Hydrogen battery
Innovative power source for raw materials exploration and extraction

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Hydrogen battery as the innovative power source for raw materials exploration and extraction

For technical processes in the mining of raw materials, adapted sources of energy are needed, and these new sources of energy need new raw materials. The prospection and exploration of raw materials under extreme conditions requires automation, robotization, and proceeding control in environments where human presence and activity is impossible.

One part of the system, allowing works under extreme conditions, is to have an **autonomous energy source, working in „island-mode conditions“**. Hydrogen (and oxygen) zeolite batteries, like long-term, safety, and high-capacity energy sources, serves as a power source for exploration and mining equipment in conditions, where energy is not available.

Long-term zeolite battery - storage of high-energy gases in liquid form, enables to fill the battery with hydrogen, store it for a long time for minimum loss.

Hydrogen battery and deep holes thermic sinking (drilling)

Autonomous, safety and long-term production and continuous gas supply are needed for progressive **thermic (flame) technology.**

The functional **melting head prototype**, as well as the **thermic sinking (drilling) system**, were successfully developed and tested on TU of Kosice.

During the sinking of the deep vertical holes by the help of both - extremely high temperatures and pressures, tensile cracks occur in the vicinity of melting head.

Hydrogen-oxygen flame generates extremely high temperature and pressure needed for melting rock below the flame injector.
Theoretically - maximum temperature of the hydrogen-oxygen flame is 2700°C, which melts the rock almost instantaneously. At the same time, the thermal process creates water steam caused high pressure, which helps the formation of radial cracks.

Hydrogen battery, as the innovative power source for raw materials exploration and extraction

Today the application of **Deep-sea mining methods** are limited because of extreme natural conditions.

Practically, all existing extracting systems of polymetallic nodules of the deep seabed, are in the form of a rigid system, with the interconnection of all components of the system - from the water level, to the collectors on the sea-bed.

By me, an important technical limitation is absence of energy source directly on the sea-bed, which anables deap-sea mining of polymetallic nodules without a direct connection to the afloat mining boat 4-5 km high above the mining site.

A self-propelled collector connected to a nearby, sufficiently robust energy source, may be more efficient in collecting polymetallic nodules placed on the seabed.

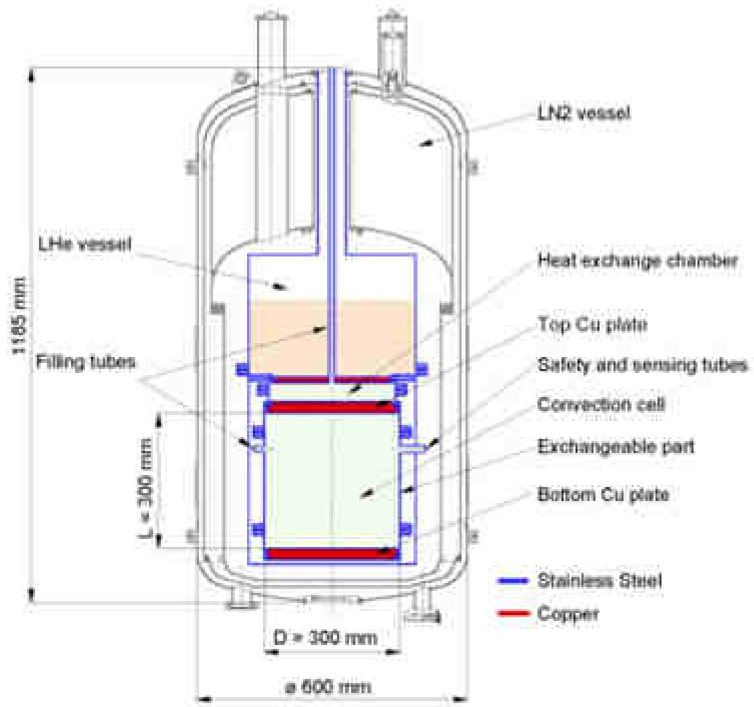
Hydrogen (and Oxygen) battery is a system suitable for exploration and extraction of raw material in extreme conditions, which includes a high-capacity and safe energy source that provides real-time energy near a mining or exploration facility.

Hydrogen storage, currently used methods

- Storage of hydrogen in the gas phase (CHG)
- Storage of hydrogen in the liquid state (LHG)
- Storage of the hydrogen bonded in the metal hydride (MH)
- Storage of hydrogen by adsorption on activated carbon
- Storage of hydrogen to carbon, or zeolite - nanotubes (CNTs)
- Hydrogen storage material of the organometallic structure (MOF)
- Storage of hydrogen in chemical hybrids

The Cryostat

Is a device used to maintain cold cryogenic temperatures of samples or devices mounted within the cryostat. Low temperatures can be achieved in the cryostat by using various refrigeration methods, most commonly cryogenic fluid bath, such as liquid helium.

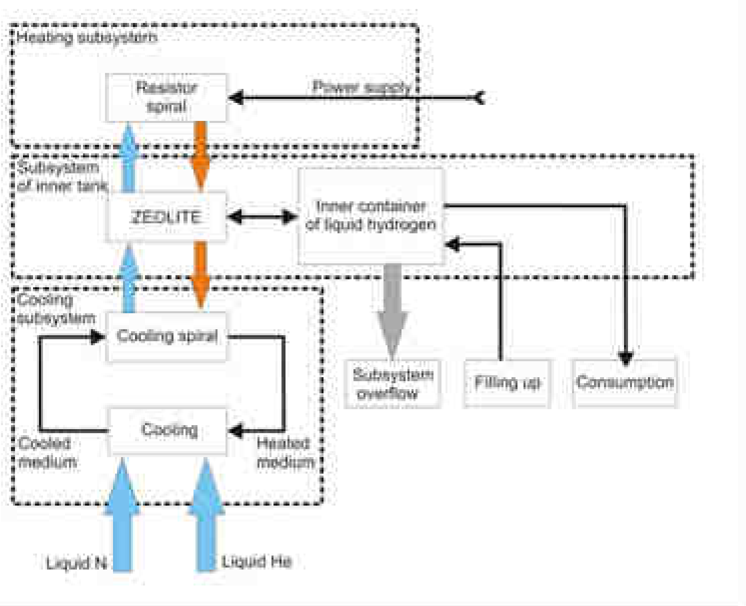


Cooling fluid	Melting point (°K)	Boiling point (°K)
Nitrogen	63.15	77.36
Argon	83.8	87.3
Helium		4.2
Oxygen	54.36	90.2

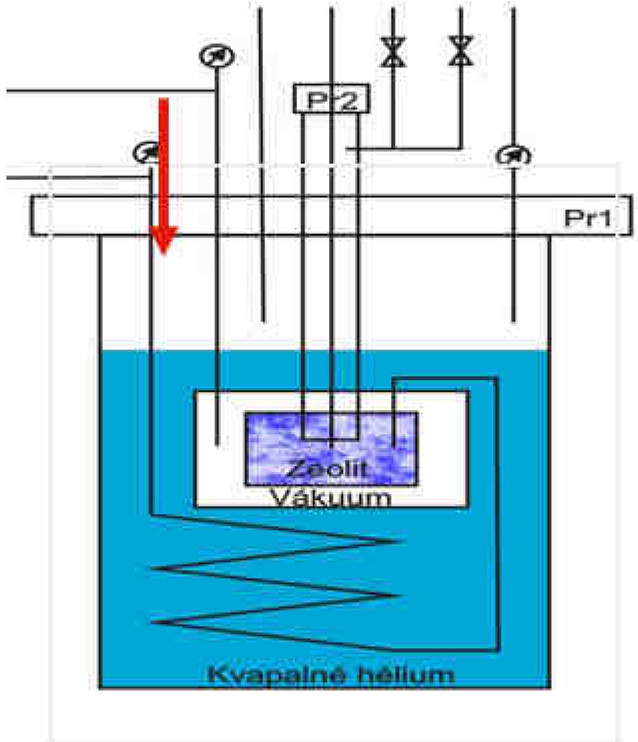
Chilled fuel	Melting point (°K)	Boiling point (°K)
Hydrogen	14.1	20.28
Methane	90.65	111.55
Ethane	90.36	184.55
Propane	85.45	231.5
Ammonia	195.42	239.81

Specially adapted cryostat

It is a particular type of cryostat which uses two liquid gases. First one is chilling - liquid helium and the second one is cooled gas-liquid hydrogen.



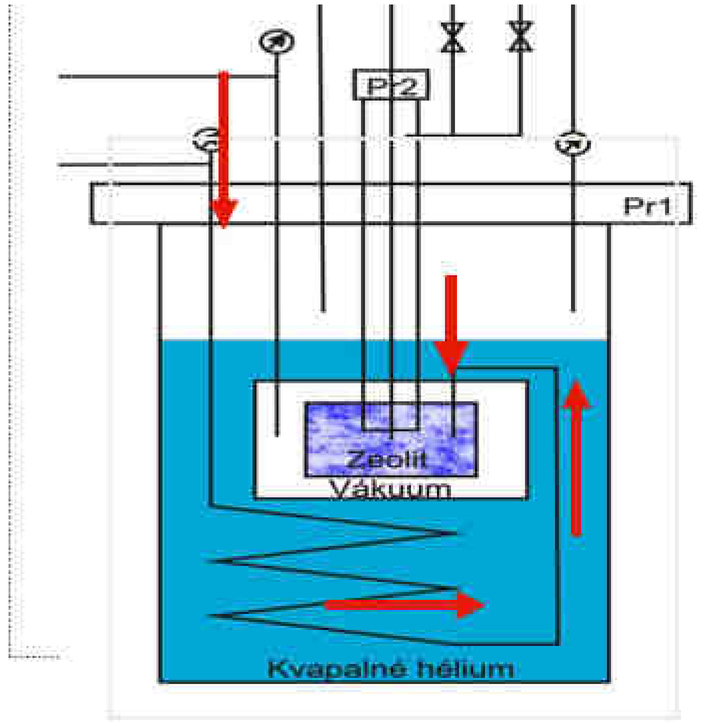
Operation of the adapted He-H cryostat
Cooling



- The cooler in the primary reservoir is filled with H_2 gas.
- The vacuum in the secondary reservoir.

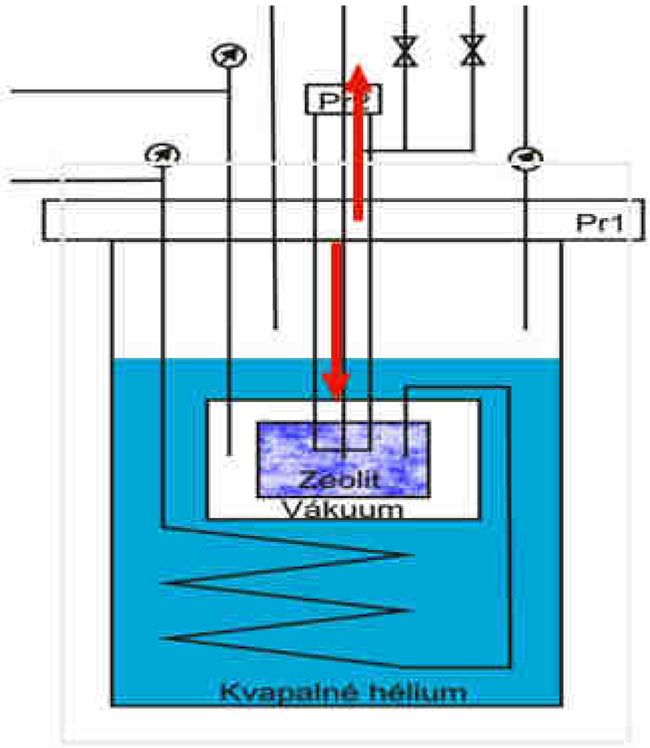
Operation of the adapted He-H cryostat
LH_2 transition into the zeolite filling reservoir

- The cooler in the primary reservoir is filled with H_2 gas.
- The vacuum in the secondary reservoir.
- LH_2 entered through liquid helium into the secondary reservoir with zeolite filling.



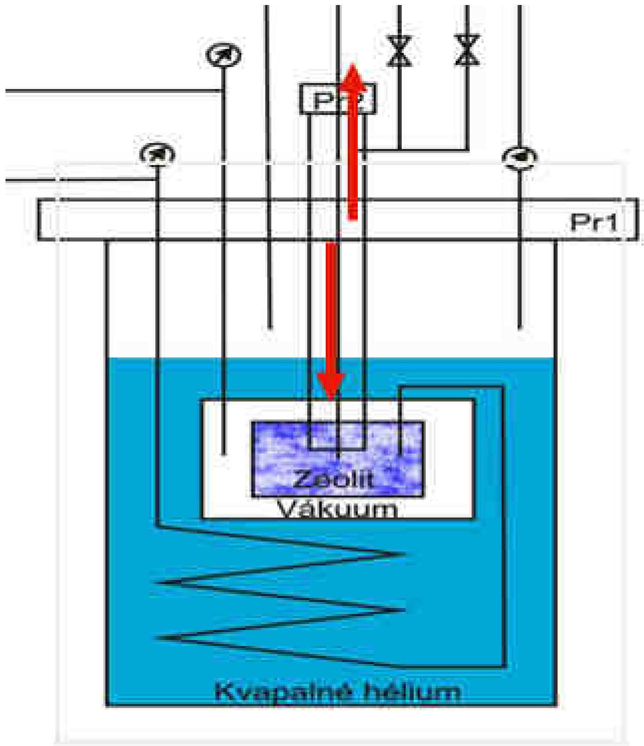
Operation of the adapted He-H cryostat
LH_2 Storing

- LH_2 in the secondary reservoir.
- LH_2 in the inner structure of the zeolite

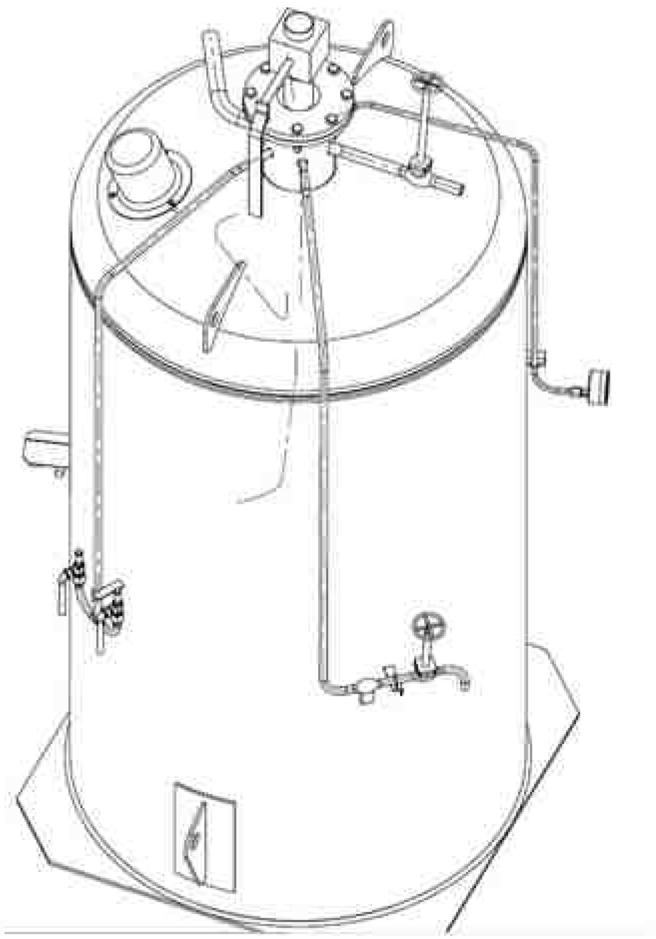


Operation of the adapted He-H cryostat
Hydrogen gas extraction

- LH2 in the secondary reservoir, and impregnated into the inner structure of the zeolite
- Releasing gaseous H_2 flow through the flange „Pr2”
- Utilisation of released H_2 gas: burner



Zeolite battery – Functional model



Modeling of liquid hydrogen storage (CNTs) in cryogenic conditions of zeolite battery

- **Zeolite battery:** M200/12 bar - special pressure vessel system
- **Storing:** Chilled liquid – Liquid argon

  Cooled fluid – Liquid nitrogen
- **Filling of the battery:** 1.6 m^3 of milled zeolite (1-2.5 mm) - with a large internal surface, in which as much as 1.2 m^3 of liquid argon was stored.

Modeling of liquid hydrogen storage (CNTs) in cryogenic conditions of zeolite battery

Zeolite battery enables to fill the battery with hydrogen, store it for a long time, and minimum losses.

Raising the temperature of the internal environment of the battery allows exhausting the hydrogen gas. The next modes of the battery are: to continue in storing of LH_2 in the battery, or the battery filling with the new amount of hydrogen. This cycle can be repeated many times.

With the help of the functional model, we have documented stable properties of the zeolite at LN_2 temperatures, and variable pressures in the range 0.1 - 1.0 MPa.

The experiments were carried out within two years.

LH_2 storage in large capacity zeolite battery Model

- **The volume of the battery**: 2 m^3
- **Filled with:** 1.6 m^3 of milled zeolite (1-2.5 mm)
  and 1.2 m^3 of H_2 gas (0.1 MPa)
- **Pressure 1 MPa:** Stored 12 m^3 of H_2 gas
- **LN_2 temperature of storage:** 4,800 LH_2 (400 times
  more then H_2 gas in normal conditions)
- **LHe temperature of storage:** 9,600 m^3 LH2 (800 times
  more then H_2 gas in normal conditions),
  + LH_2 stored in the zeolite inner structure -
  details under study

Safety, capacity and energy balance of the bulk zeolite battery

- The more we use zeolite, the operation of the zeolite batteries is safer, but we are reducing the capacity of the H storage.
- For example, the zeolite battery with a capacity of 12 m^3, holds approximately 450 m^3 of "condensed" H gas. The zeolite battery with a volume of 60m^3 can store about 2,160 m^3 of "condensed" H gas.
- The functional model of zeolite battery contains as much as 35.92 kg of "condensed" H gas at cryogenic conditions and pressure of 1 MPa.
- In the battery with 12 m^3 of H gas, pressure of 1 Mpa and room temperature, there is stored as much energy, which corresponds to 3.57 kWh, or 12.8 MJ.

Safety, capacity and energy balance of the bulk zeolite battery

- In the battery, at the pressure of 1 Mpa, and the temperature of LN_2 is located at 4,800 m^3 of "compressed" H, what corresponds to 1, 430.4 kWh (5.15 GJ).
- The battery at the pressure of 1 MPa and temperature of LH_2 is disposed of 9,600 m^3 of liquid hydrogen (800 times more then helium gas in normal conditions), what corresponds to 2,860.8 kWh (10.3 GJ).
- The + volume of LH_2 is placed In the inner structure of zeolite.

Conclusions

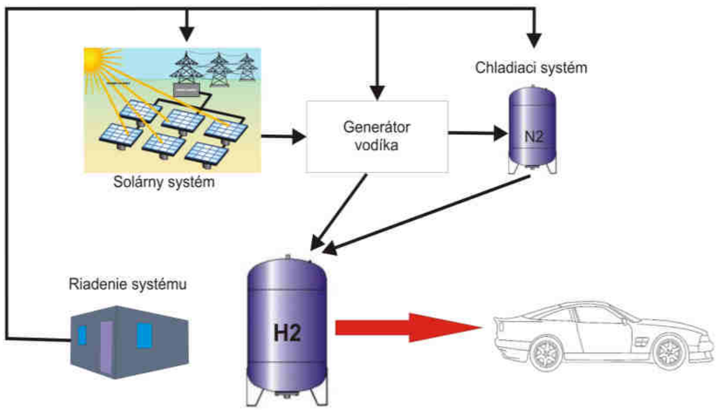
- Zeolite battery enables to fill the battery with hydrogen and store it for a long time with minimum losses.
- Raising the temperature of the internal battery environment allows all - exhausting of the stored hydrogen, keeping the battery with a fixed amount of residual stored hydrogen, or repeated charging of the battery with the new amount of hydrogen gas battery fill, with the new amount of hydrogen.
- The cycle can be repeated many times.

Potential uses of zeolite battery

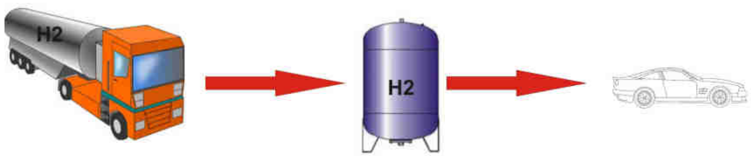
- A separate unit for supplying hydrogen as an fuel
- An entity which forms the part of the island system to secure the terminal equipment with hydrogen.
- High capacity battery for storage and balancing of fluctuating energy supplying from renewable sources of energy.
- Other possible uses

Potential uses of zeolite battery

Use of zeolite battery for pumping hydrogen into hydrogen-powered cars



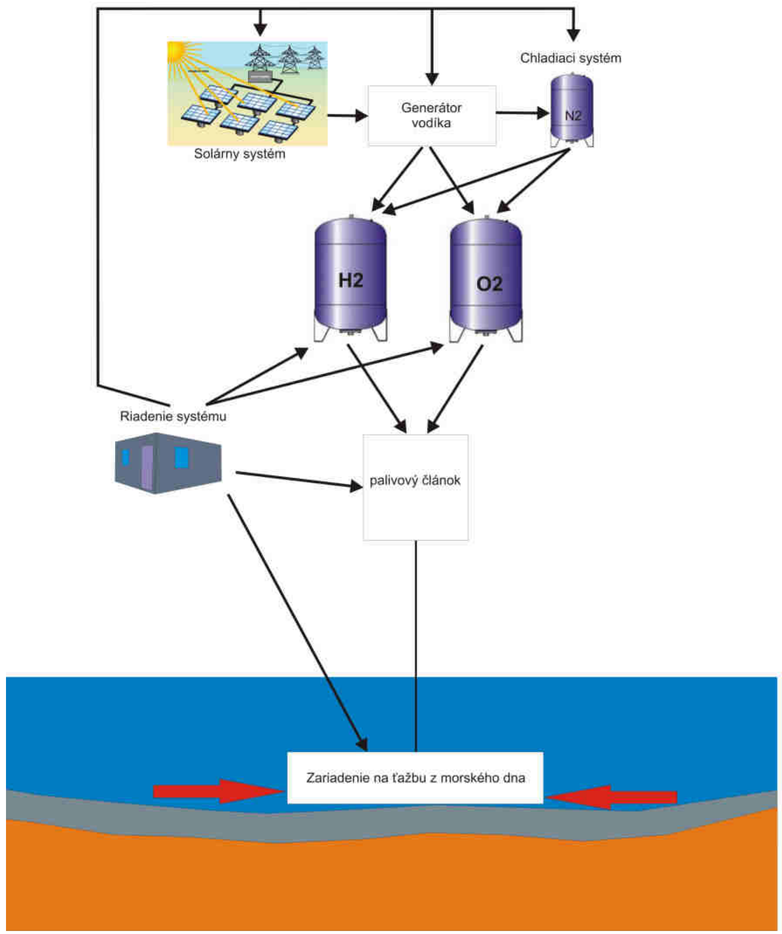
An alternative is the production of electricity from stored hydrogen, and the supply of electric vehicles (garages, family houses).



Hydrogen pumping station

Potential uses of zeolite battery

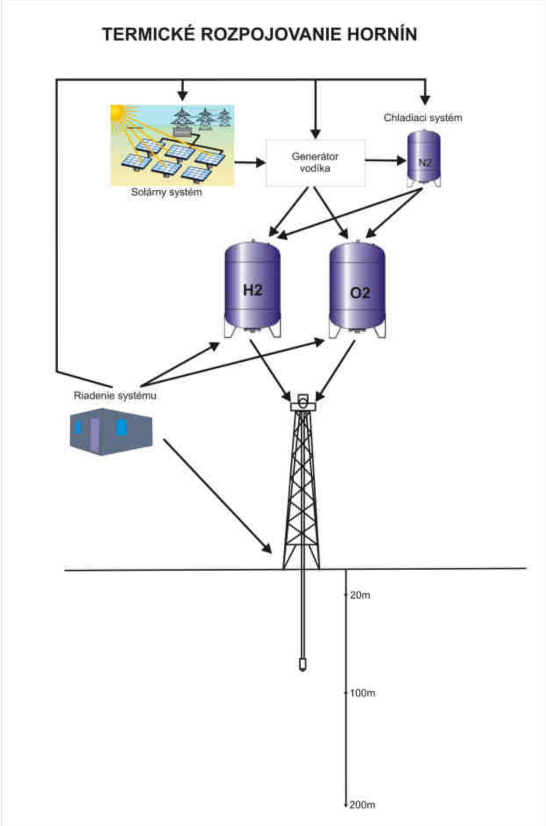
Seabed exploitation system using the zeolite battery



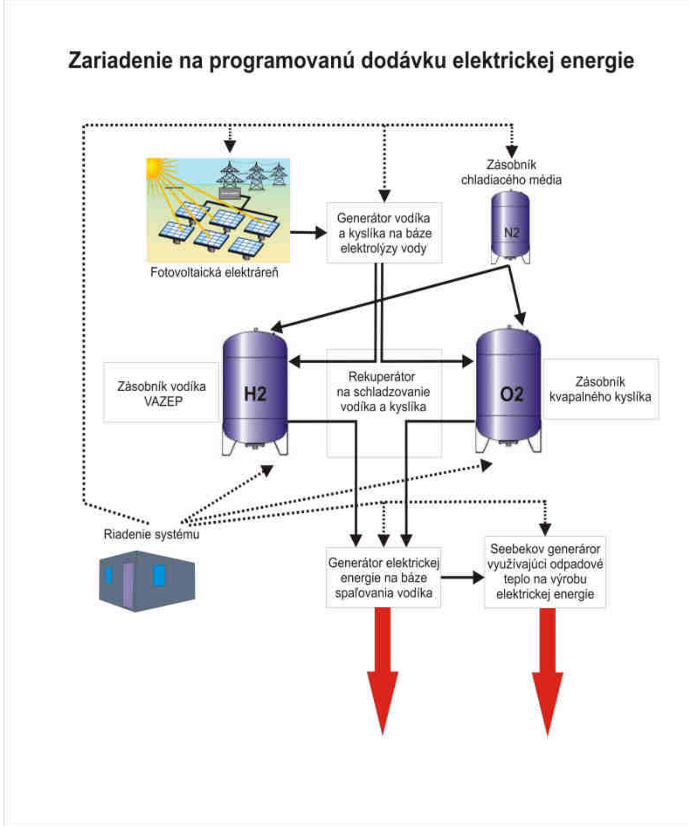
- Hydrogen produced at the sea level.
- Zeolite battery placed on the seabed.

Potential uses of zeolite battery

Thermal sinking of vertical „drill-holes“



Device for programmed power supply



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