MŰEGYETEM 1782

Energy Storage

3rd lecture

Chemical Storage (P2X, P2F, P2H, P2M & other funny ones)

(http://energia.bme.hu/~imreattila/Energystorage2022/)

Back to the batteries

Nickel hydride batteries:

Hydrogen forms on the negative side, but not as gas. Atoms can diffund to the metal. Therefore the metal has to be some compound, good for interstitial hydrogen storage, like AB5 (from nickel, cobalt, mangane, aluminum, lantane, prazeidymium, neodymium) or AB2 alloys (zirconium, vanadium, mangane, titane).

Example (AB5) $LaNi_{3.55}Mn_{0.4}Al_{0.3}Co_{0.4}Fe_{0.35}$

AB5: A is a rare-earth mixture of lanthanum, cerium, neodymium, praseodymium, and B is nickel, cobalt, iron, manganese, or aluminium.

AB2: A is titanium or vanadium, and B is zirconium or nickel, modified with chromium, cobalt, iron, or manganese

Chemical Storage

Transformation of a material (fuel1, pre-fuel) to an other material (fuel2) using electricity. The new material (fuel2) can be used later/elsewhere to produce electricity. Fuel2 has to be:

- better fuel than fue1 (for example higher energy density)
- and/or can be stored easier
- and/or can be transported easier
- And/or can be used to produce electricity with less difficulties / higher efficiency

(unofficial definitions!)

Chemical Storage

In this way, even making some high-quality fuel from biomass (biodiesel from corn stalk or charcoal from wood) could be considered as energy storage, if (and only of) part of the energy used for the transformation (E_{in}) is electrical one.

It is important, that sometimes the original material (fuel1) can also be used as fuel or to produce electricity. Sometimes the energy content (not the energy density) for fuel2 can be smaller than fuel1, due to the high mass of fuel1 (corn stalk) and low mass of fuel2 (biodiesel). In that case, "storage" seems to be meaningless, because E_{in} would be totally lost. These processes are often referred as fuel refinery processes.

P2X – Power to Everything

Power to Everything: common name for all technologies, starting from simple materials (water, air, CO_2), using electricity and producing "everything" (useful products). With sufficient amount of energy, one can produce polystyrene from water and CO_2; and the polystyrene can be used to produce slippers….

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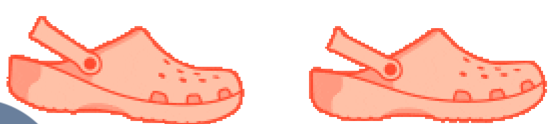

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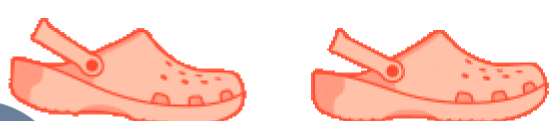
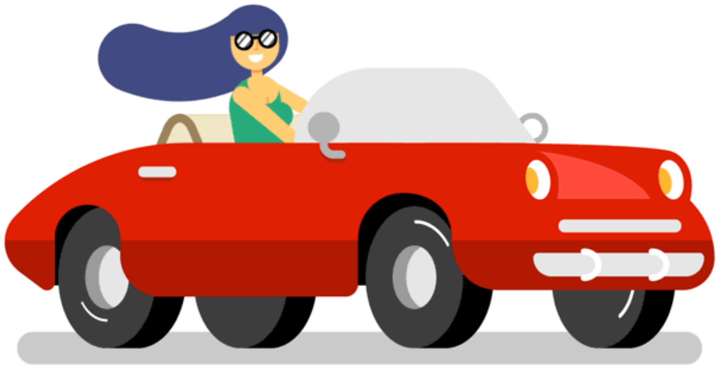
…or coffee-mug…



….or even….



….some fancy fuel

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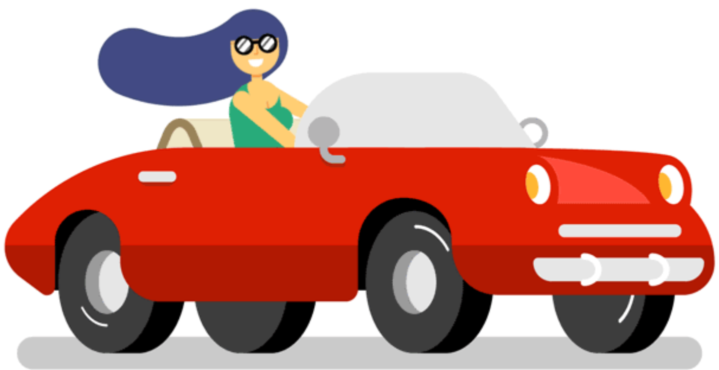


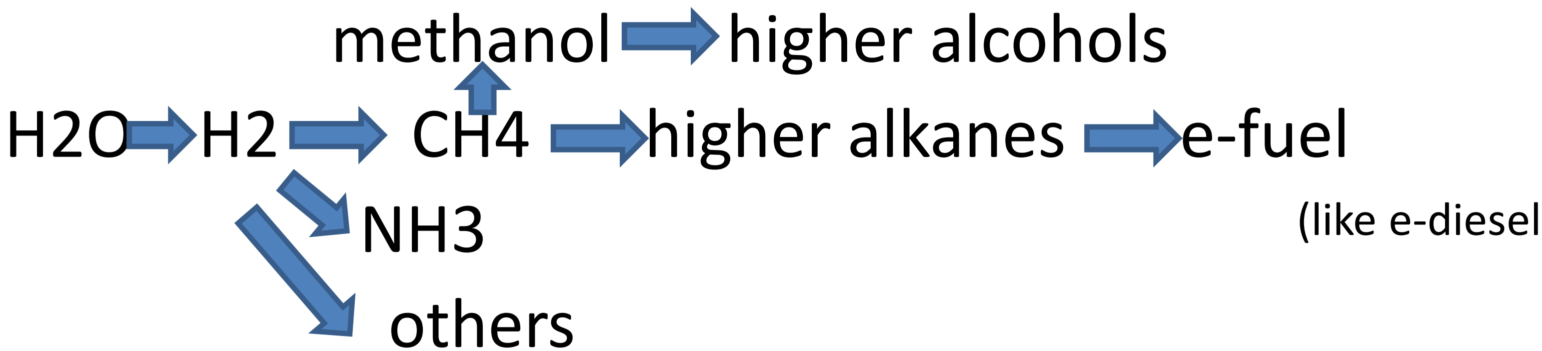
….some fancy fuel → P2F (Power to Fuel)

(with very low efficiency)

Power to Fuel (P2F)

In P2F energy storage technologies, where the initial material is usually water (sometimes with some added materials, like CO2 or air), using electricity (and usually catalysts, microorganisms) to produce some fuel (so, here the initial material is not fuel1, just material1). The product can be used in transportation or to recover the electricity later/elsewhere.

Power to Fuel (P2F)



Going further provides a better storable, easier usable fuel, but the storage efficiency will go down with each step. Optimization! Recently the optimum would be somewhere between H_2 and CH_4.

P2F – main groups

P2H …. Power to Hydrogen

P2M… Power to Methane

P2G … Power to Gas

P2L … Power to Liquid (various liquid fuels, like e-diesel, e-kerosene or alcohols)

P2H

First step is always the production of hydrogen. There are various ways, but water electrolysis seems to be the greenest:

$$2H_2O \rightarrow 2H_2 + O_2$$

The electrolysis can be

- Alkaline electrolysis (modest price, slightly lower efficiency, need at least 30 minutes for "warming up" and produce H2, therefore permanent use preferred with constant power – not too good for PV downregulation. Runs on 80-90 Celsius.
- PEM (membrane) electrolysis (higher price, higher efficiency for the state-of-art models, runs on 60-70 Celsius, can be used for down regulation; built in various sizes, even reaching MW-scale).
- High temperature ones: very expensive, can be used only in permanent mode

P2H

An other way to produce H2 from water is the thermal break; needs temperature above 1000 Celsius (nuclear power plants of electrical plasmalysis). The NPP-one is not considered as energy storage, although one can define an electricity equivalent for the heat used for the process.

For NPP-based H2 production: lets make some flammable gas in a nuclear power plant, surely it will work safely…

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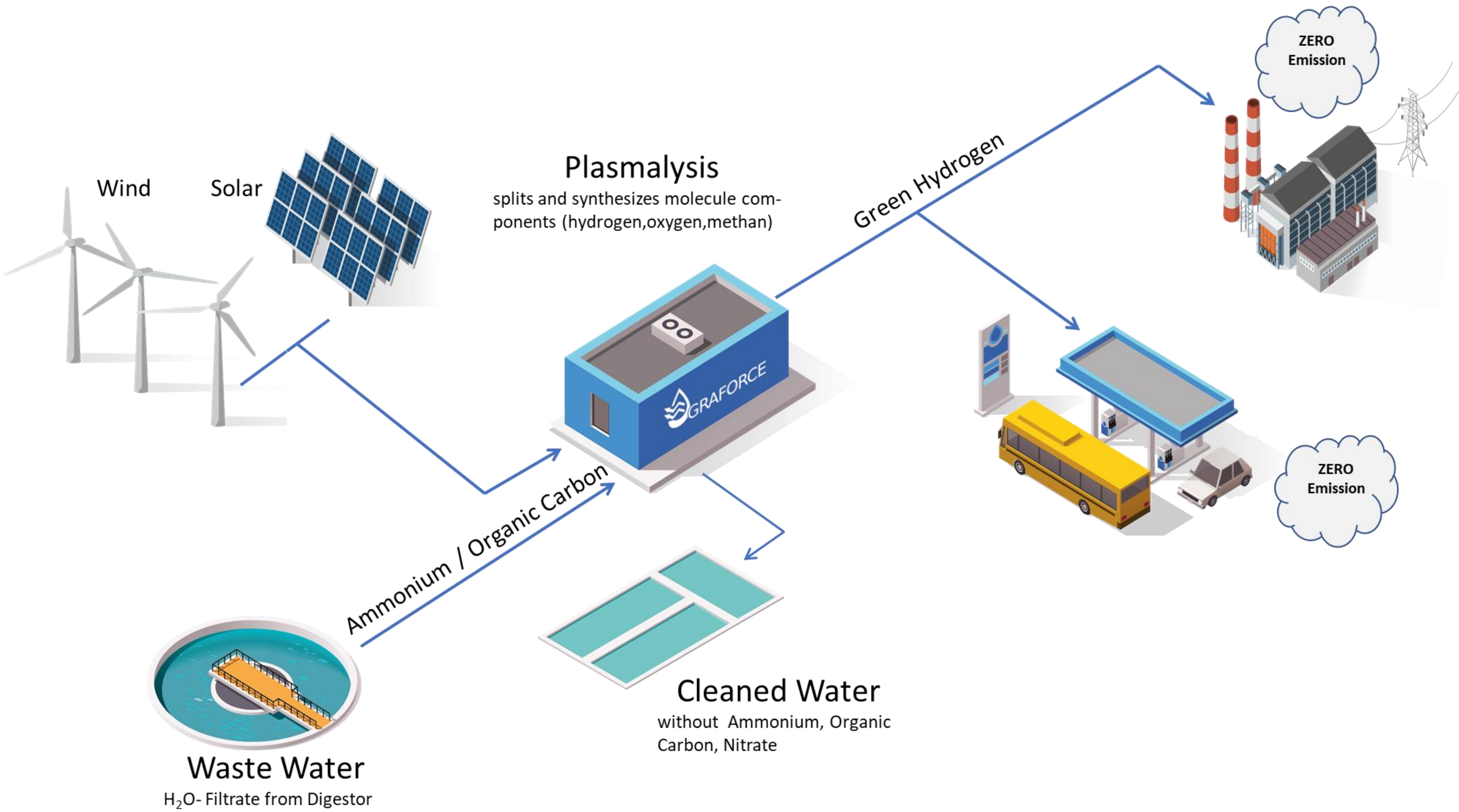
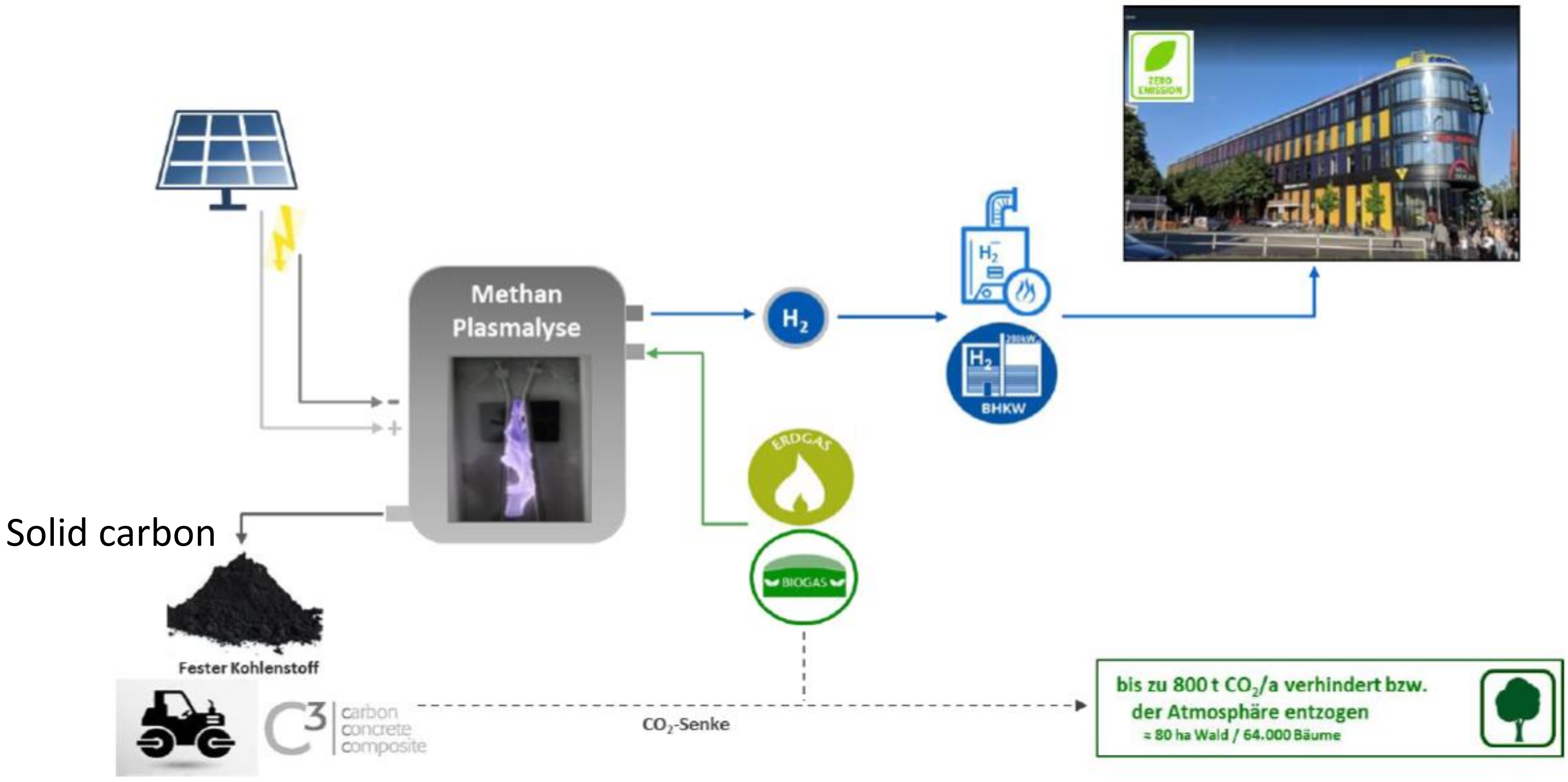
P2H

- Plasmalysis: production of hot plasma by electricity. Can be used for H2 production, when applied on a H-containing material. Presently used with biomethane (not with water); needs 5-times less electricity (10 kWh/1kg H2) than for water electrolysis. Problem: need to find proper amount of biomethane first…. Oh, if I already have biomethane, why do not use that directly (it is also net carbon-free)

Plasmalysis



Plasmalysis



Mercure Hotel MOA Berlin
Needs 138 kWh electricity and 60 Nm3/h biogas,
Produces 30 kg carbon/hour, 30 kWh waste heat
and 115 Nm3/h hydrogen .

Carbon-negative, -800 t CO2/year (equivalent for planting 64 000 tree)

P2H pros and contras

- One step process, depending on the method to produce hydrogen and recover electricity, it might reach 30-70% power-to-power efficiency
- No pollution or even CO2 emission during usage (although it might be some of them during H2 production).
- With PEM electrolyzer, it can be an effective tool for down-regulation (€€€ !!!)
- H2 can be mixed, stored and used with natural gas (CH4) (up to 20 v%); but be aware for the trickiness of v%!
- Can be used as fuel in transportation.

P2H pros and contras

- Needs pure water! Water purification is costly and (presently) cannot use salty water.
- Extra use of water can be problem is several countries (Sudan/Egypt, Syria/Israel, etc.).
- Needs special equipment for power recovery (fuel cell).
- Hydrogen combustion requires tricky solutions (flame shape, temperature…)
- Can be stored as high pressure or liquefied gas, but costs are high. Future: underground storage or chemical storage.
- Storage is difficulty, H2 leaks everywhere!

Storage

- High pressure tanks (leaking and embrittlement).
- Liquefied form (needs permanent cooling; it requires a lot of energy or a lot of evaporated hydrogen).
- Mixed to natural gas (presently can be done up to 20v%; above that, the use of mixture is difficult; others problem, like leaking, layering).
- Chemically bounded form (several technologies, usually the loss of energy is too high).

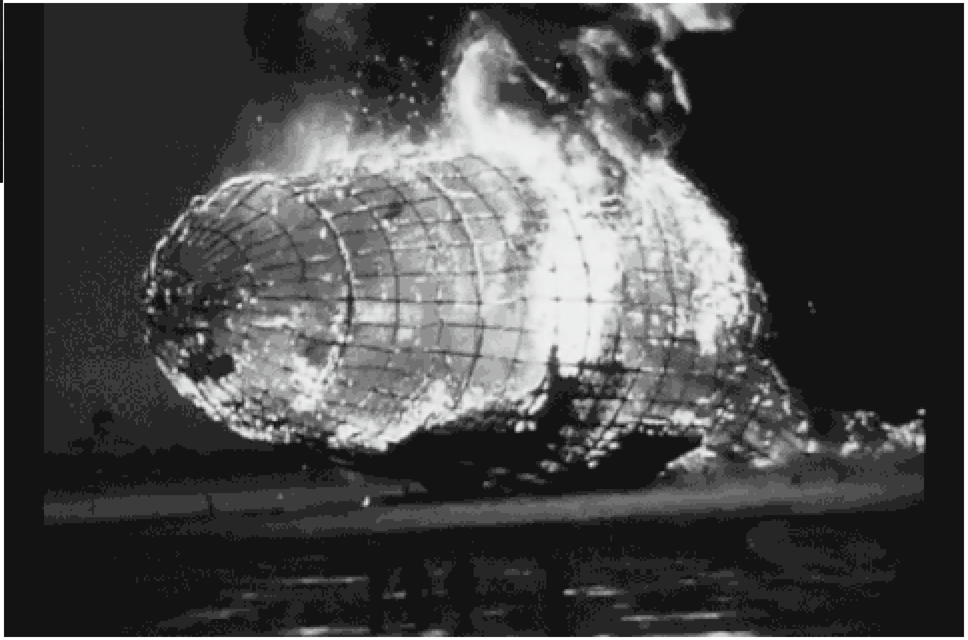
Hydrogen-to-Power

- Hydrogen-powered gas-engines, gas turbines (for pure H2); there are some working version, but can be expected to appear on the market after 2030.
- Mixed with natural gas: “traditional” gas-engines, gas turbines
- Fuel cells.

Although H2 can be used as fuel in transportation, presently THAT hydrogen is usually not green one, due to the high price. Usually it is from methane, by steam reformation.

Hydrogen as fuel: it can be used in electric cars, where the battery is replaced by a H2-tank and fuel cell. Or it can be used as an additive to the fuel, (LNG, CNG, even diesel) in traditional engines.

About the safety of H2 as fuel …



LZ 129 Hindenburg, May 6th, 1936
(although here the H2 was not
fuel, just filling material)

Conclusions for P2H

Presently OK for mid-capacity, daily-weekly storage; but not for high capacity seasonal one.

Optimal to use in polluted regions (zero pollution).

In some countries (Japan, Germany) H2 is already intensively used, but for example in Hungary, it is only for demonstration (2-3 cars, 1 bus, etc.), one house with PV-battery-electrolyzer-fuel cell combo (but does not work properly, high cost of compression).

Hungary: H2+Li-ion

Bátaszék/Gemenc

Former E-on project

10 kW PV

2 bunches of H2-container (2*15=30), max. total capacity: 20 kg H2.

Electrolyzer and fuel cell in the container, H2 containers below the PV panels.

Powering a small hunting lodge.

Italy: "first" Hydrogen powered house

H-Zeb (Hydrogen Zero Emission Building), Benevento, Southern Italy, University of Sannio

Heat pump (with shallow geotherm heat) for heating, PV for electricity, hydrogen for storage. Not too much public info, but they are using high temperature fuel cell; surely not good for this purpose, runs 24/7 , not only during nights. (One project idea: collect some real info about this project and compare it with other claims, like zerosun.se and https://energynews.biz/worlds-first-hydrogen-powered-house/)

Storage

50 bar
Needs further compression to 250 bar before fueling.

One Toyota Mirai – 4 kg. One truck; 20-40+ kg.

P2M – Power to Methane

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (plusz heat)

- Chemical methanation (Sabatier reaction), high pressure, high temperature, need catalyst (usually platinum or some other rare/expensive material). Need a chemical factory.
- Biological/biochemical methanation, by bacteria (archaea) on low temperature, low pressure. Some of them are quite fast (after 2 minutes, pure methane is coming out). The proper dispersion of H2 is water is a problem. Also, some percent (for example 4%) of carbon atoms turns to the body mass of bacteria, so, only 96% will turn to methane. The 4% solid should be handled somehow.
- Although the methane-to-power process has CO2 emission, this CO2 can be used again for methane production. Also, when the CO2 is "green" (for example from biogas), the whole process is considered as carbon-neutral.

P2M – Power to Methane

The produced methane (sometimes referred as Renewable Natura Gas) can be used as natural gas. During “discharging” (i.e. producing electricity), 25-35 % of the initial energy can be recovered. Using it as fuel, it can be over 50%. Not too much, but….

… it can be stored “forever”, so, it is OK for seasonal or multi-annual storage…

…. and it can be stored in high amount (in depleted underground gas fields).

No need for special equipment to store and use it.

Can be used not only in energy applications, but elsewhere.

Biomethanation

Can use “dirty” CO_2, for example biogas (66% methane, 33% CO_2, 1% else). In that case, the originally low-quality gas will be upgraded; turning one CO_2 molecule to CH_4, the other two CH_4 molecule will be also “improved”, therefore the gas can be sold as “Syntethic Natural Gas” or “Renewable Natural Gas”.

Contras

- Works with H_2; green H_2 can be produced, when cheap green electricity (usually PV- or wind-based) are available; therefore it works only part-time, return of investment is slow.
- Difficult to find proper CO_2 source. Non-purified flue-gas or air is not good. Geological CO_2 is not green. Strangely, one of the purest CO_2 sources are the breveries…

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P2M examples

Underground Sun Storage (already closed), restoration of a depleted gas field by pumping H2 and CO2 un derground. CH2 is produced “in” the gas field. Small scale, input of electrolyzer is 500 kW (this is the number used to characterize biomethanation facilities).

P2M examples

Works	2013-
Location	Werlte, Germany
Electrolyzer type	Alkaline
Electrolyzer power (kWe)	6000
Methanation	Sabatier
Pro	High power

ETOGAS – AUDI E-GAS, 6 MW, presently the biggest one.

P2M examples

Works	2016-
Location	Avedøre, Denmark
Electrolyzer type	Alkaline
Electrolyzer power (kWe)	1000
Methanation	biological
Pro	Biggest biological, based on biogas

Electrochaea – BioCat

1 MW, unfortunately it is closed now.

Ammonia – NH_3

Produced: Haber-Bosch method, from N_2 (from air) or from H_2 (from various sources, mostly from CH_4), above 100 bar, 300 Celsius, using catalyst

In energetics:

- Can be used for energy storage, when the H_2 is produced by electricity (usually from water). It can be handled as chemical storage for H_2.
- Combustible (i.e. can be used as fuel), but produces NO_x
- There are special fuel-cells, first “stripping” the hydrogen off from the nitrogen, then using the hydrogen for power production.

Pros

- Easy to store (liquefy at 10 bar on room temperature or around -10 Celsius on atmospheric pressure)
- Because it is used widely (producing fertilizers), there are well-established methods for transportation and storage.
- The volumetric “hydrogen” density is higher than for pure hydrogen.
- Carbon-neutral

Contra(s)

Low acceptance for the public….

Contra(s)

Low acceptance for the public, because it smells terribly!

Comparison

Method	Storage pressure	Storage temperature, °C	Max. energy density, kWh/L (in liquid form)	Maximal storage time, h
Ammonia	9	-33 - ambient	4.3	10-10000
Hydrogen	350-700	-253 – ambient	2.5	10-1000
Methane	1-200	- 162 - ambient	5,5-6	10-100000

Liquids can be kept in liquid form, using partial evaporation. The evaporated part can be used immediately or can be stored in gas form.

P2F – Power to Fuel
P2L- Power to Liquid

Presently it has very low storage efficiency, but this is a new technology, can be good later, when high energy density fuels are needed (e-kerosene).

Production (green)

H2 from water, that adding CO2, a mixture of CO, H2 and water will be produced, which can be used for chemical synthesis of various products, for example e-diesel (Audi – Sunfire cooperation).

Usage

Chemically almost identical to the diesel or kerosene, can be used in the same way. The energy density is well above the previous three (H_2=2,5, CH_4=6 and NH_3=4,3), it is 10 kWh.

Next week

- Fuel cells
- Mechanical energy storage

Projects

Power-to-ammonia: the present status

Power storage by heat: the Carnot batteries

Heat storage by phase change materials

- for a house
- transportable version for industrial vaste heat

Energy Vault : a tower for energy

Estimation for fueling the transportation of a country entirely with green hydrogen (from PV or wind)

…or anything else!

Thanks for your attention