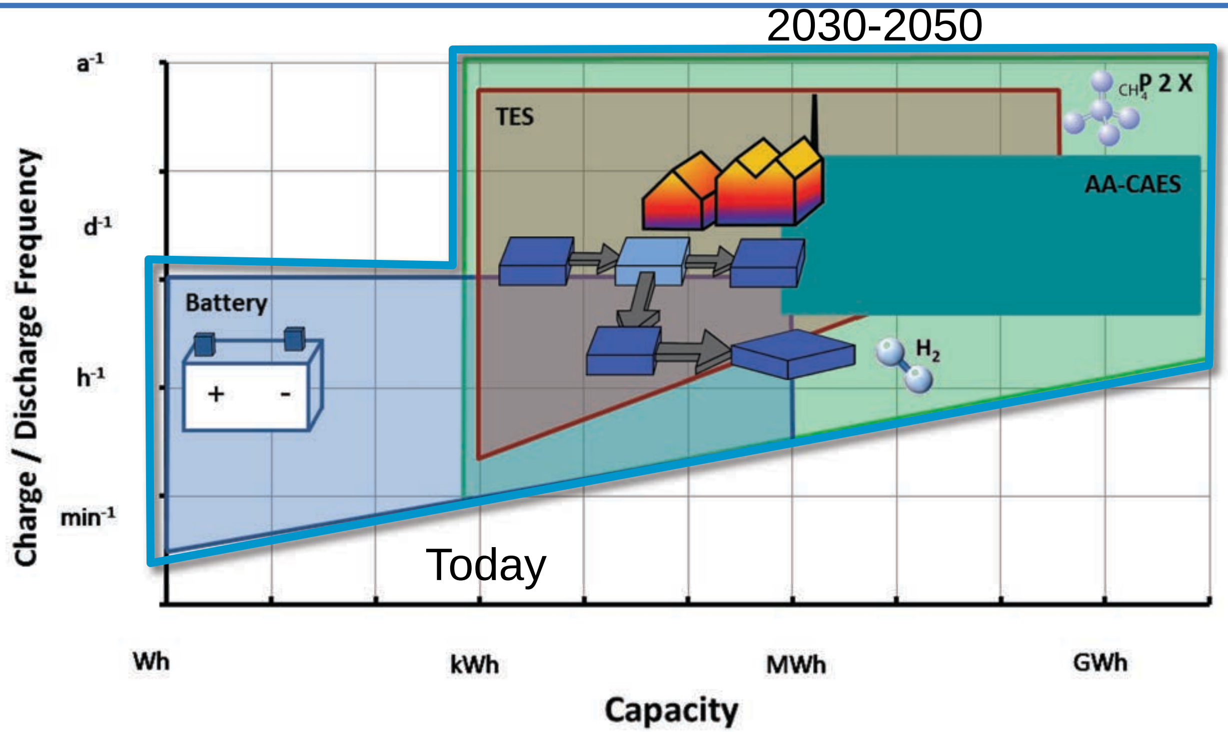


Mission



a-1
d-1
h-1
min-1
Charge / Discharge Frequency
TES
P 2 X
CH4
AA-CAES
Battery
+
-
H2
Wh
kWh
MWh
GWh
Capacity

Mission



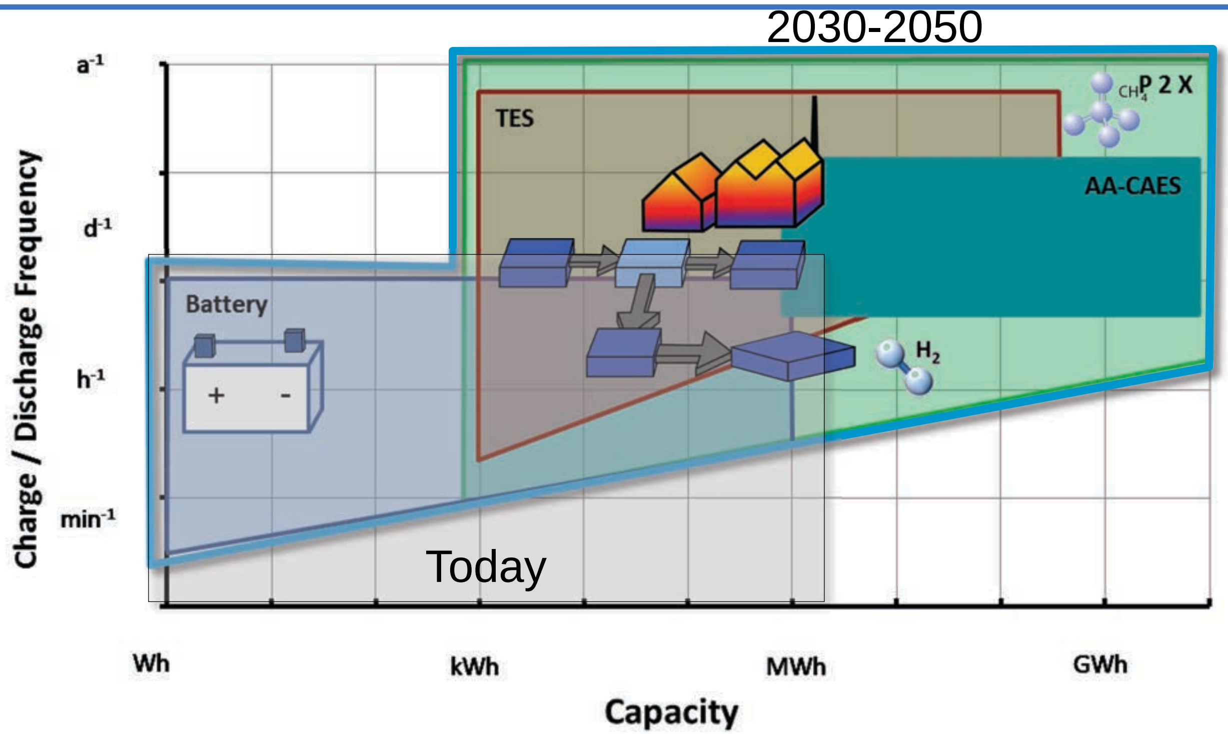
Mission

Advancing research, development and technologies in the field of

- electricity and heat storage
- conversion and storage of energy in fuels
- overall technology interactions

by bridging activities from fundamentals to applications and the technology transfer in industrial environment

Mission



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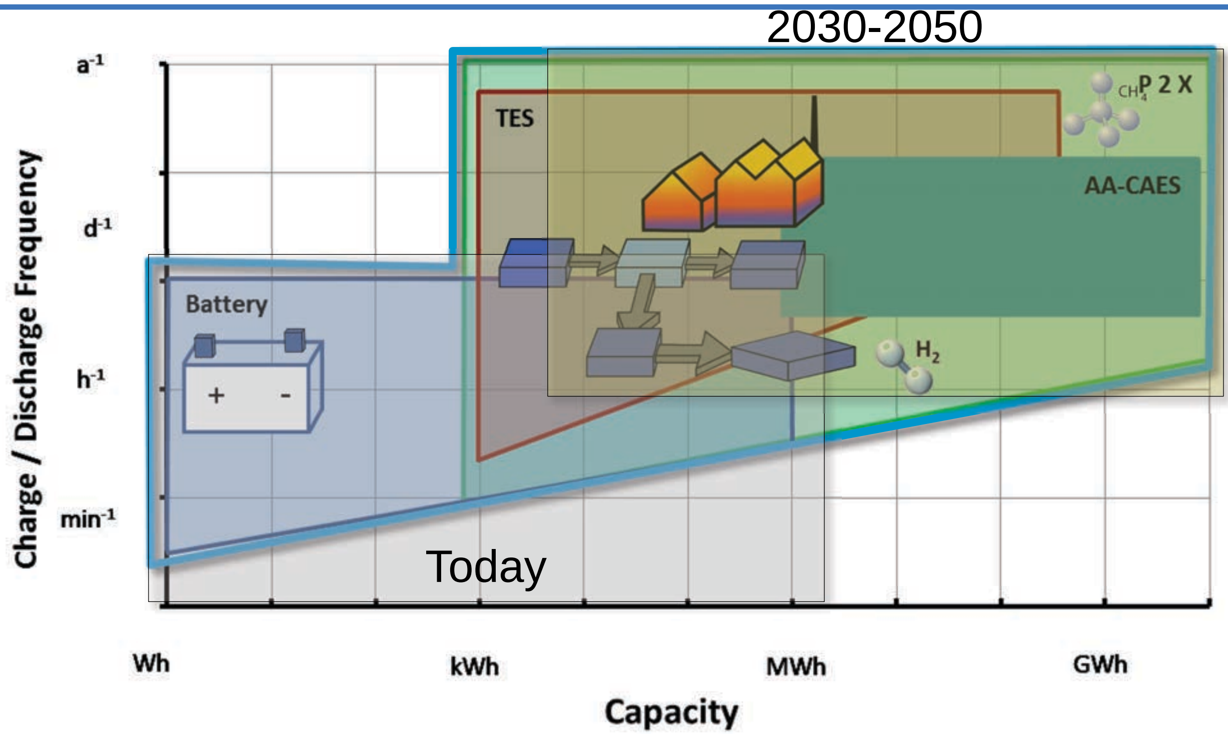
Mission

Storage
Swiss Competence Center for Energy Research



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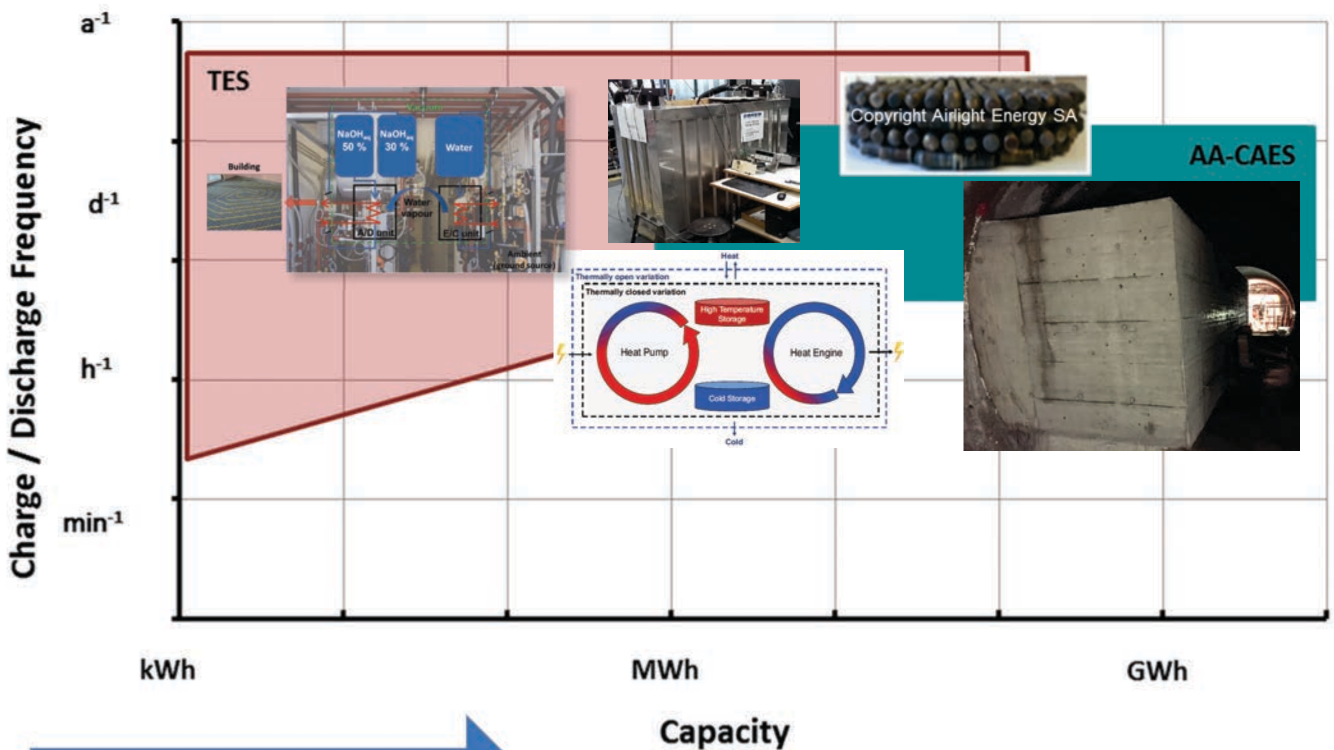
Storage
Swiss Competence Center for Energy Research

Storage of thermal energy

Haselbacher
Haussener
Barbato
Rommel
Roth
Ribi
Worlitschek

Thermal Energy Storage Systems

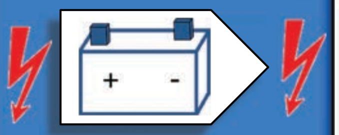


Short term (<10y)

Medium term (10-15y)

Battery Storage

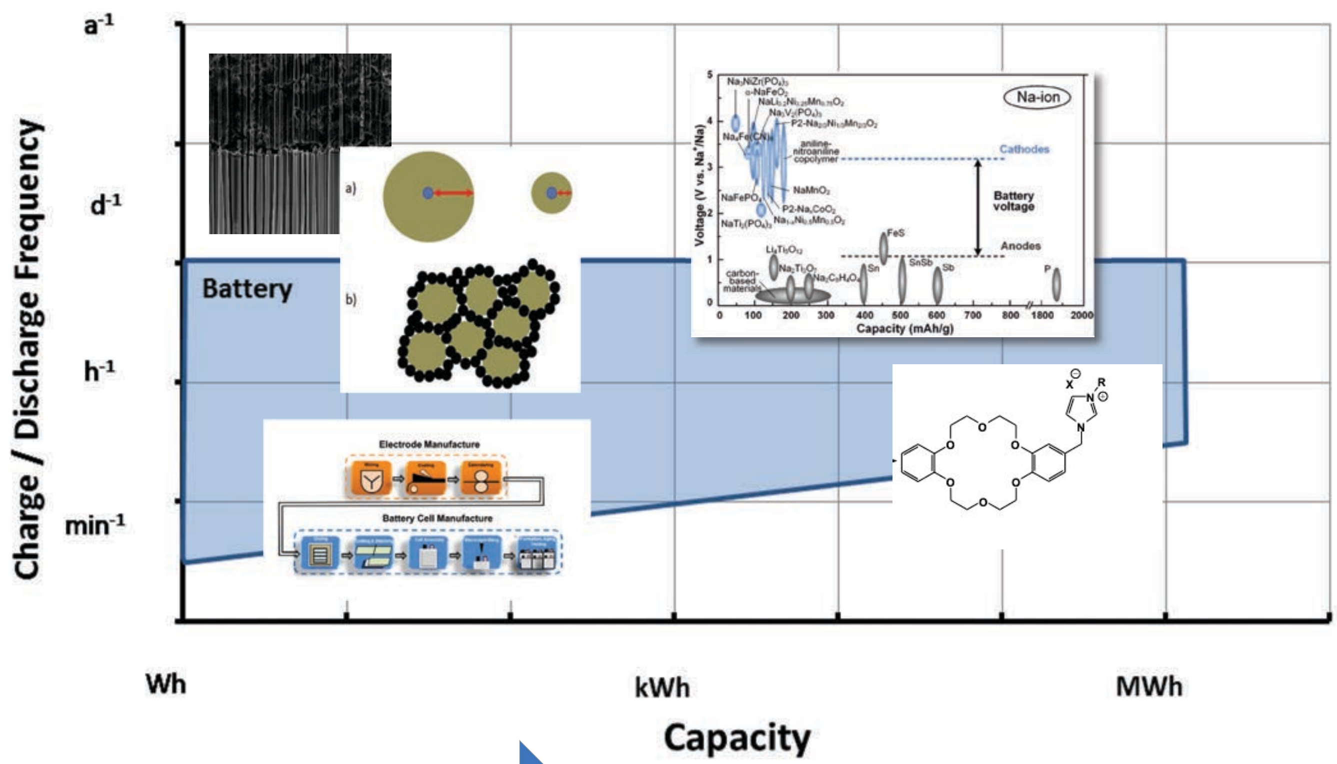
Storage
Swiss Competence Center
for Energy Research



Storage of electrical energy

Kovalenko
Fromm
Villevieille
Sennhauser
Fuerst

Advanced Batteries and Battery Materials



Short term (<10y)

Medium term (10-15y)

Power to Hydrogen

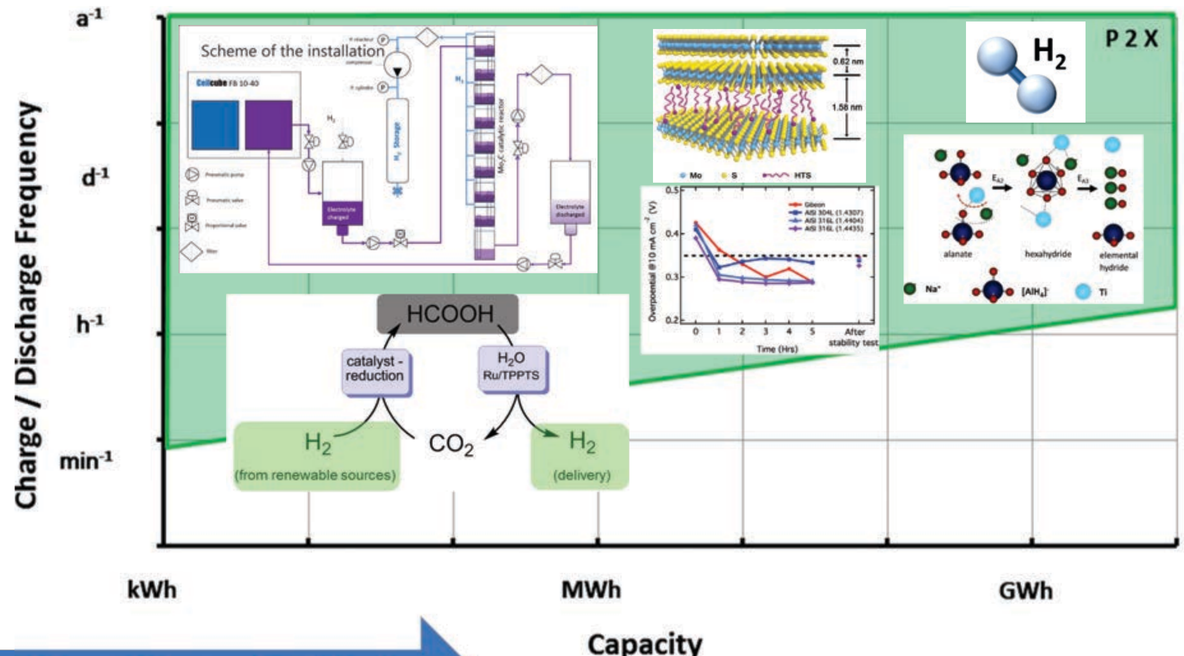
HyStorage
Swiss Competence Center for Energy Research

H_2 Production & Storage

Züttel
Sivula
Girault
Laurenczy

WP 3

Hydrogen Production and Storage

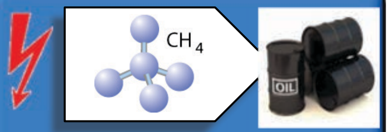


Short term (<10y)

Medium term (10-15y)

Long term (>15y)

H2 Storage
Swiss Competence Center for Energy Research

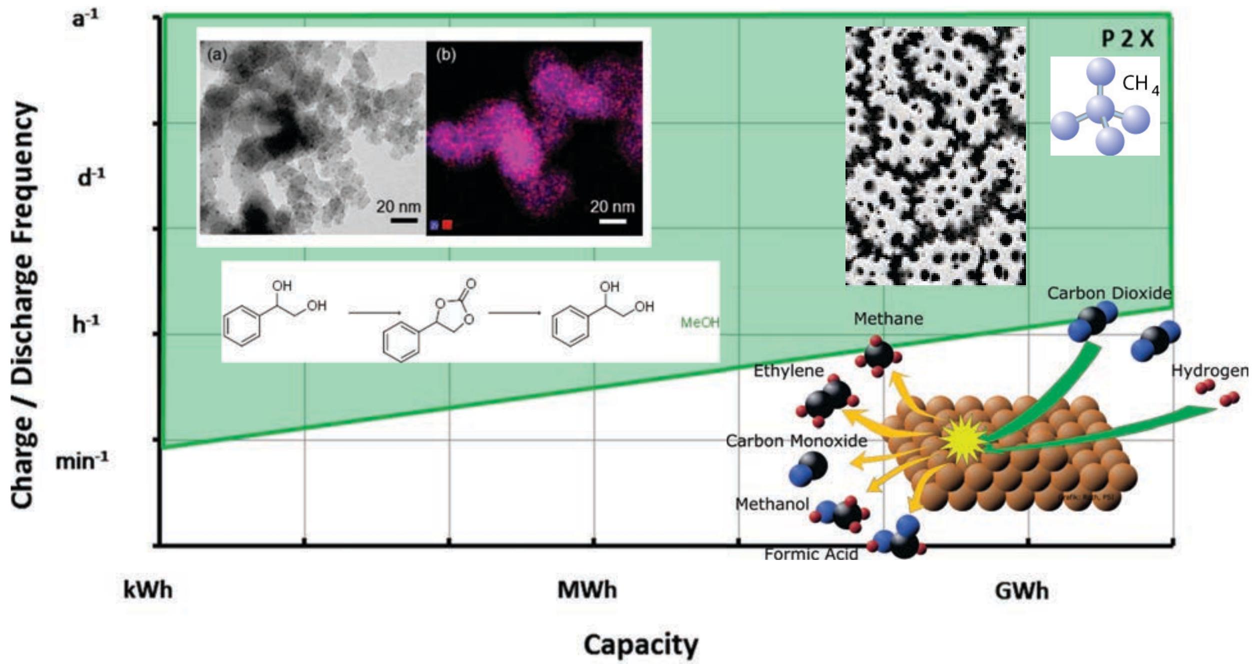


Catalytic & Electrocatalytic CO_2 Reduction

Dyson
Coperet
Broekmann
Schmidt

WP 4

Catalytic and Electrocatalytic CO_2 Reduction

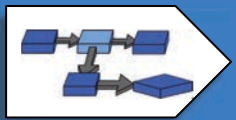


Medium term (10-15y)

Long term (>15y)

Technology Assessment

Storage
Swiss Competence Center for Energy Research

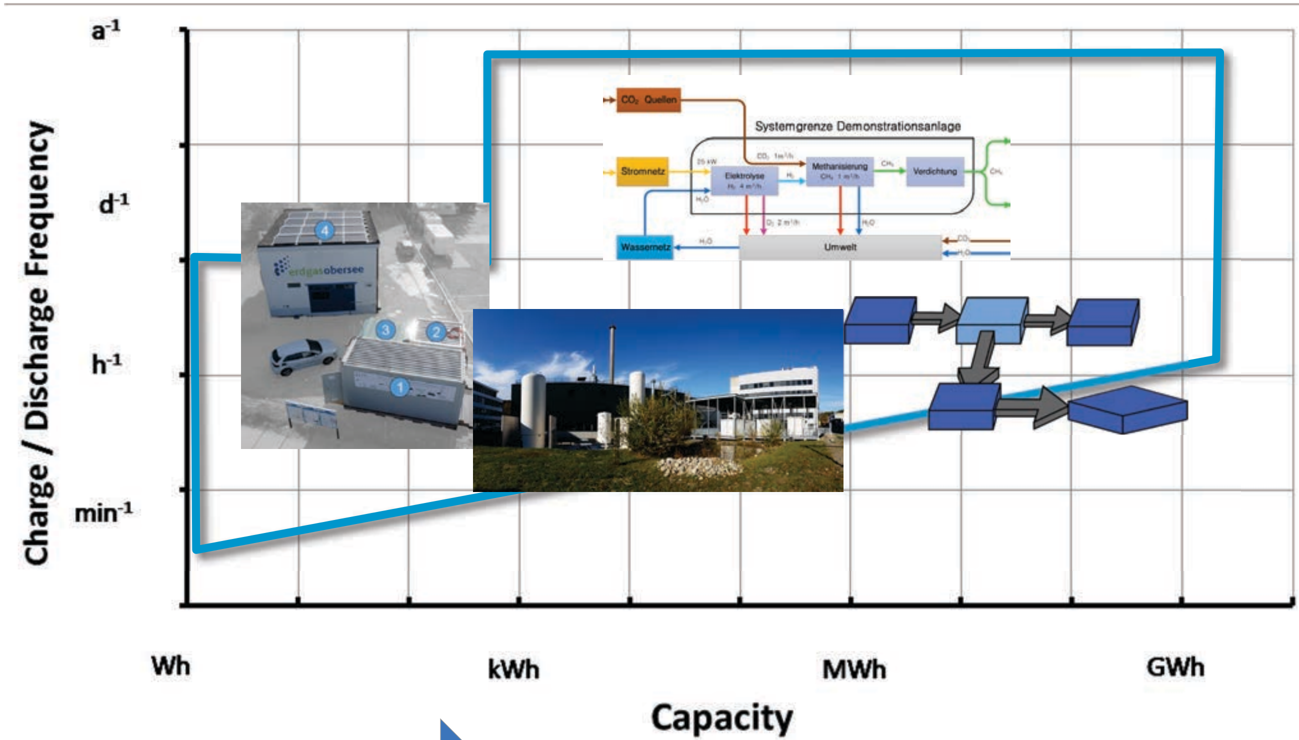


System Modeling

Worlitschek
Patel
Bauer
Friedl

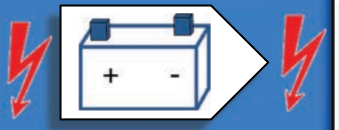
WP 5

Assessment of Energy Storage



Component

Energy System



Storage of electrical energy

Kovalenko
Fromm
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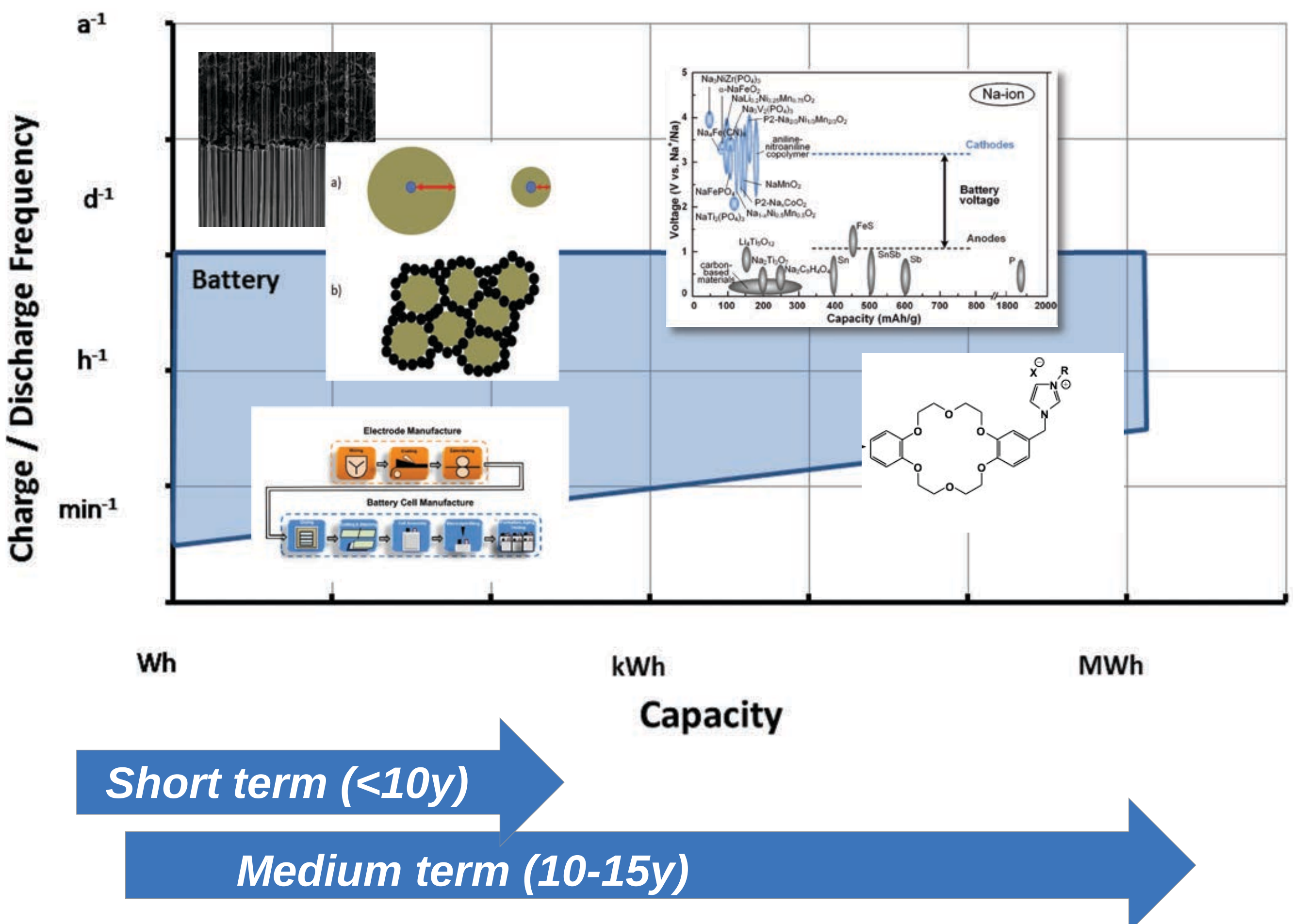
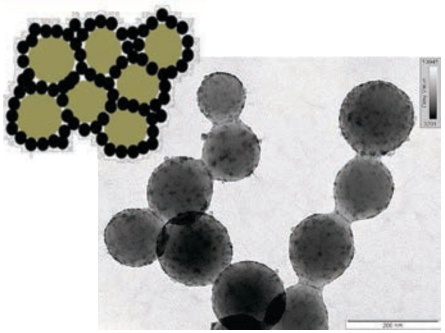
Sennhauser
Fuerst

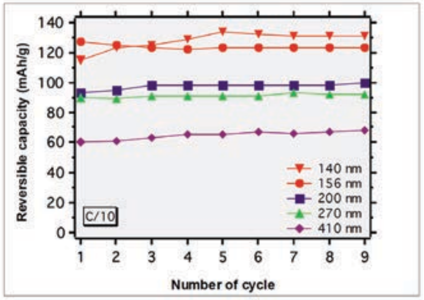
sccer mobility

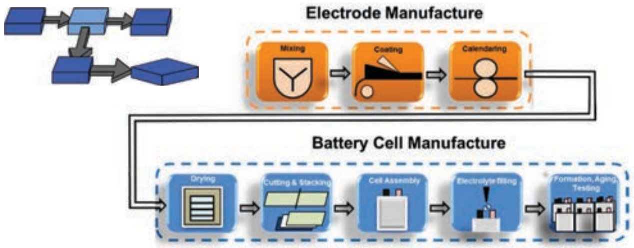
Advanced Batteries and Battery Materials



Advanced Batteries and Battery Materials





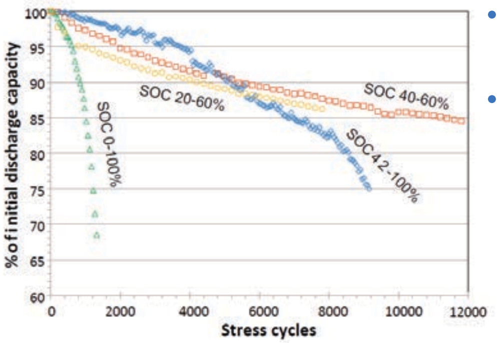


Pilot Manufacturing Line

- Technology screening finalized
- Test plan to optimize parameters for slitting and welding in place.
- Prototype production of battery electrodes on newly developed processing machinery tested with NS-$LiCoO_2$..

Li-ion batteries

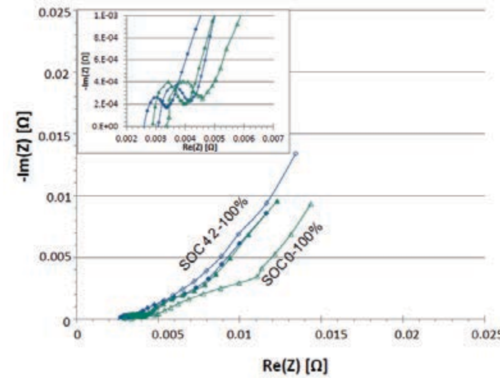
- Cost effective synthesis of nano sized (NS) anode (Sn/Sb, metal phosphides, Sb-P composites)
- Cathode materials (BiF_3, $LiCoO_2$, $LiMnPO_4$)
- Core-shell Sn/C composites



Short term (<10y)

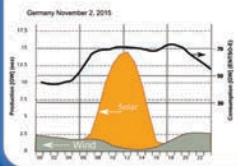
Cell testing

- Cells investigated by impedance spectroscopy, surface analysis.
- Models for optimized operation of storage battery systems designed.



H2-Storage
Swiss Competence Center for Energy Research

RFB Hydrogen Production



Short term (<10y)

RFB Hydrogen Production

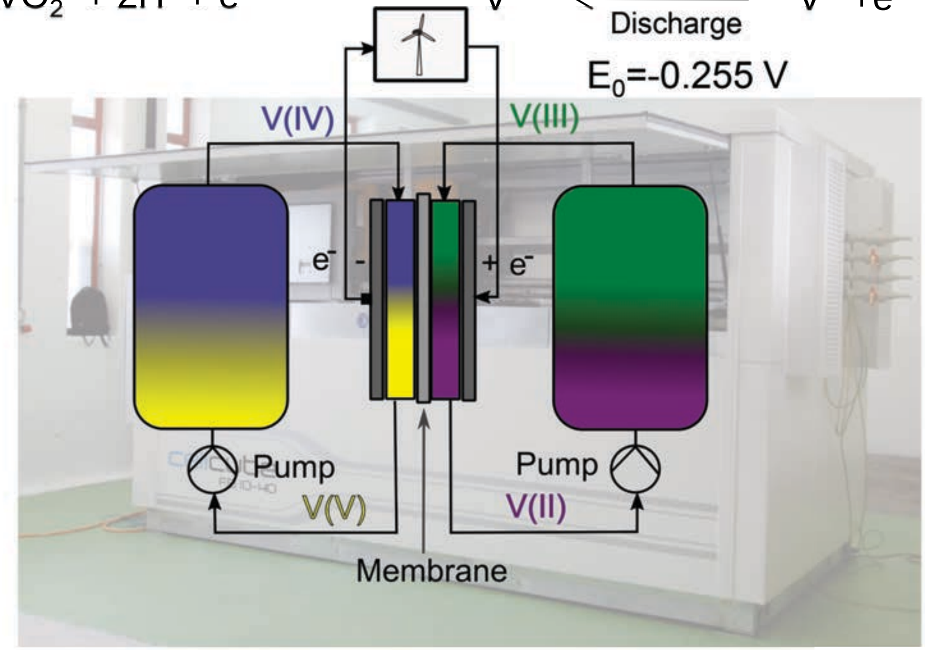
Cathodic reaction 25 – 40 Wh/L **Anodic reaction**

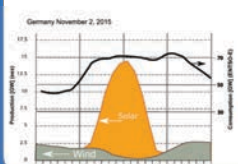
$$VO^{2+} + H_2O \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} VO_2^{+} + 2H^{+} + e^{-}$$

E_0=0.991 V

$$V^{3+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+} + e^{-}$$

E_0=-0.255 V





Short term (<10y)

Power to X

Storage
Swiss Competence Center for Energy Research

H_2 Production & Storage

Züttel
Sivula
Girault
Laurenczy

Catalytic & Electrocatalytic CO_2 Reduction

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SCCER FURIES
SCCER CREST
sccer mobility
biosweet
Biomass for Swiss Energy Future
Swiss Competence Center for Energy Research

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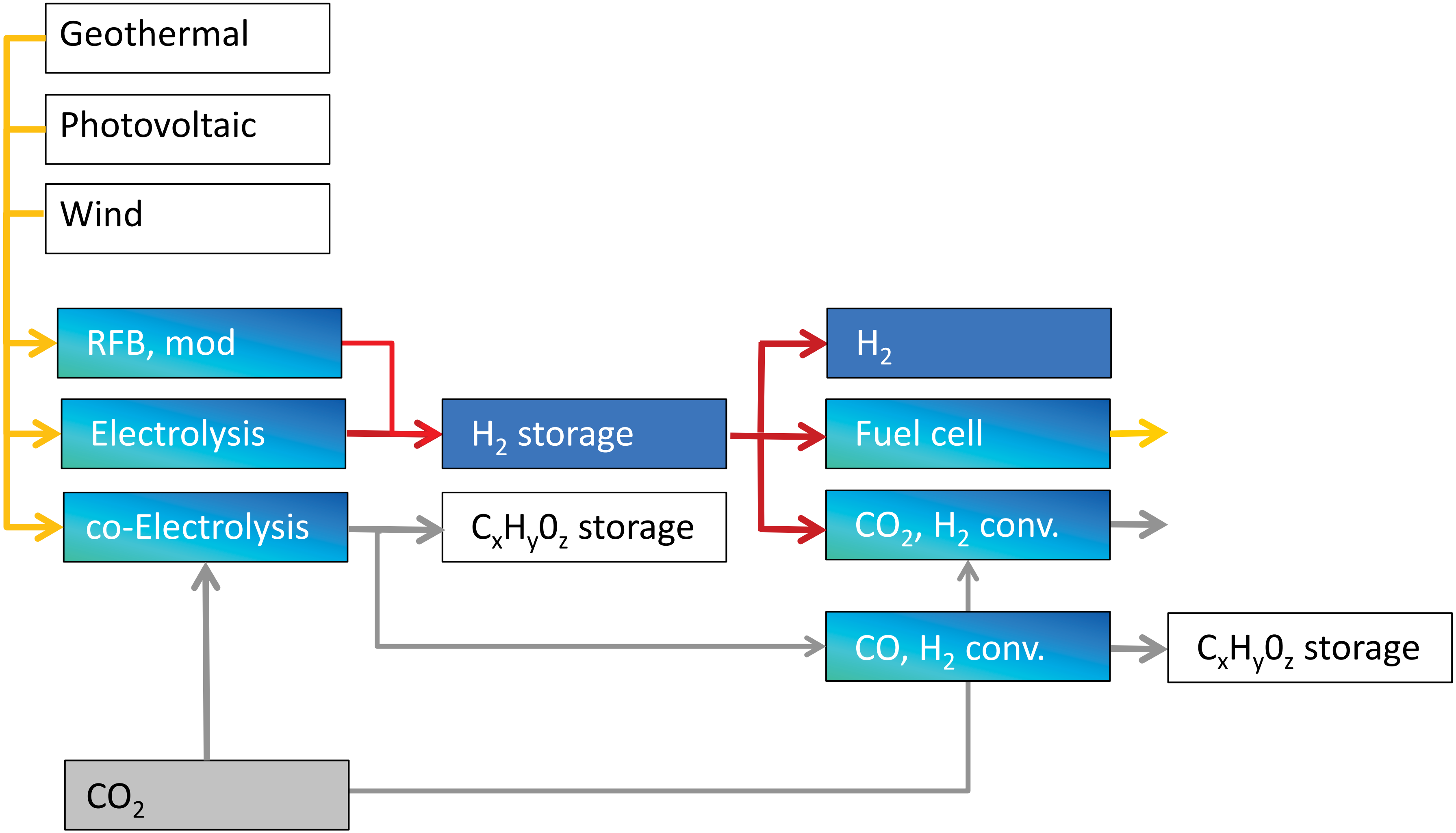
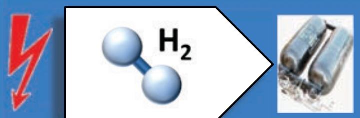
Power to X



Geothermal
Photovoltaic
Wind
RFB, mod
Electrolysis
co-Electrolysis
H_2 storage
$C_xH_y0_z$ storage
H_2
Fuel cell
CO_2, H_2 conv.
CO, H_2 conv.
$C_xH_y0_z$ storage
CO_2

Power to Hydrogen

H2-Storage
Swiss Competence Center for Energy Research

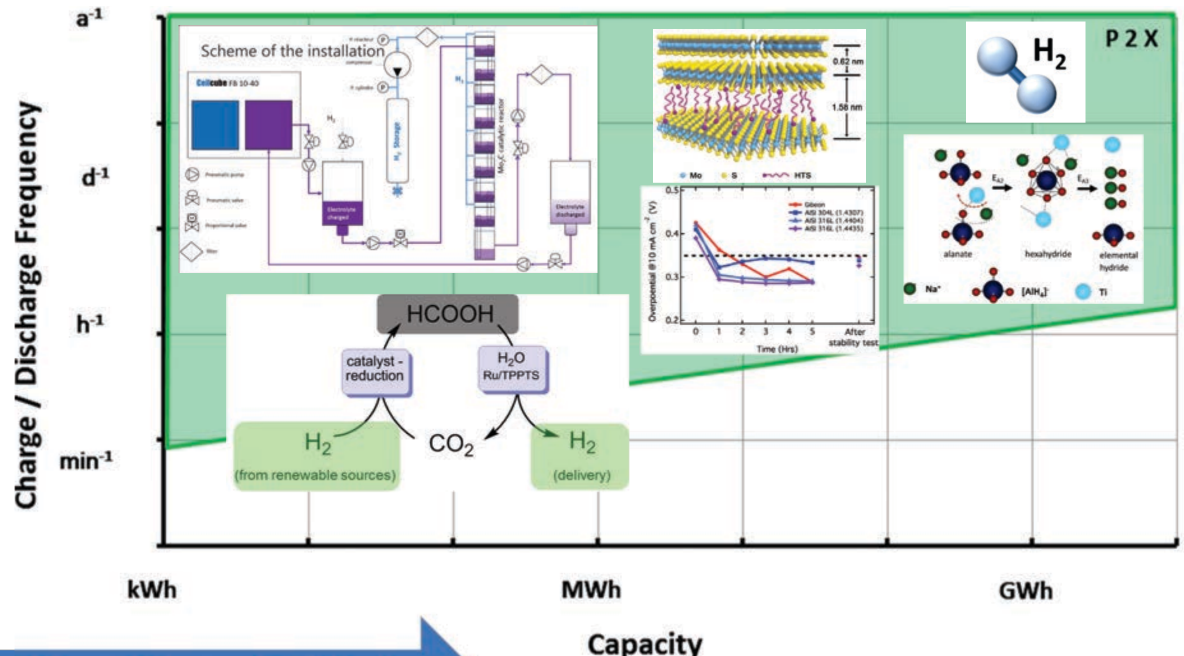


H_2 Production & Storage

Züttel
Sivula
Girault
Laurenczy

WP 3

Hydrogen Production and Storage

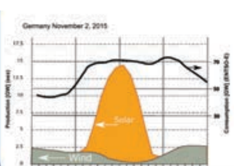


Short term (<10y)

Medium term (10-15y)

Long term (>15y)

RFB Hydrogen Production



Short term (<10y)

RFB Hydrogen Production

Cathodic reaction

25 – 40 Wh/L

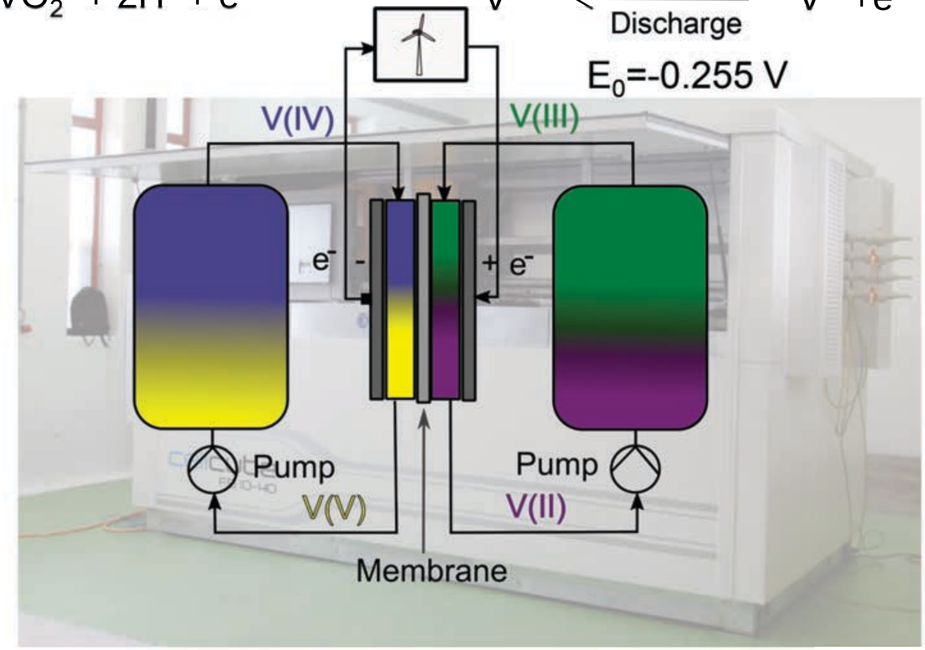
$$VO^{2+} + H_2O \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} VO_2^{+} + 2H^{+} + e^{-}$$

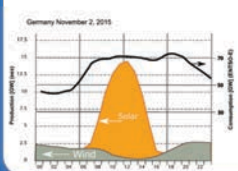
$E_0 = 0.991$ V

Anodic reaction

$$V^{3+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+} + e^{-}$$

$E_0 = -0.255$ V





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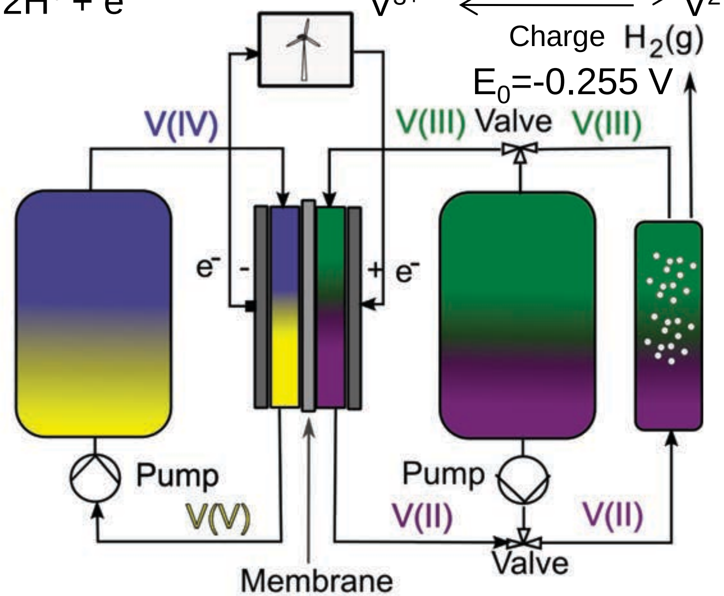
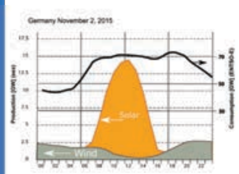
$H_2(g)$

E_0=-0.255 V



$$2V^{2+} + 2H^{+} \xrightarrow[\text{Discharge}]{Mo_2C} 2V^{3+} + \mathbf{H_2}$$



Short term (<10y)

H2-Storage
Swiss Competence Center for Energy Research

RFB Hydrogen Production

Cathodic reaction

25 – 40 Wh/L

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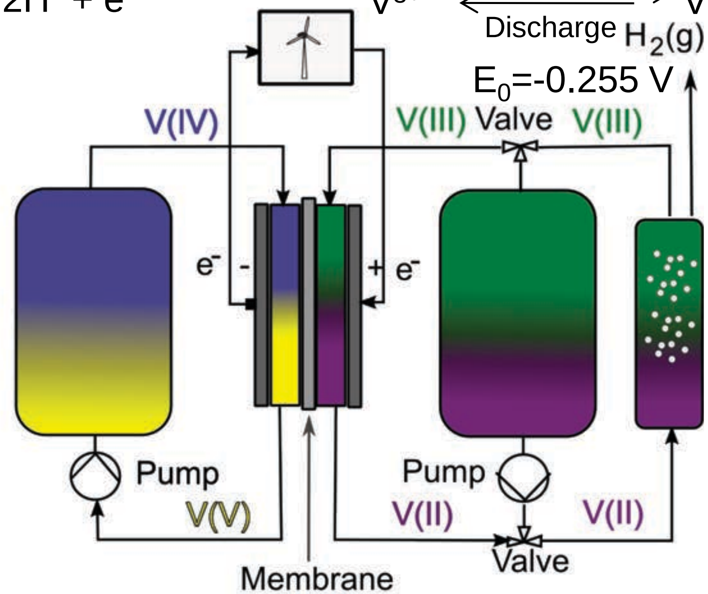

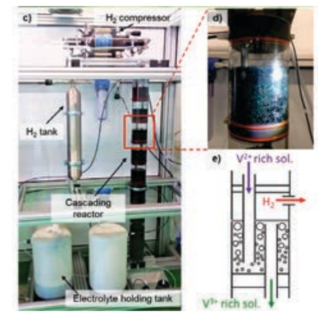

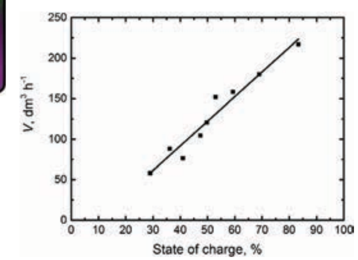

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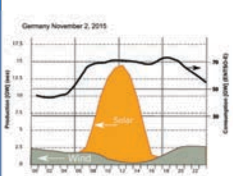

Short term (<10y)

RFB Hydrogen Production

Cathodic reaction 25 – 40 Wh/L **Anodic reaction**

$$VO^{2+} + H_2O \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} VO_2^{+} + 2H^{+} + e^{-}$$

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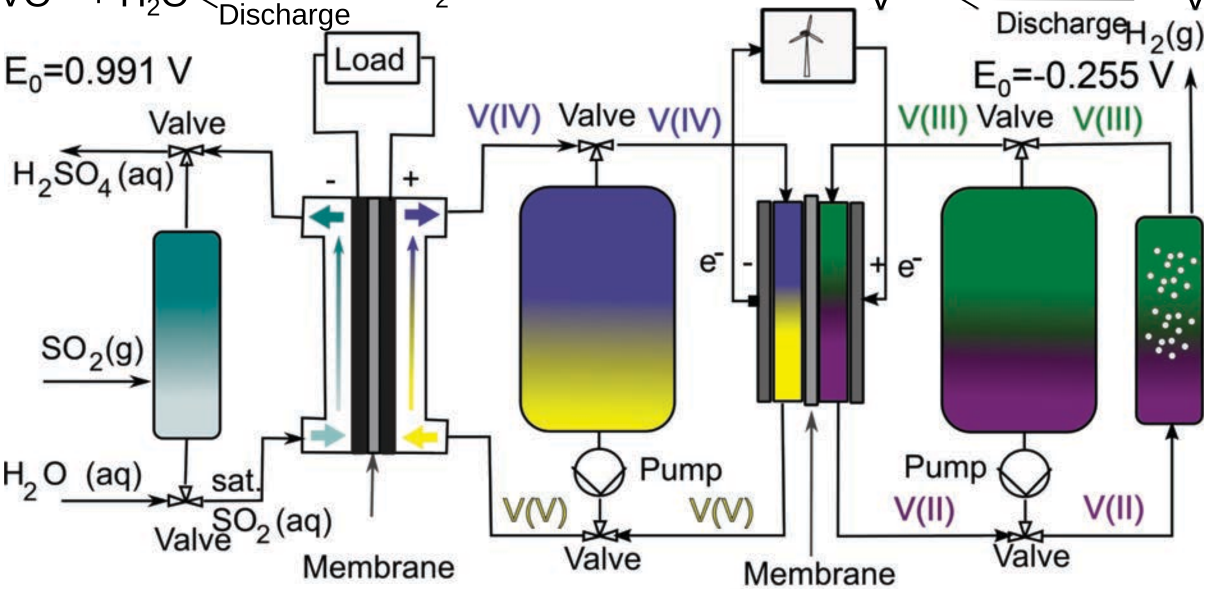
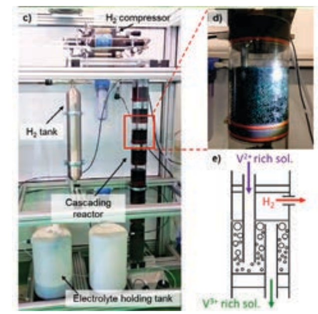
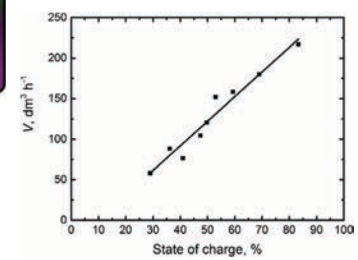


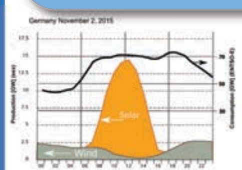




$VO_2^{+} + 2H^{+} + e^{-} \xrightarrow{\text{Discharge}} VO^{2+} + H_2O$ $E_0 = 0.991$ V

$SO_2 + 2H_2O \xrightarrow{\text{Discharge}} H_2SO_4 + 2H^{+} + 2e^{-}$ $E_0 = 0.158$ V

$2V^{2+} + 2H^{+} \xrightarrow[\text{Discharge}]{Mo_2C} 2V^{3+} + \mathbf{H_2}$



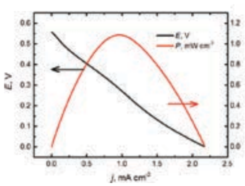
Short term (<10y)

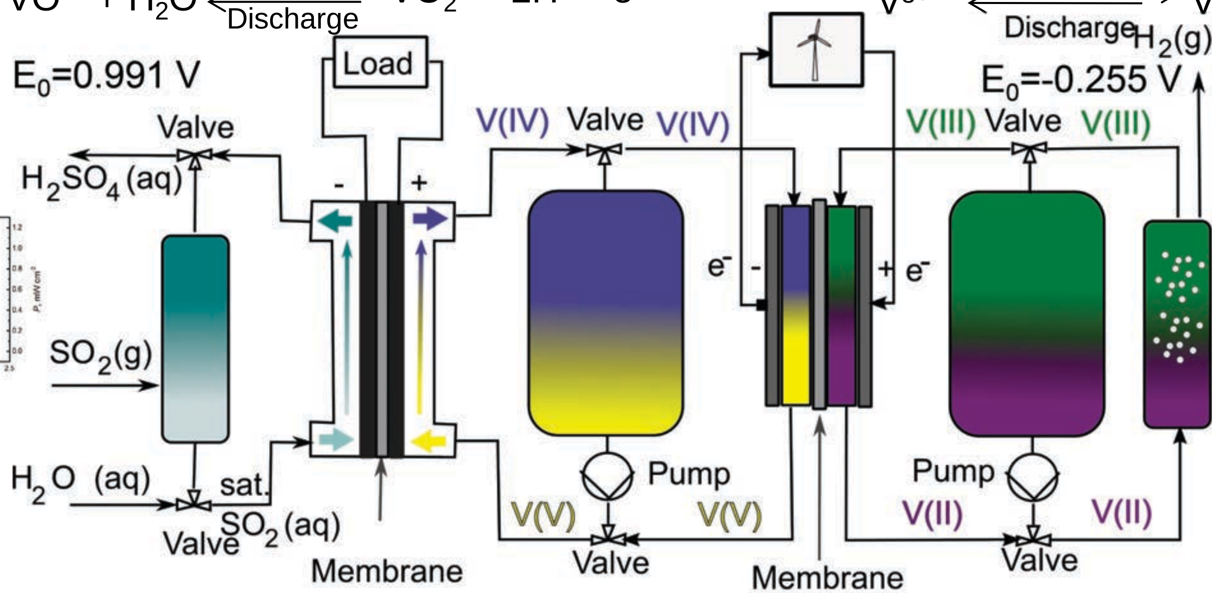
RFB Hydrogen Production

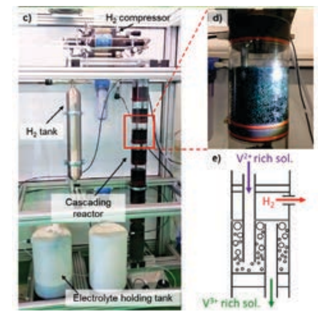
Cathodic reaction 25 – 40 Wh/L **Anodic reaction**

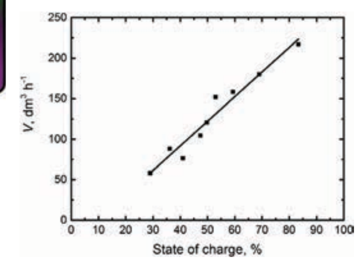
$VO^{2+} + H_2O \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} VO_2^{+} + 2H^{+} + e^{-}$

$V^{3+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} V^{2+} + e^{-}$





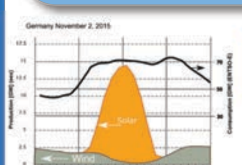




$VO_2^{+} + 2H^{+} + e^{-} \xrightarrow[\text{Discharge}]{} VO^{2+} + H_2O \quad E_0=0.991\text{ V}$

$SO_2 + 2H_2O \xrightarrow[\text{Discharge}]{} H_2SO_4 + 2H^{+} + 2e^{-} \quad E_0=0.158\text{ V}$

$2V^{2+} + 2H^{+} \xrightarrow[\text{Discharge}]{Mo_2C} 2V^{3+} + \mathbf{H_2}$



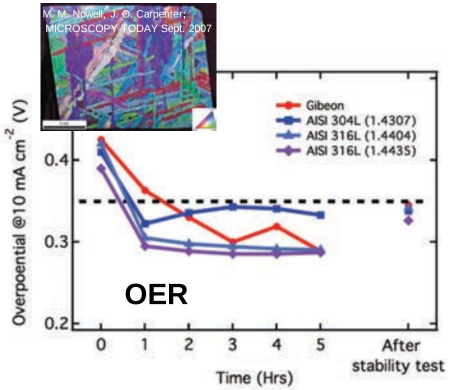
Short term (<10y)

H_2 Production RFB

- 10 kW/40 kWh all-vanadium RFB with hydrogen generation bypass developed from TRL 3 to TRL 6
- 1.8 kgH_2/day (17 hrs) 1.3 kg of H_2 proven

Green Chem., 2016, 18, 1785–1797

Hydrogen Production Alternatives to Pt/Ir



Medium term (10-15y)

Long term (>15y)

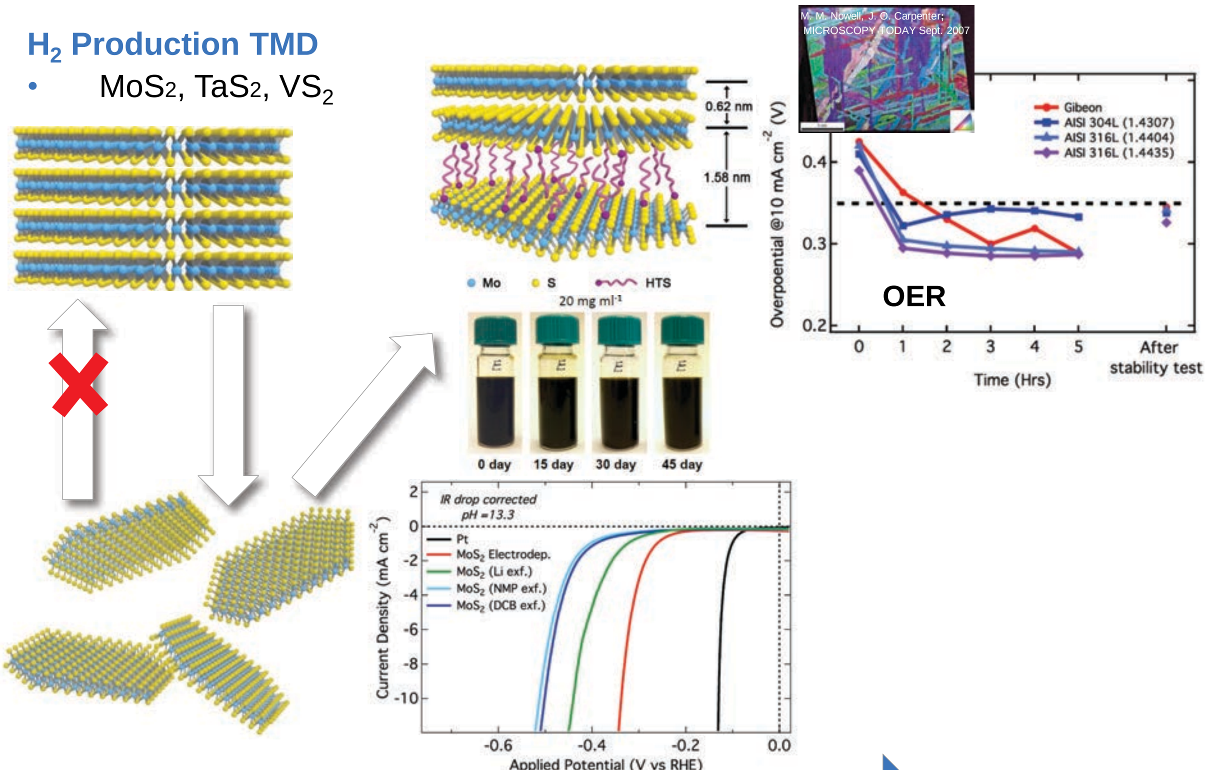
Xiaoyun Yu, Mathieu S. Prévot, Néstor Guijarro & Kevin Sivula Nature Communications 6, 01 July 2015

Results Phase I

Hydrogen Production Alternatives to Pt/Ir

H_2 Production TMD

- MoS2, TaS2, VS_2



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Hydrogen Production Alternatives to Pt/Ir

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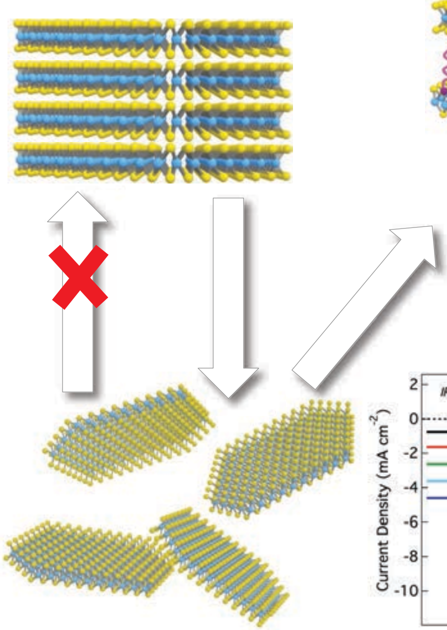
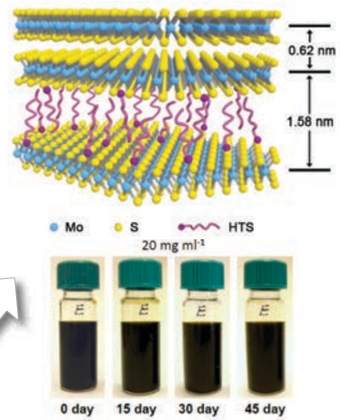
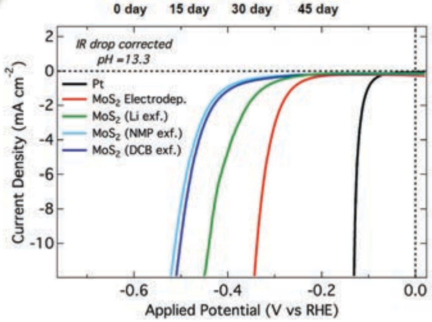
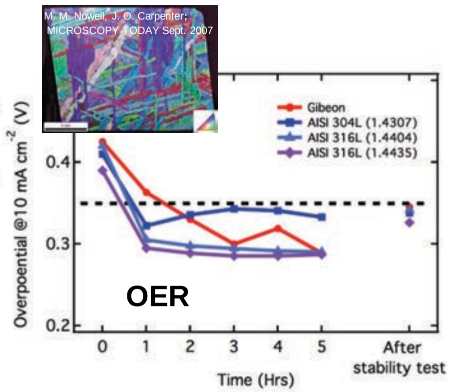
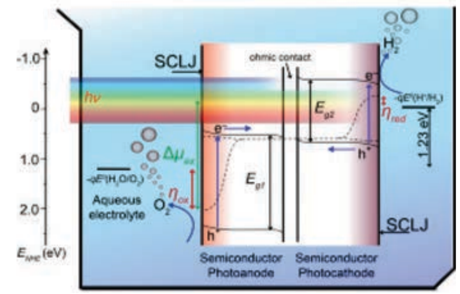
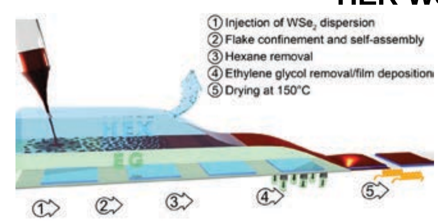


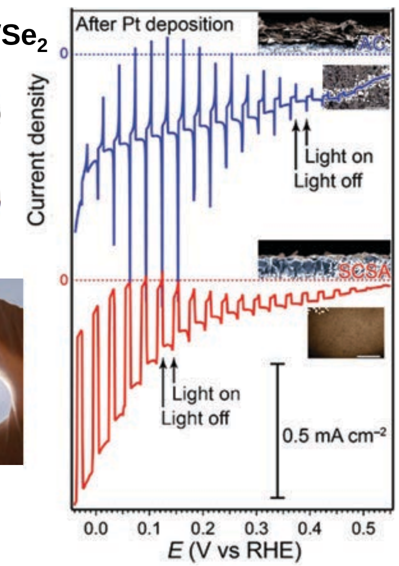










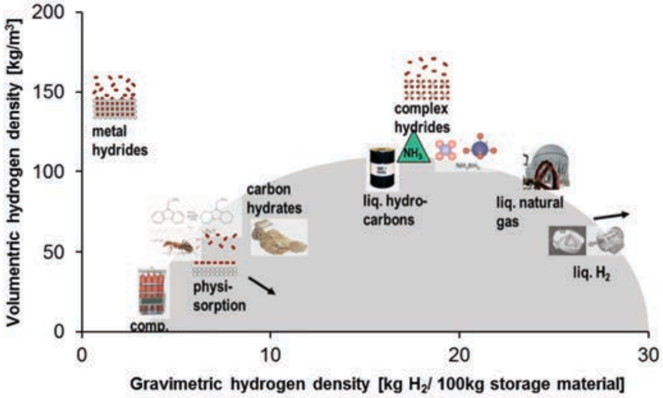


Medium term (10-15y)

Long term (>15y)

Xiaoyun Yu, Mathieu S. Prévot, Néstor Guijarro & Kevin Sivula Nature Communications 6, 01 July 2015

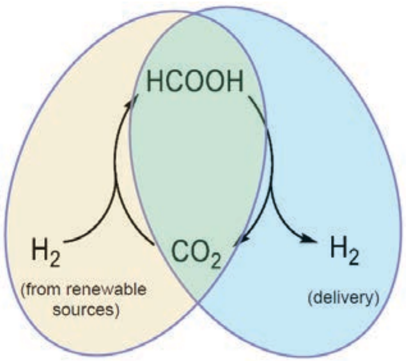
Hydrogen Storage

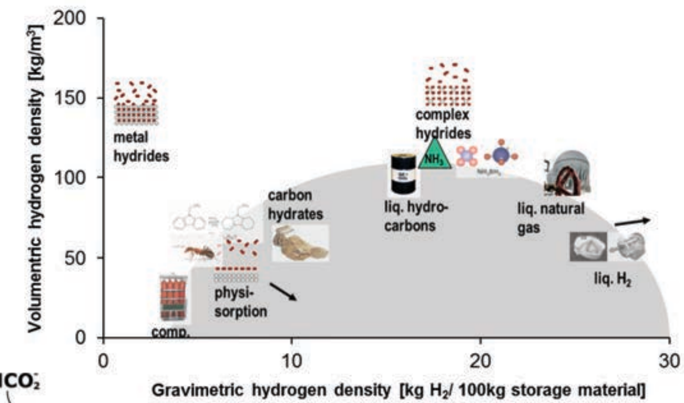


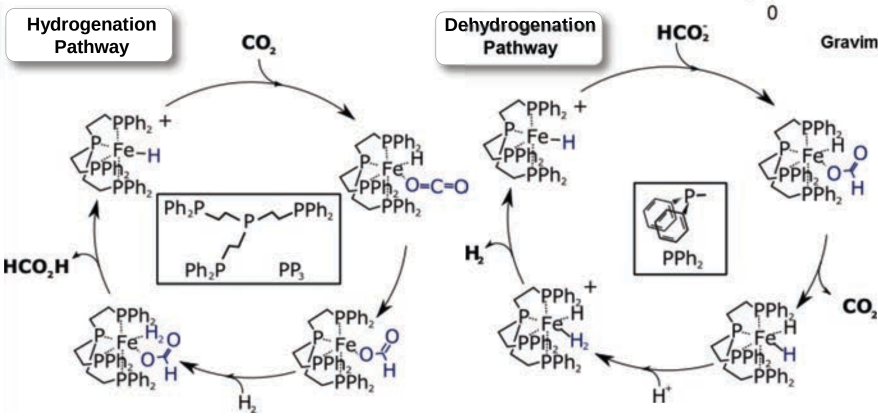
Medium term (10-15y)

Long term (>15y)

Hydrogen Storage







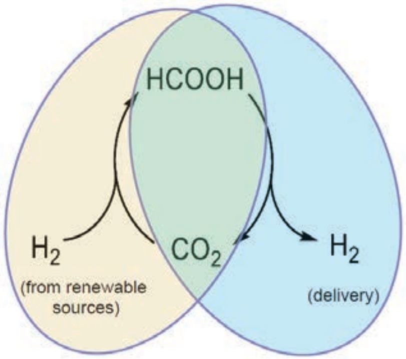
Medium term (10-15y)

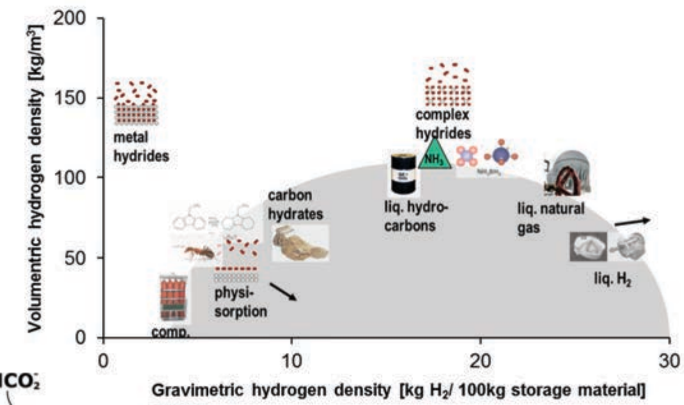
Long term (>15y)

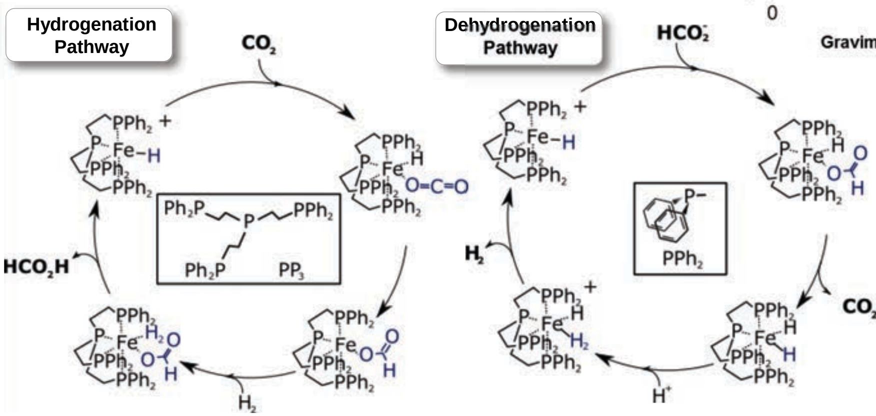
H_2 Storage Formic Acid

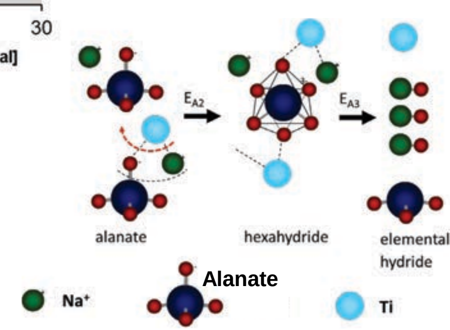
- abundant catalyst for formic acid dehydrogenation was identified to replace the Ruthenium

Hydrogen Storage









H_2 Storage Physisorbed NS

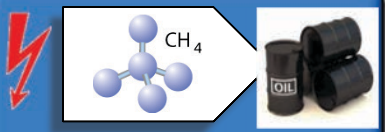
- Ti(BH4)3 incorporated into metal organic framework (stable)

Medium term (10-15y)

H_2 Storage Formic Acid

- abundant catalyst for formic acid dehydrogenation was identified to replace the Ruthenium

Long term (>15y)

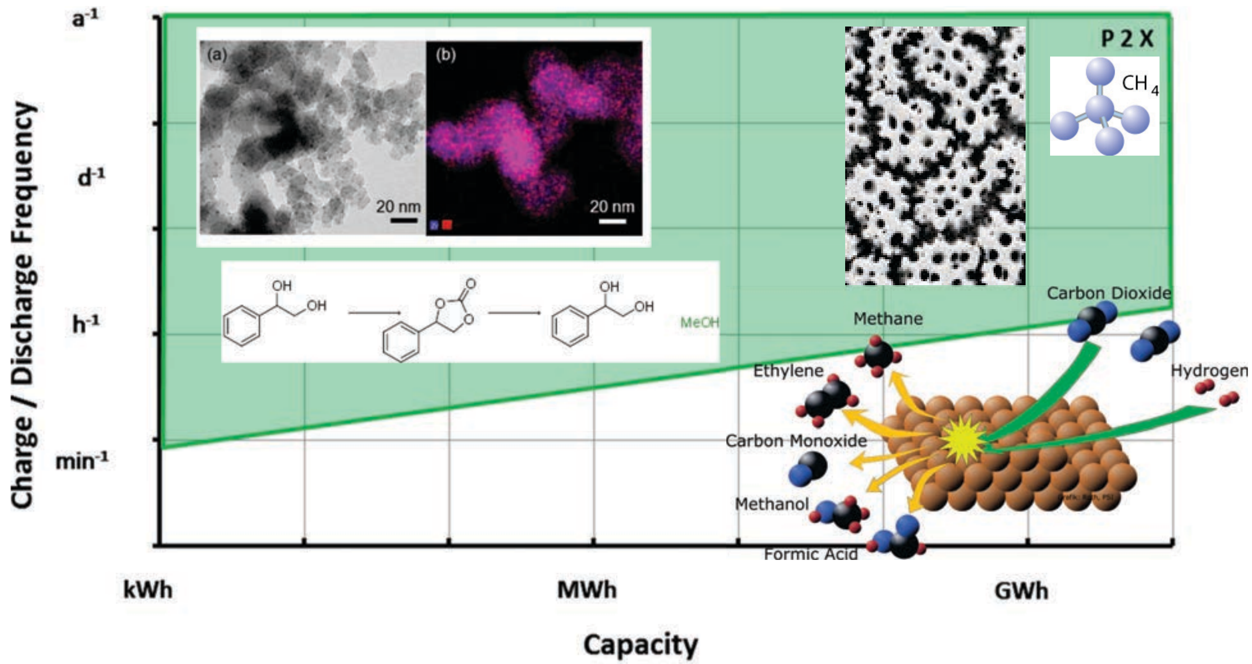


Catalytic & Electrocatalytic CO_2 Reduction

Dyson
Coperet
Broekmann
Schmidt

WP 4

Catalytic and Electrocatalytic CO_2 Reduction

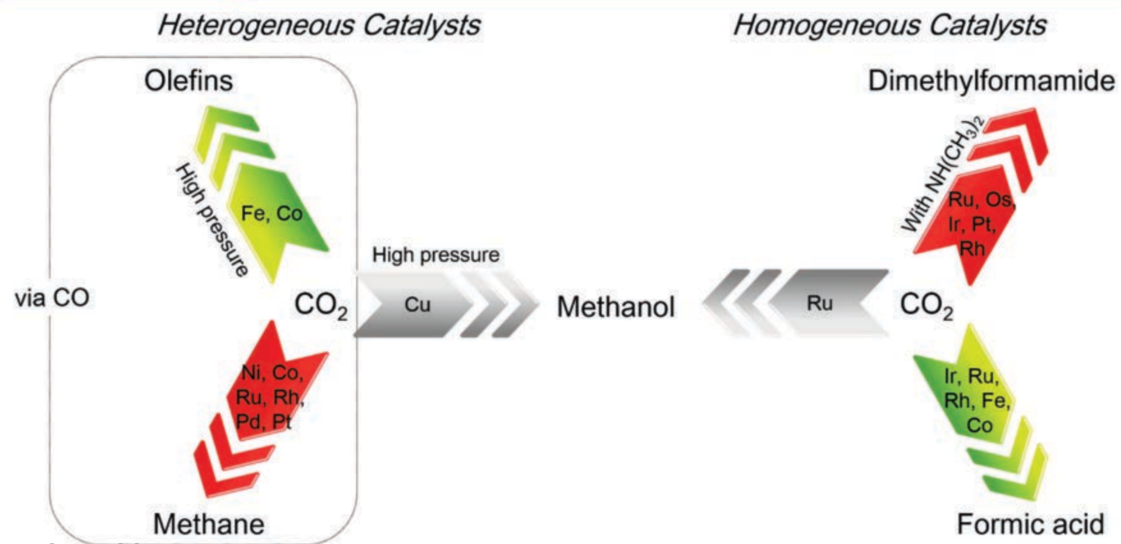


Medium term (10-15y)

Long term (>15y)

Storage
Swiss Competence Center for Energy Research

CO_2 Reduction – Economic View



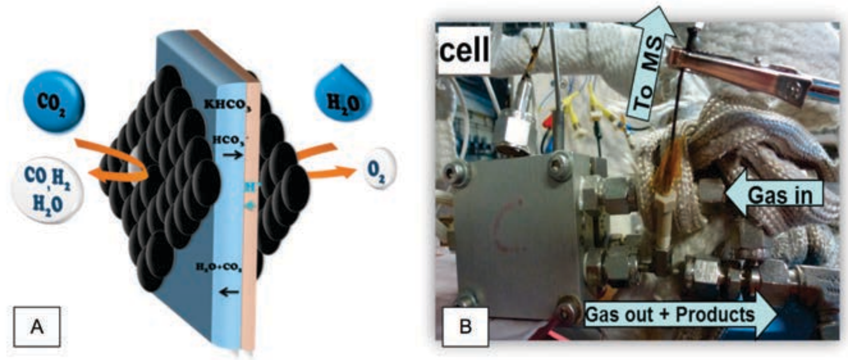
Product	Produced by	Current market price [$ kg^{-1}]	Current production volume [Mt y^{-1}]
H_2	steam reforming, partial oxidation of methane or gasification of coal	2-4	65
CH_4	methanogenesis or hydrogenation of CO_2	<0.08 (0.25)	2400
C_2H_4	pyrolysis or steamcracking	0.8-1.5	141
CO	Boudouard reaction	0.65	210000
$HCOO^-$ /HCOOH	hydrolysis from methyl formate and formamide or by-product of acetic acid production	0.8-1.2	0.8
CH_3OH	From natural gas, coal, biomass, waste	0.4-0.6	100[

J. Durst, A. Rudnev, A. Dutta, Y. Fu, J. Herranz, V. Kaliginedi, A. Kuzume, A. A. Permyakova, Y. Paratcha, P. Broekmann, T. J. Schmidt, CHIMIA 2015, VOLUME 69, NUMBER 12/15, Pages 769 ff

Results Phase I

H2 Storage
Swiss Competence Center
for Energy Research

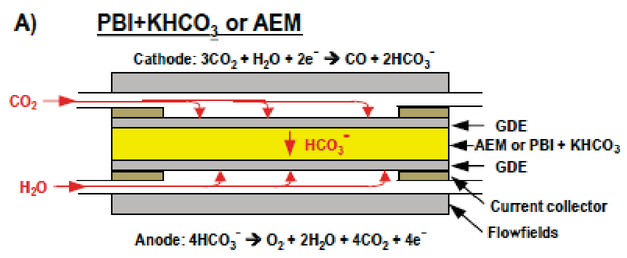
Electro-Catalytic CO_2 Reduction

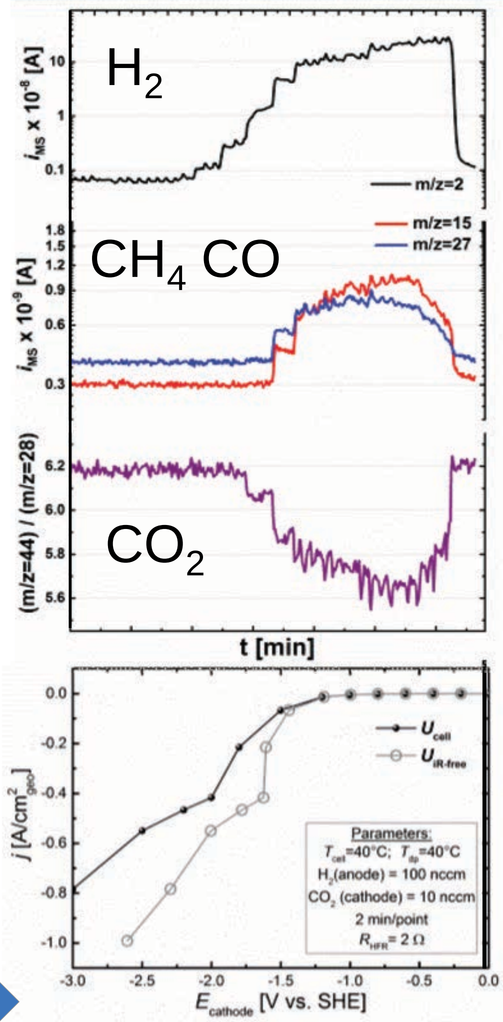


Product	Produced by	Current market price [$ kg^{-1}]	Production price by electrolysis [$ kg^{-1}]
H_2	steam reforming, partial oxidation of methane or gasification of coal	2-4	4
CH_4	methanogenesis or hydrogenation of CO_2	<0.08 (0.25)	2-4
C_2H_4	pyrolysis or steamcracking	0.8-1.5	1.6-3.2
CO	Boudouard reaction	0.65	0.27-0.54
$HCOO^-$ /HCOOH	hydrolysis from methyl formate and formamide or by-product of acetic acid production	0.8-1.2	0.17-0.34
CH_3OH	From natural gas, coal, biomass, waste	0.4-0.6	0.7-1.4

Long term (>15y)

Electro-Catalytic CO_2 Reduction

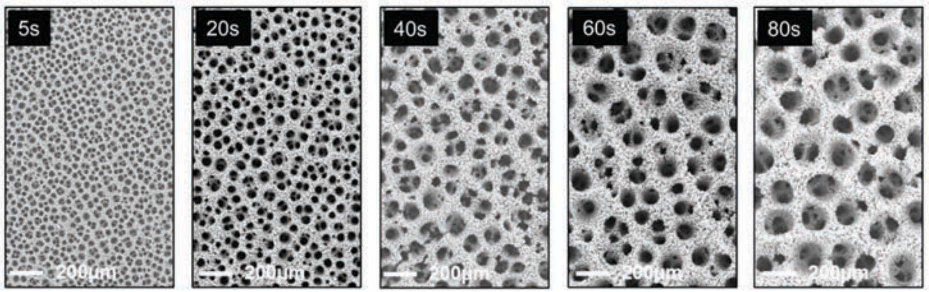


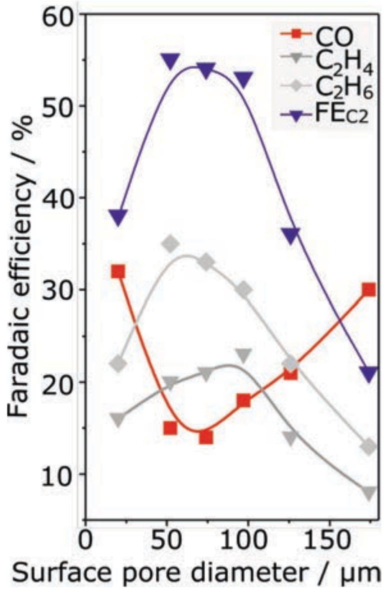


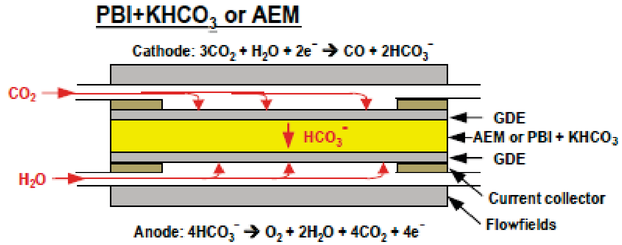
Long term (>15y)

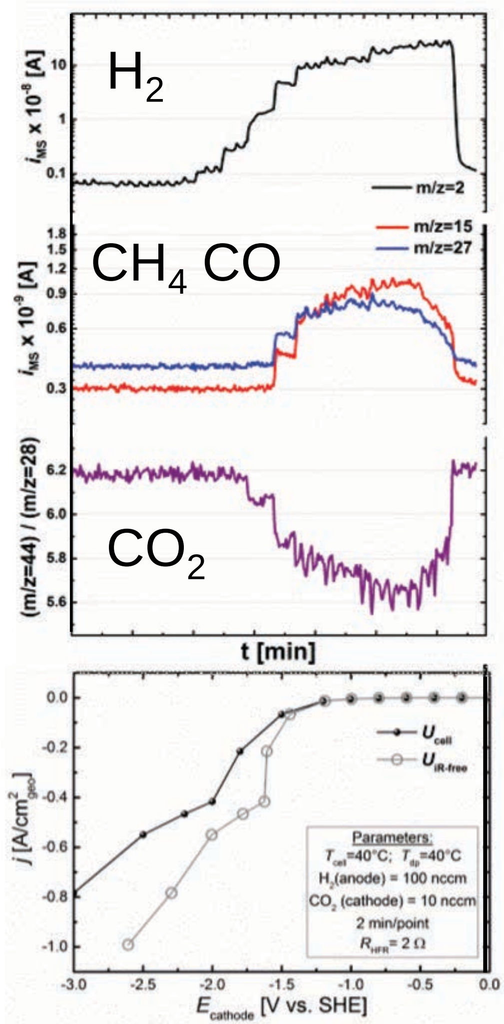
Storage
Swiss Competence Center for Energy Research

Electro-Catalytic CO_2 Reduction







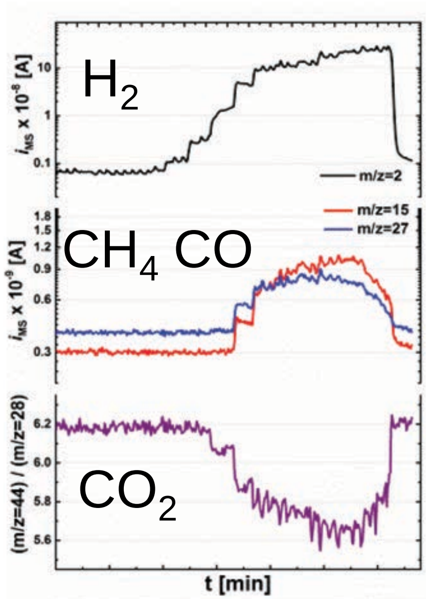


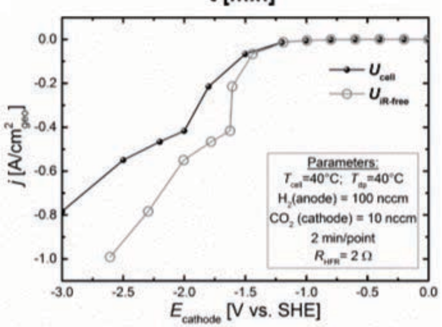
Long term (>15y)

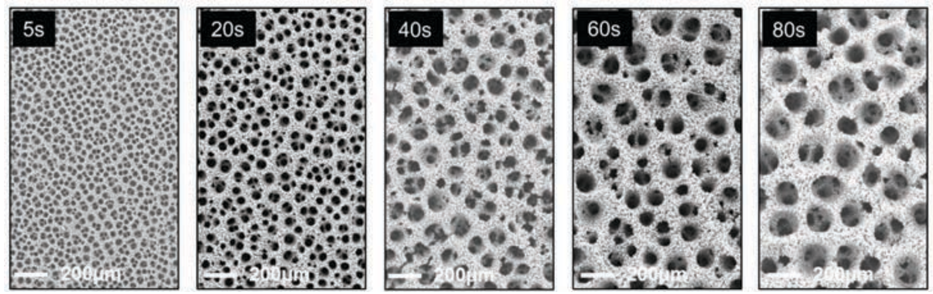
Results Phase I

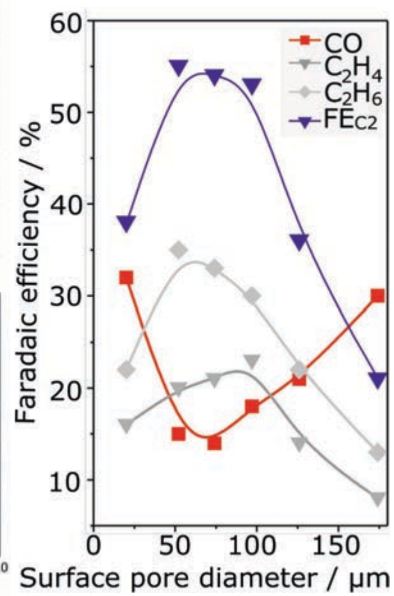
Storage
Swiss Competence Center
for Energy Research

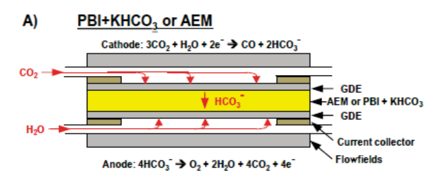
Electro-Catalytic CO_2 Reduction











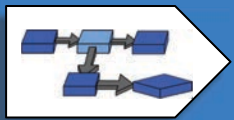
Electro-Catalytic CO_2

- Nano- and mesoporous electrocatalysts
- Sn: FE > 80 % formate
- Cu: FE > 45 % C2-product
- Selectivity and activity depend on morphology.
- Soluble, stable and electro catalytic active ionic liquid co-catalysts for CO production (FE for CO > 90 %).
- 1A/cm^2 for co-electrolysis cell level demonstrated

Long term (>15y)

Technology Assessment

H2 Storage
Swiss Competence Center for Energy Research

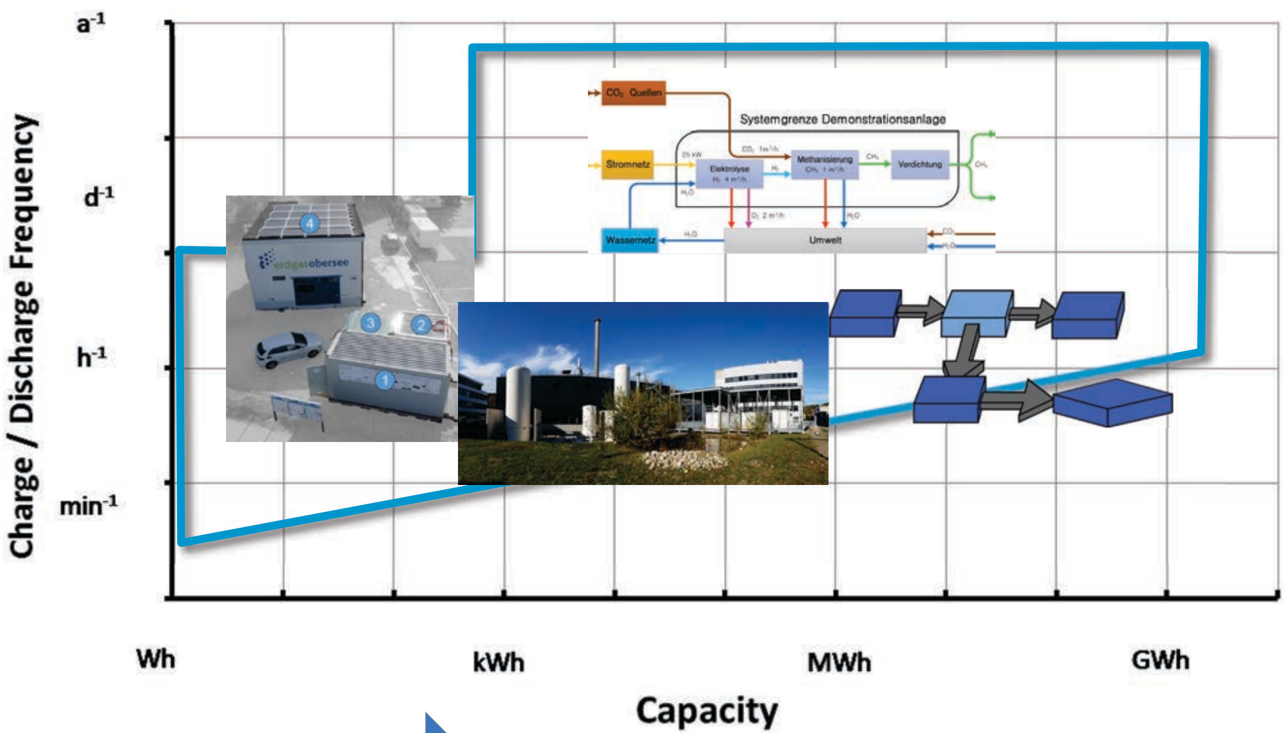


System Modeling

Worlitschek
Patel
Bauer
Friedl

WP 5

Assessment of Energy Storage



Component

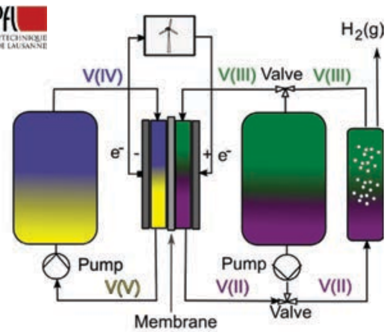
Energy System

Power to X Demostrators and Pilots

Storage
Swiss Competence Center
for Energy Research

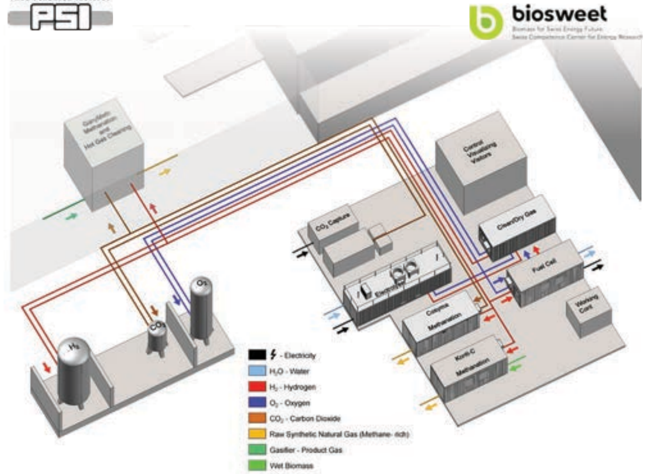
Power to Gas @ SCCER Hae

EPFL ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE

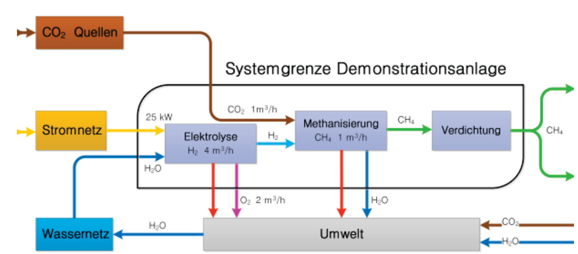


PAUL SCHERRER INSTITUT PSI

biosweet



HSR HOCHSCHULE FÜR TECHNIK RAPPERSWIL



H_2 Production RFB

- 1.8 kg H_2/day (17 hrs)
  1.3 kg of H_2 proven
- η: 50% (el.-> H_2)

Component

Power to Gas @ SCCER Hae: ESI

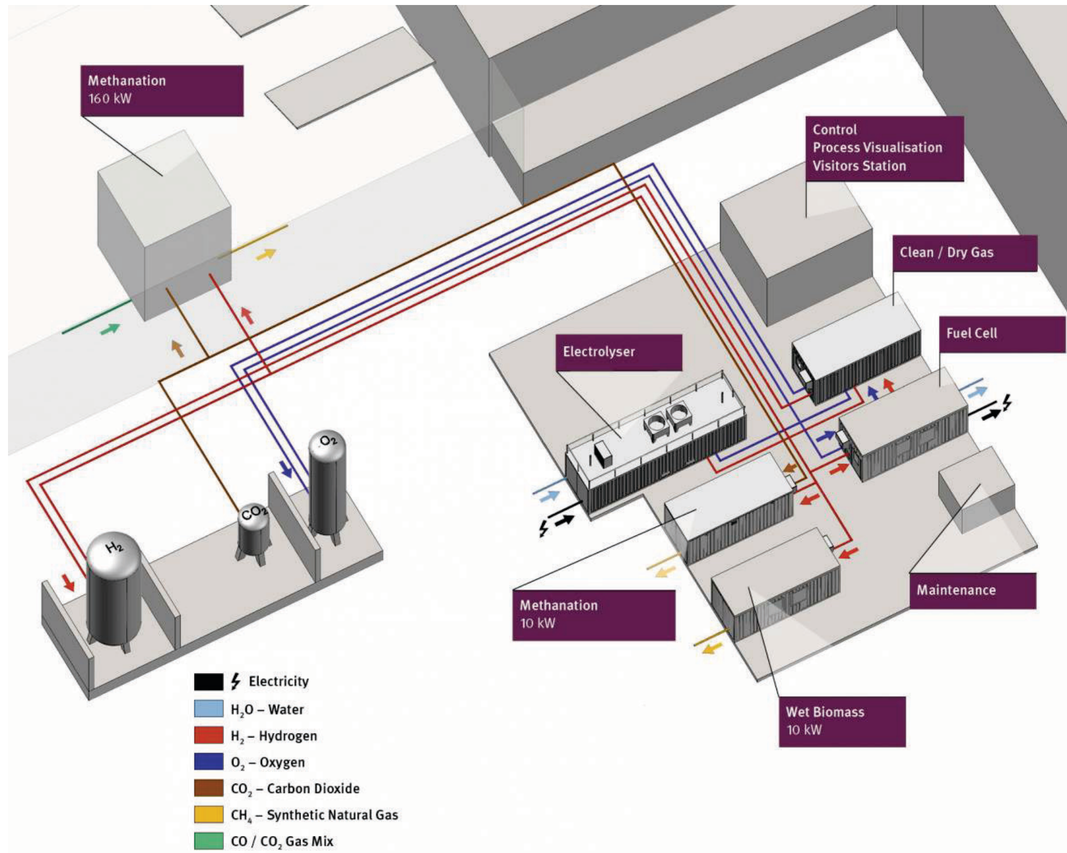
Energy System Integration Platform

- System Power ~10 kW -100 kW
- Exchangeable units
- Virtually linked with PV supply, and consumer (NEST, Mobility Demostrator)
- Currently under commissioning
- Start of operation Fall 2016

Research Question:

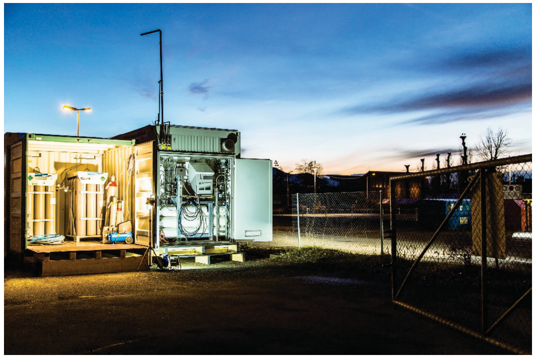
Understand the system interaction in terms of

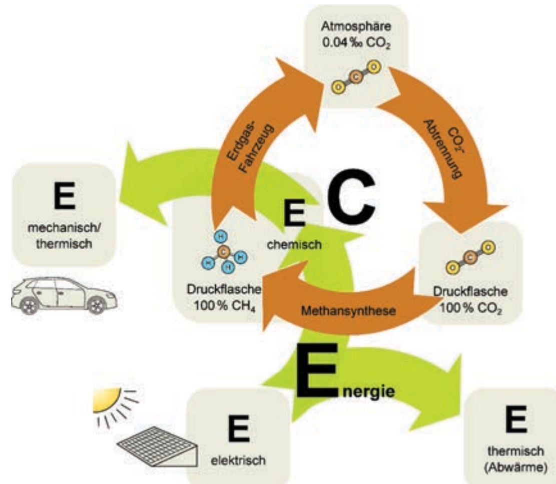
- Controls
- Dynamics
- Efficiency
- Economics



Component

Power to Gas @ SCCER Hae: Demonstrator at HSR





Technical Specification

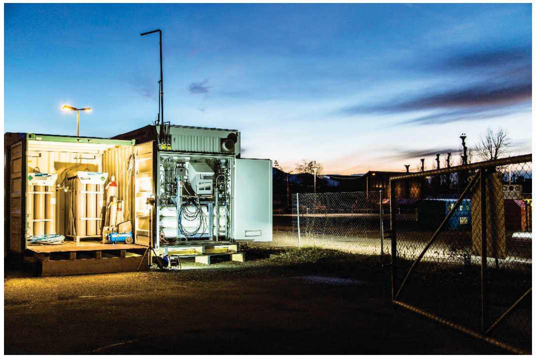
- Commercial components (Etogas, Climeworks)
- Power input: 31 kW (excl. CO_2 capt.)
- PV panels 7kWp
- CO_2 sources:
  - Bottles
  - Climeworks unit
  - Raw biogas (waste water treatment)
- Gas production 1m^3/h (92% CH_4, 3% H_2, 4% CO_2)
- Start of operation 01.01.2015

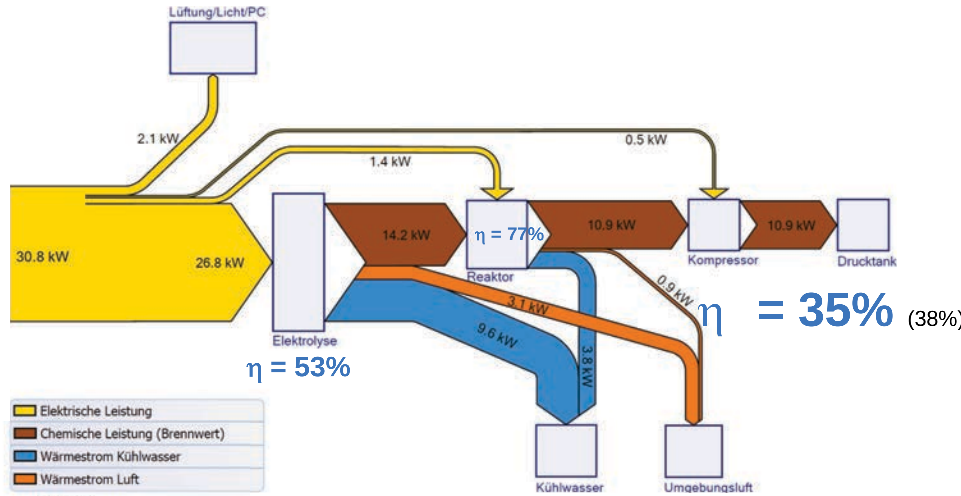
Energy System

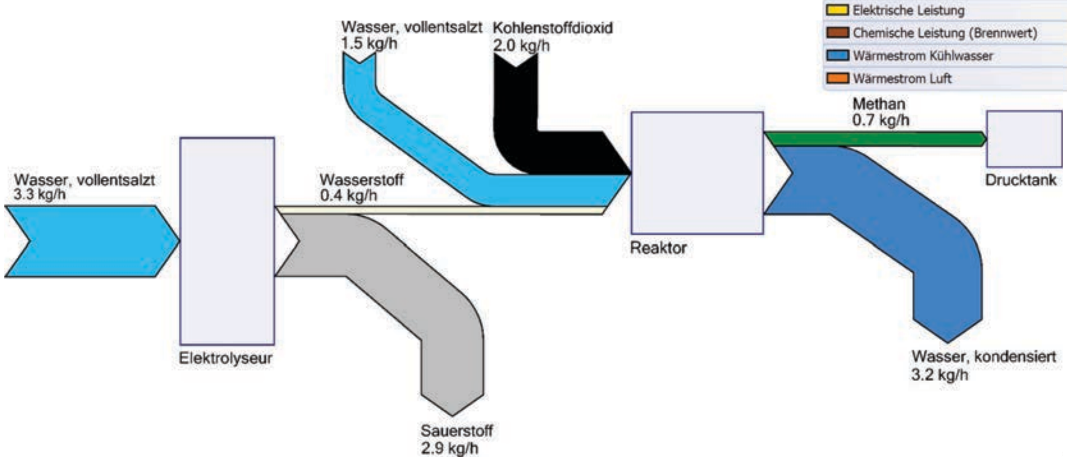
Power to X Demonstrators and Pilots

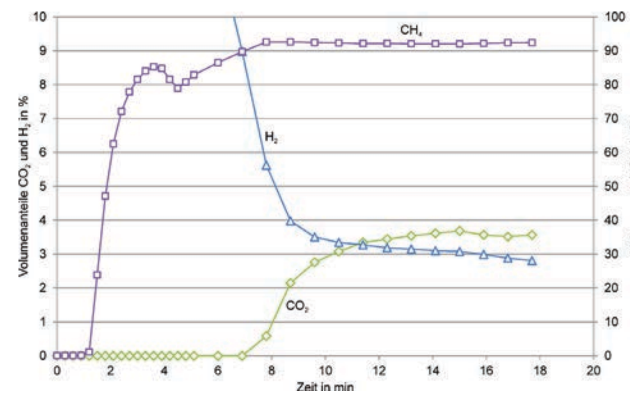
Storage
Swiss Competence Center for Energy Research

Power to Gas @ SCCER Hae: Demonstrator at HSR





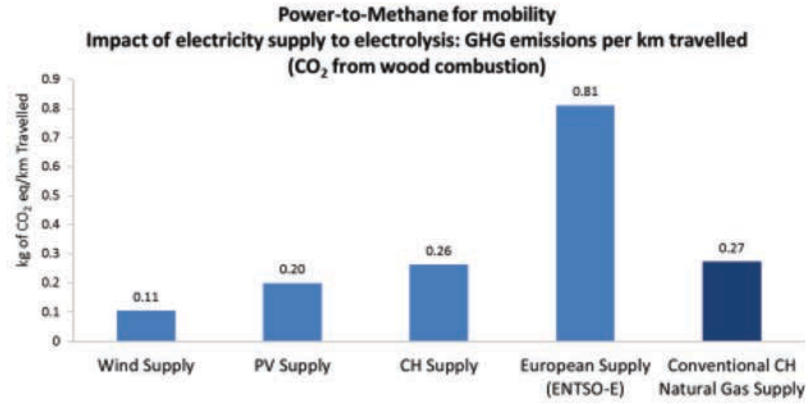


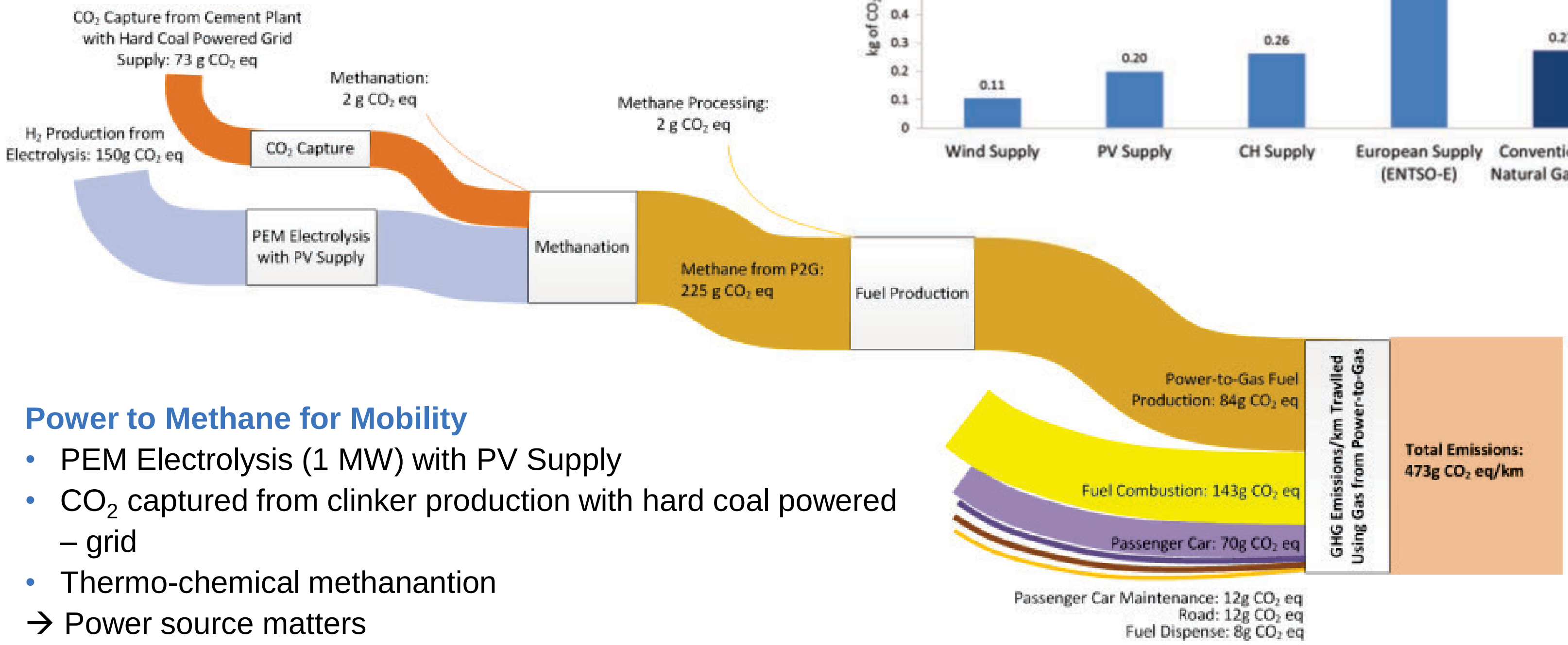


Energy System

H2 Storage
Swiss Competence Center for Energy Research

Power to Gas @ SCCER Hae: Ecologic Aspects



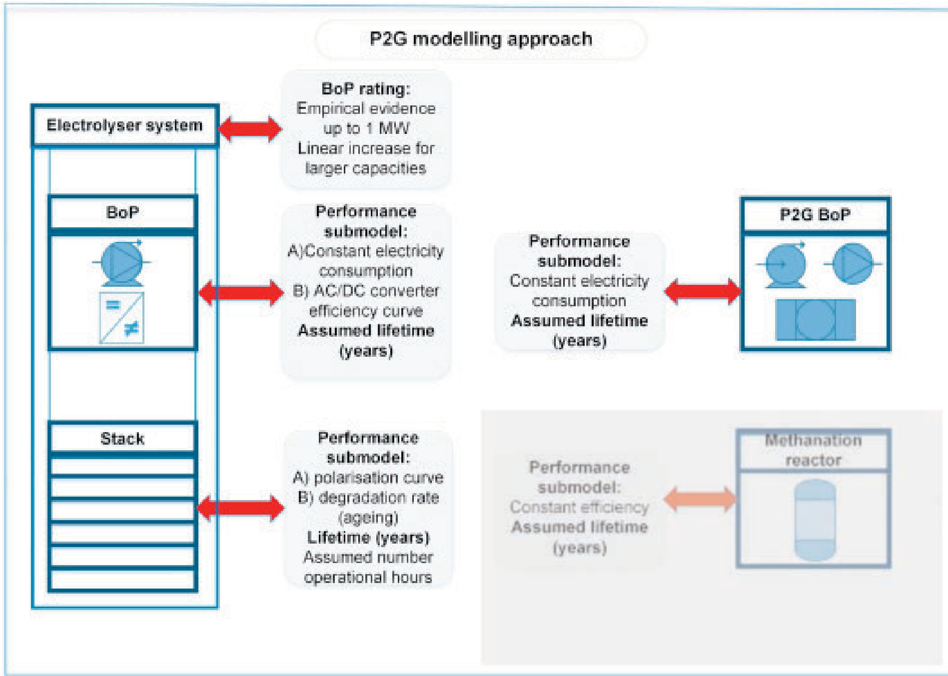


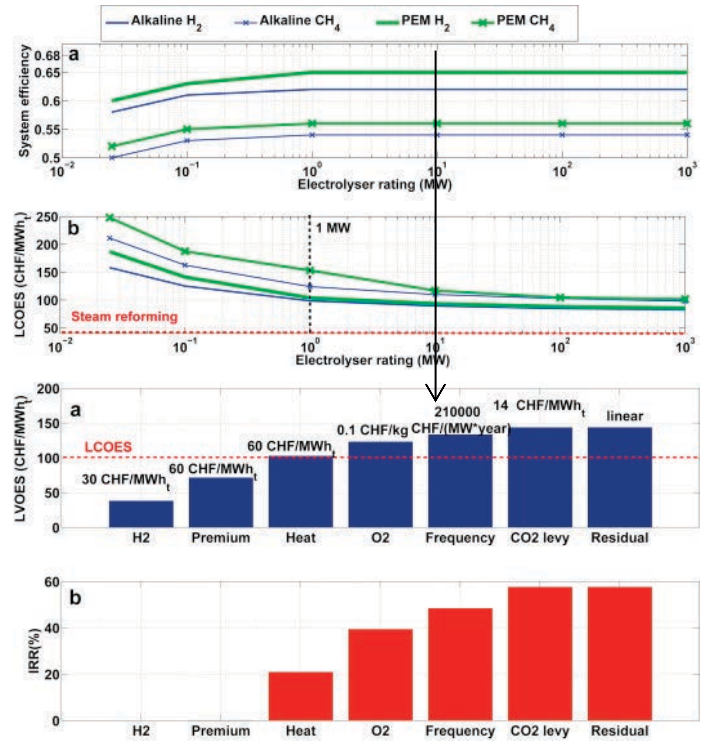
Power to Methane for Mobility

- PEM Electrolysis (1 MW) with PV Supply
- CO_2 captured from clinker production with hard coal powered – grid
- Thermo-chemical methanantion

→ Power source matters

Power to Gas @ SCCER Hae: Economic Aspects



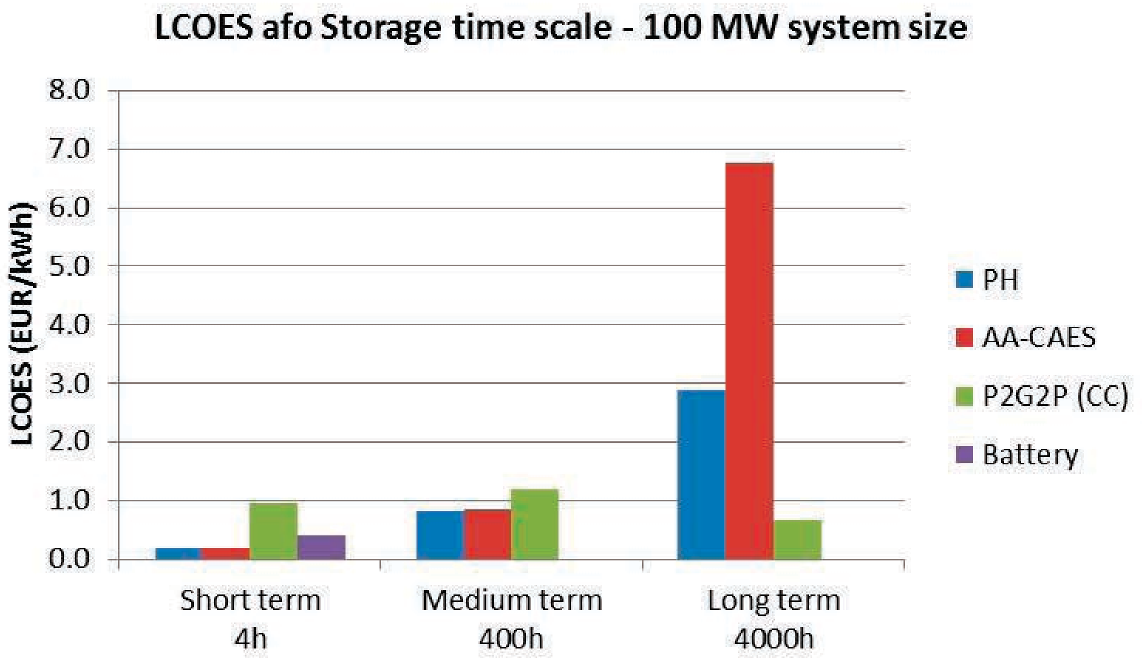


Alkaline versus PEM and Hydrogen versus Methane are compared for Power to Hydrogen

- Wholesale electricity market operation was optimised for each configuration.
- Alkaline electrolysers operated with 11% lower capacity factor than PEM systems.
- The levelised cost of PEM systems was 15% higher than alkaline systems.

D. Parra, M. Patel International Journal of Hydrogen Energy, *Volume 41, Issue 18*, *18 May 2016*, *Pages 7527-7528*

Technology Assessment Aspects



Energy storage on (inter-) national scale:

- Pumped hydro (PH) is most efficient and economic but almost completely utilized.
- Battery for short term OK (peak shaving, load shifting @ home).
- Good chance for AA-CAES
- P2X required for long-term storage transportation and chemical sector.

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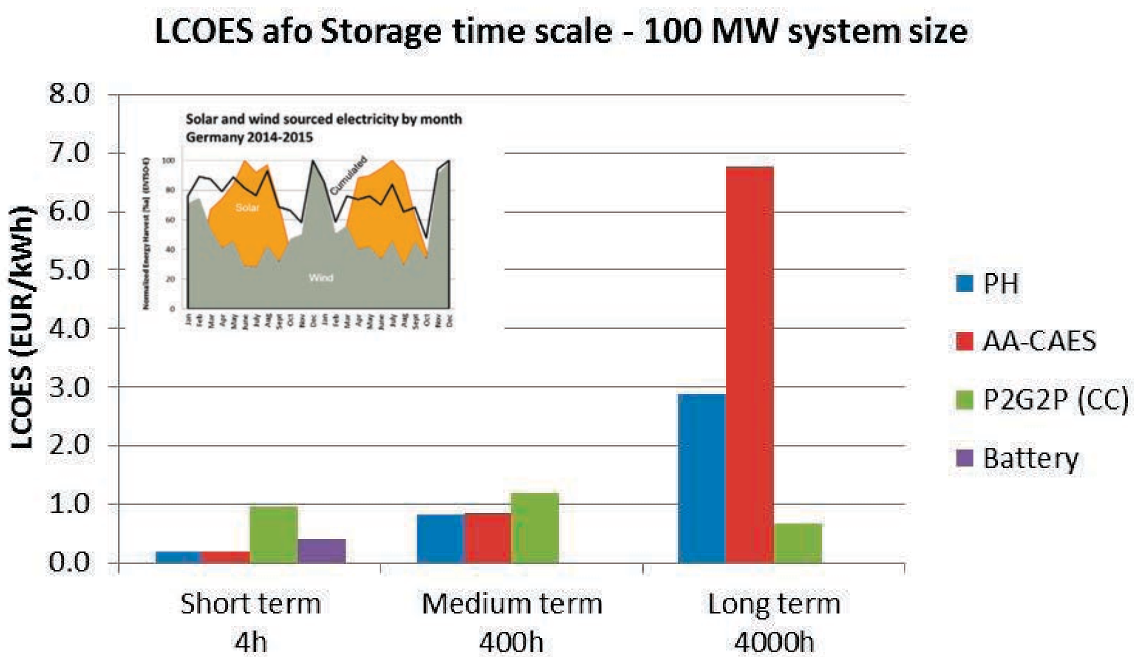
Technology Assessment Aspects



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→ Storage in the order of weeks (~400h) needed

IF Wind AND PV are sourced in a good way.

Storage
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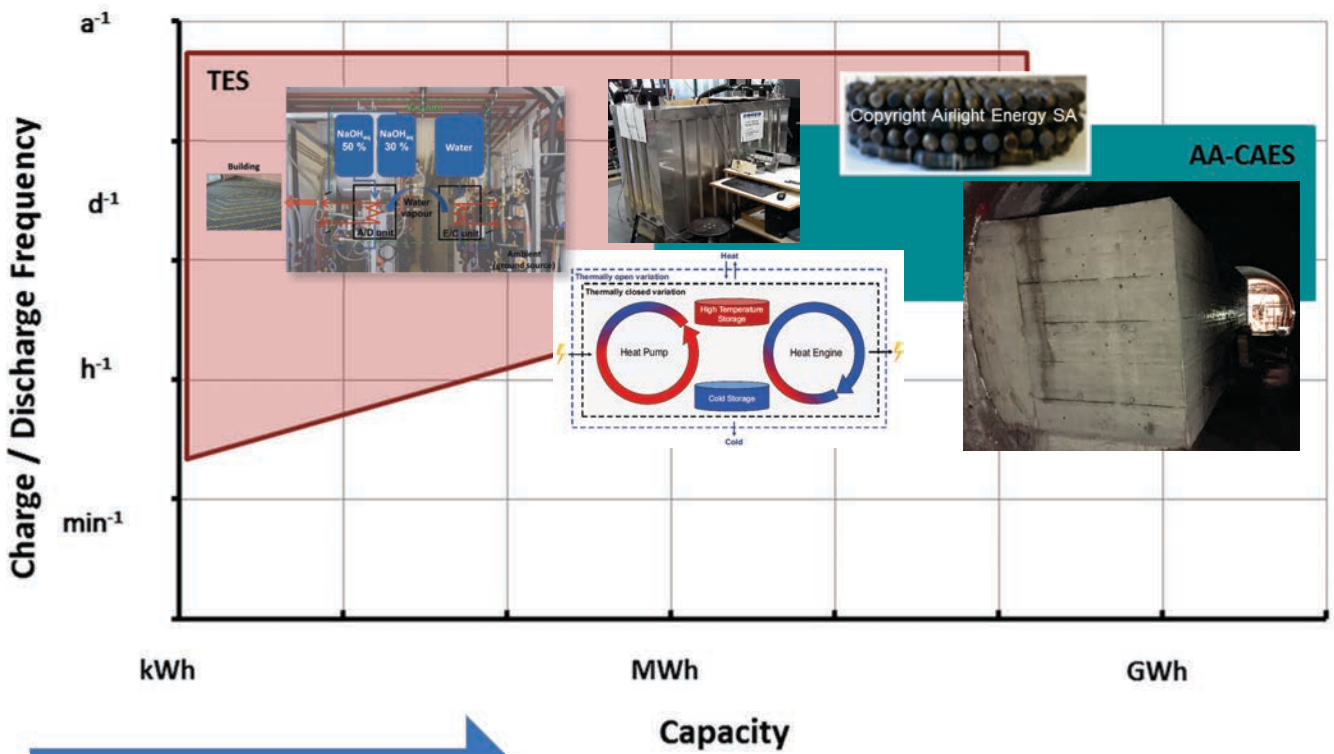
Storage of thermal energy

Haselbacher
Haussener
Barbato
Rommel
Roth
Ribi
Worlitschek

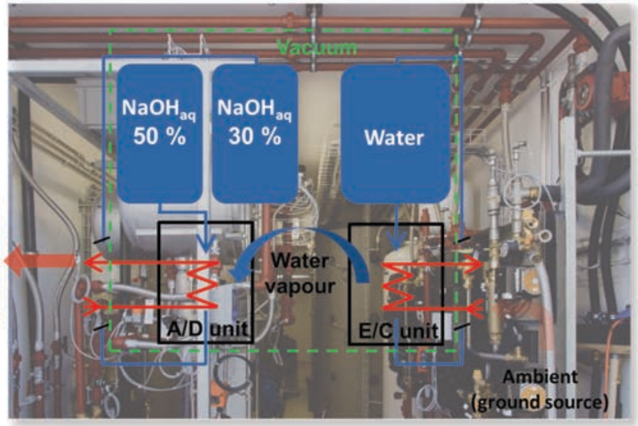
Thermal Energy Storage Systems

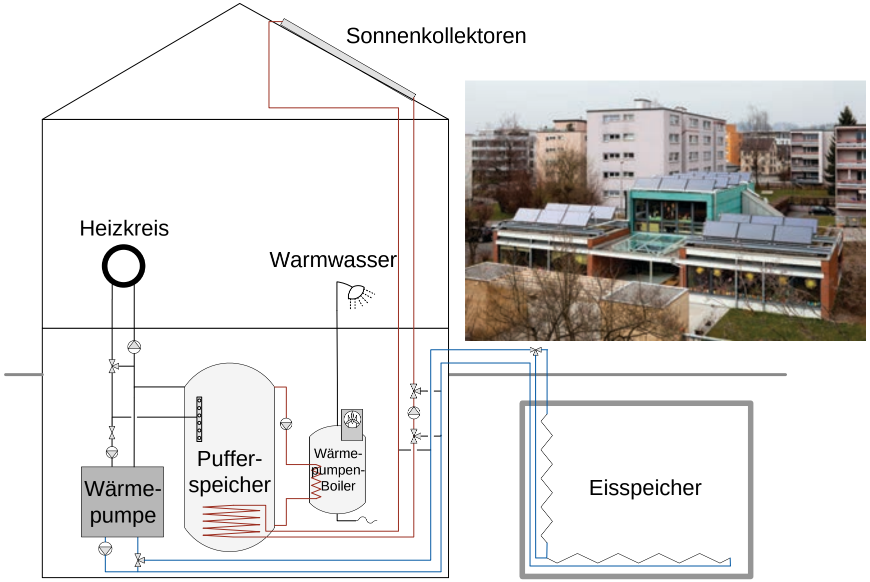


Short term (<10y)

Medium term (10-15y)

Residential, Seasonal, Thermal Energy Storage Systems





Seasonal storage, sorption based

- Prototype installed
- 250 kJ/m^3, η=0.6
- Absorption process has to be improved (low exchanged power; improve numerical model)

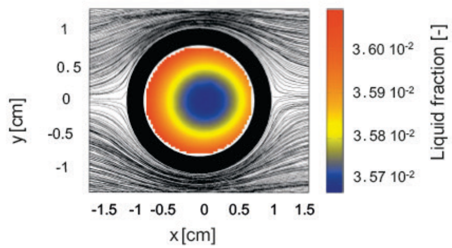
Seasonal storage, ice based

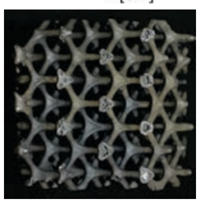
- Measured seasonal system performance figure JAZSys: 5.2

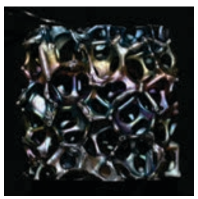
Short term (<10y)

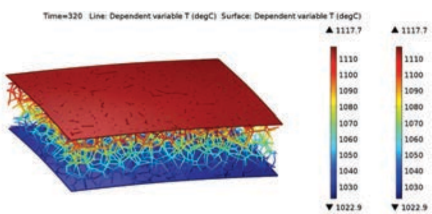
Results Phase I

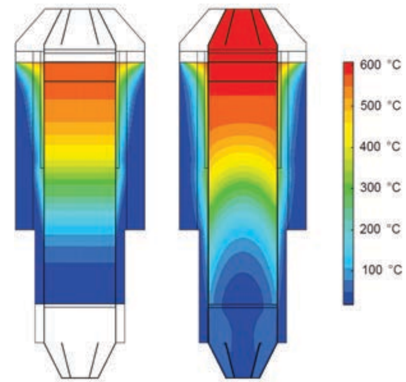
High Temperature, Industrial, Thermal Energy Storage

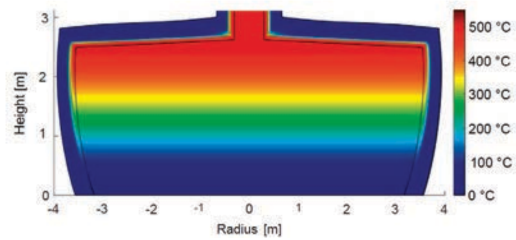


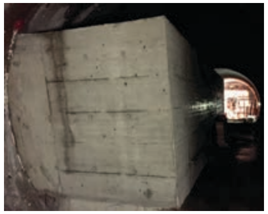












High temperature latent heat Storage

- First composite structures produced and tested for performance at the level of materials properties for Heat storage application
- 550 °C, 1.2 kJ/cm^3 (0.5J/Kg) $Al_{12}Si$
- 20 CHF/kWh_{th}

AA-CAES

- Simulations have demonstrated the validity of the combined sensible/latent storage concept
- Low storage material cost: 5-10 \$/kWh_{th}
- AA-CAES Pilot to be commissioned

Medium term (10-15y)

Energy Storage in a Nutshell

Heat storage is relevant and under investigation
- Seasonal low temperature
- Short term high temperature

Battery storage is investigated
- incrementally (Li ion) to get a more reliable product
- “disruptive” (Na ion) to get a more economic product for stationary application

Power to Hydrogen
- Alternative method (RFB)
- Precious metal free catalysts
- Storage options

Power to X
- Synthesis of hydrocarbons (Methane was found as not Ideal for economic reasons)
  - Catalytic
  - Electrocatalytic

Technology Assessment
- Tools are developed and will be further used.

  Result: Power to gas needs additional business options
  Good chance for AA-CAES
  P2X required for long-term storage transportation and chemical sector.

Mission, Status at End of Period I

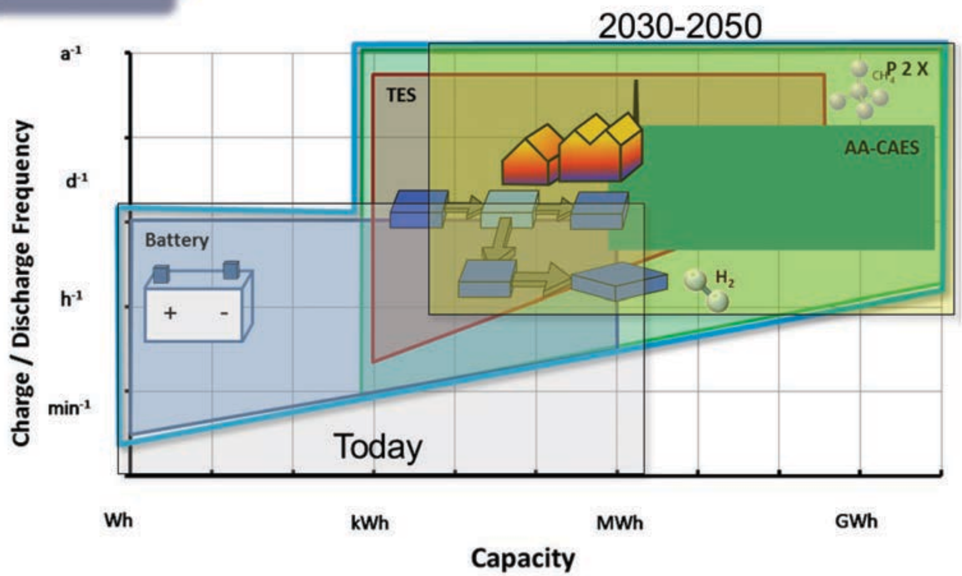
H2-Storage
Swiss Competence Center for Energy Research

Mission

Advancing research, development and technologies in the field of

- electricity and heat storage
- conversion and storage of energy in fuels
- overall technology interactions

by bridging activities from fundamentals to applications and the technology transfer in industrial environment

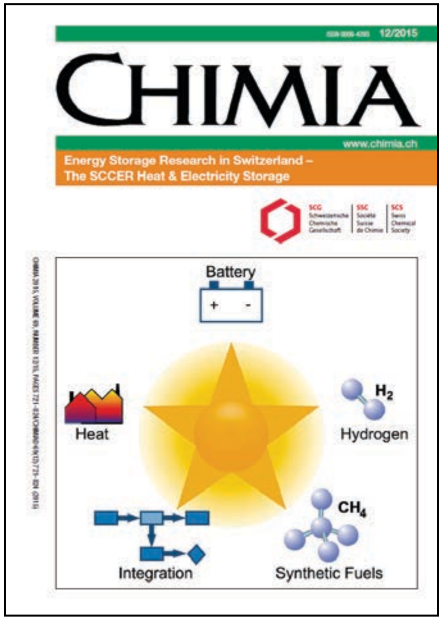


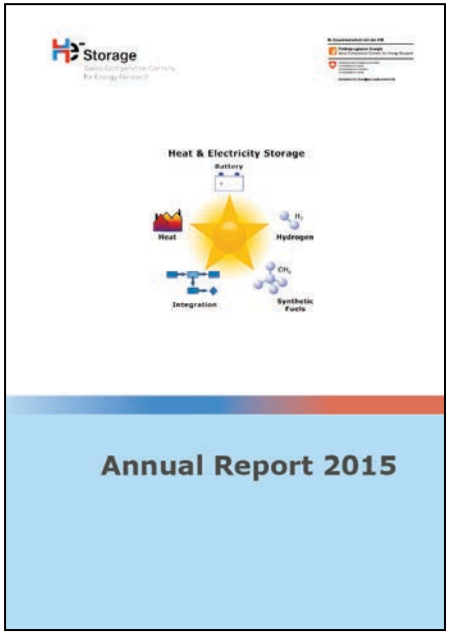
Observation

→ Technology and science are on track, business plans and legislation are not.

Quo Vadis Helvetia ?

Further reading and information





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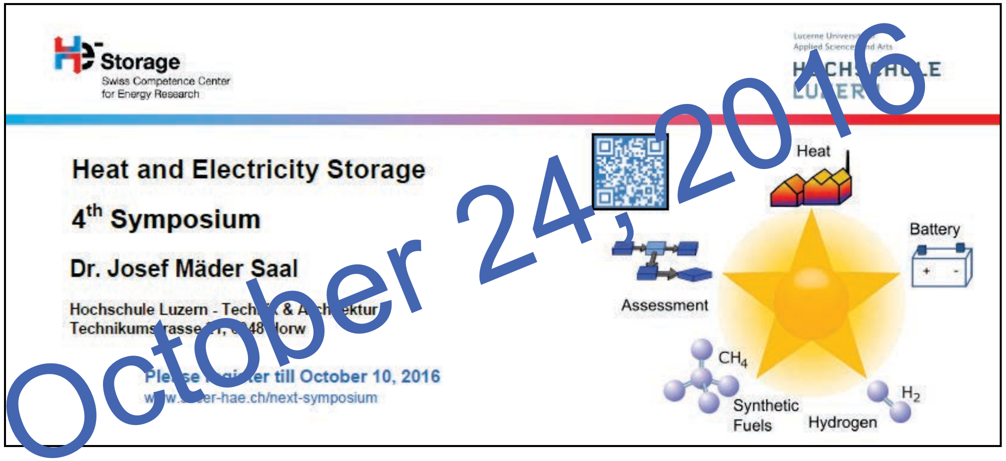

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H2-Storage

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Exen Sarl, HakaGerodur