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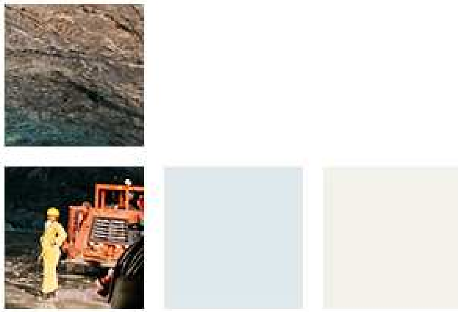
The international key player in underground storage

Drawing on UGS experience to store Renewable Energy



Jacques Grappe

IGU WOC 2 Meeting. Copenhagen. September 15 to 17, 2014

together @ VINCI

ENTREPOSE

Setting the scene

- **Emergence of energy transition policies worldwide**

- **Green, Renewable Energy (REN) gains a growing share in the energy mix**

- **Currently mostly developped REN are wind and solar:**
  - intermittent and weather dependent
  - still have ‘’priority access’’ to the grid

- **Long established equilibria are disturbed: Difficulties in balancing production and demand; how to convert intermittent electricity generation to a stable stream?**

A STORAGE ISSUE

Setting the scene

- **100 years experience in the Natural gas UGS industry of balancing supply and demand at whatever time scale**

- **No proven solution exists currently to store electricity as such. Need for conversion into another energy vector**

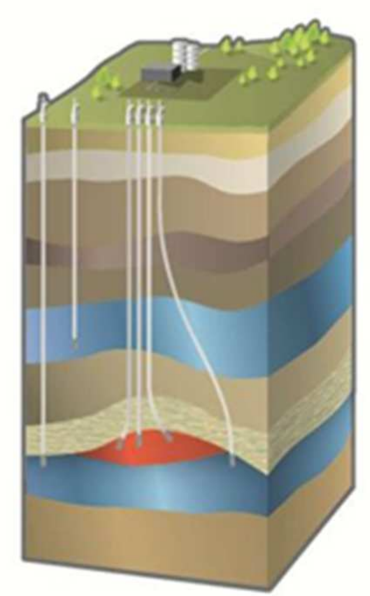
- **AIE forecasts: 1700 GW REN by 2035…**

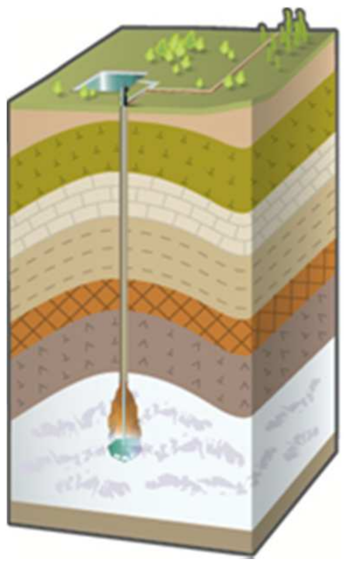
- **Storage needs evaluated (wide scatter) in the order of tens to hundreds of TWh**

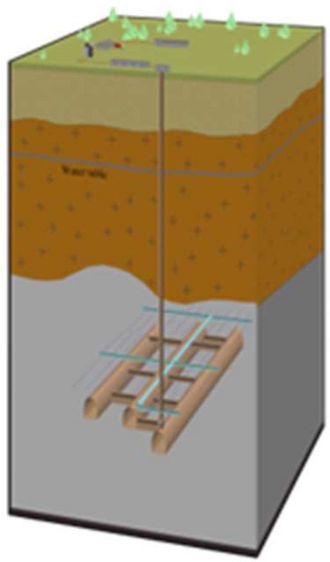
SOLVING THE CHALLENGE CALLS ON A COMBINATION OF SOLUTIONS AMONG WHICH UGS CAN PLAY A ROLE

Main UGS storage options

- **Natural gas UGS: from 10 MMm3 up to 10 bcm+ (110 GWh to 110 TWh)**
- **Global working gas capacity 377 bcm (4150 TWh) with 6,8 bcm (3100 GWh) max. daily deliverability**



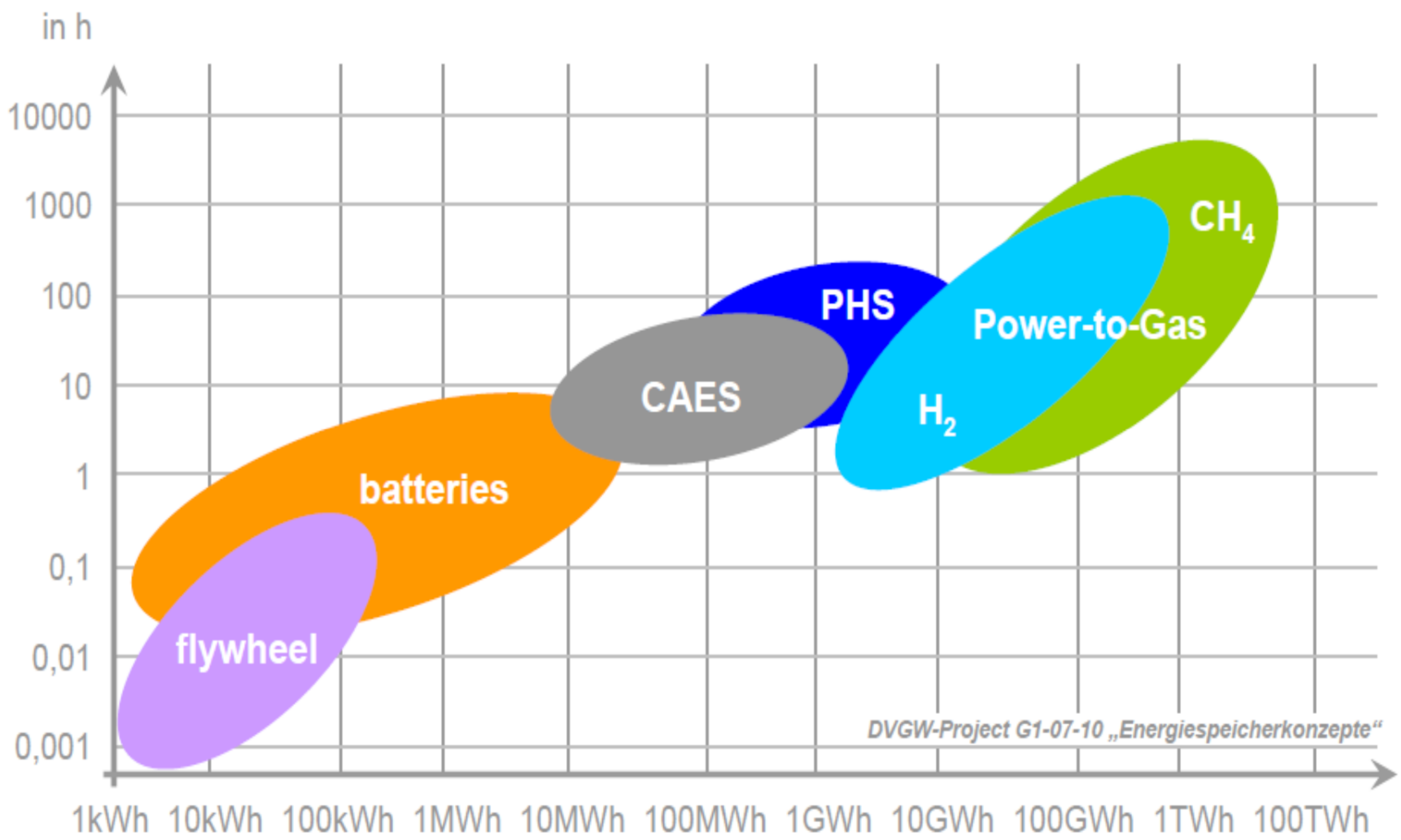




Main electricity storage options

TYPE OF ENERGY VECTOR	STATE OF THE ART	UGS SOLUTION
MECHANICAL/KINETIC ENERGY		
Pumped Hydro Storage (PHS)	Proven	Salt or Rock Caverns ?
CAES	Proven. R&D effort to improve efficiency	Peak shaving mainly Salt caverns, (reservoirs ??)
THERMAL & THERMOCHEMICAL		
Heat (enhanced geothermal energy)	Proven concept. Still some R&D effort needed for industrial implementation	Seasonal. Aquifer Thermal Energy Storage (ATES) or rocks Underground Energy Storage (UTES) Rock Caverns ??
CHEMICAL		
Hydrogen	Proven. R&D to achieve in particular performance improvement of electrolysers and cost reduction.	Short & Long term storage Salt Caverns Rock caverns ? Reservoirs ?
Methanation (from hydrogen)	Proven concept. R&D effort to optimize process Buffer Storage needed for CO_2, H_2, CH_4 (and possibly O_2)	Short & Long term storage Salt Caverns Rock Caverns ? Reservoirs ??
Process feedstock	Production of valuable chemicals requiring massive electricity with electricity in excess… but stop & go process is a handicap	To be evaluated on a case by case basis

Electricity storage options



UGS solutions applicable for 10 MWh and above to be released over at least a few hours

1. Pumped Hydraulic Energy Storage (PHS)

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- **10 MW to a few GW (a few to a few tens of full load hours of power plant)**
- **Installed capacity: 400 facilities; 125 GW**
- **Potential energy storage between a lower and an upper retention basin**
- **UGS options (surface pond/source needed):**
  - Salt caverns
  - Rock cavern, disused mines
- **Obstacles:**
  - Limited capacity of the lower basin
  - Need for large shafts, high performance pumps, etc…
  - Economics if underground store not readily available

ENTREPOSE

2. Compressed Air Energy Storage (CAES)

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- **10 MW to 1 GW. For a unit 300 000 to 600 000m3 cavern: 1 to 2 GWh (300 MW during 4 to 6 hours). Approx. 3 KWh /m3**
- **Response time: 1 minute**
- **Energy efficiency 40 to 70%**
- **Lifetime: >30 years, large cycling stability**
- **Existing facilities:**
  - Huntorf, Germany. 1978. Efficiency 42%; 2 caverns (150,000 m^3); Capacity 0.66 GWh each (330 MW for 2 hours); Pressure range 5 to 7 MPa.
  - McIntosh, Alabama, USA. 1991. Efficiency 54%; one 540,000 m^3 cavern; Capacity 2.9 GWh (110 MW for 26 hours); Pressure range 4,5 to 7,5 MPa.

2. CAES New Developments

Main CAES technologies under development: adiabatic and isothermal.

- **ACAES: compression heat stored on surface in a specific material. Released during emission into compressed air flow. No fossil fuel burning. Energy efficiency up to 70%.**
  - Technological issues: reaction of salt caverns to quick cycling of large air flow; heat storage at 600°C; efficient and reliable turbines; corrosion.
  - Pilot project: ADELE (Germany; RWE Power, GE, Züblin); 80 MW (5 h)
  - Large towers for heat storage: a handicap in terms of public acceptance.

- **ICAES: temperature fluctuations are limited. No fossil fuel needed.**
  - Several pilot projects in the USA (use of surface pressure vessels).
    - SustainX: 1.5 MW in Seabrook, New Hampshire. Compression heat is trapped in water (warmed air-water mixture stored in pipes).
    - General Compression, ConocoPhillips : 2 MW (500 MWh) in Gaines, Texas.

2. CAES New Developments
Sustain X pilot plant

2. CAES: Conclusions

- **CAES: an attractive technical solution for peak shaving…**

- **UGS Industry can contribute experience & knowledge**
  - Salt caverns: technology is there; some adaptations needed
  - Mined caverns:
    - Unlined: tightness, stability and cost issues
    - Lined: would strongly reduce geographic constraint –at increased cost !
  - Reservoir storage:
    - Depleted fields: excluded
    - Aquifers: size of the trap, large emission flowrates (permeability, number and size of wells, wellbore stability, interaction with reservoir, air flow dehydration, conflict of use etc…)…maybe, BUT

- **Salt caverns: the preferred option…where salt, leaching water and brin disposal are available (rather as extension of an existing cavern field than as a greenfield, stand-alone project).**

- **Main obstacle: geographic location and ECONOMICS…**

3. Power to Gas (P2G); Hydrogen

- **Gravimetric energy content of hydrogen is high: 33 kWh/kg (3 x pure methane)**

- **Volumetric energy density is low: 3 kWh/m3(n); 9.9 kWh/m3(n) for methane; 11.5 kWh/m3(n) for high cal. natural gas**

- **No marked difference in thermodynamic behaviors of hydrogen and methane. Z factor of hydrogen >1 and increasing with pressure in the pressure domain of UGS applications.**

3. Power to Gas (P2G); Hydrogen

- **Worldwide hydrogen production: 60 Mt/year (energy content 2000 TWh). 95% from methane and hydrocarbons steam reforming and from coal gasification; less than 5% from water electrolysis.**
  - Use in refineries, petrochemical industry, fertilizers (90%), food industry and mobility applications.
  - Local, dedicated transportation grids in some parts of the world, to supply refineries and petrochemical sites (in Europe in the Antwerp-Rotterdam and in the Ruhr areas; in the USA in the Gulf of Mexico region).

Northern Europe Hydrogen grid (1100 km)

AIR LIQUIDE

3. Power to Gas (P2G); Hydrogen

Hydrogen:

- a very flexible and versatile energy vector

- a common denominator giving surplus electricity after conversion to hydrogen (and oxygen) via water hydrolysis (efficiency: 60%; 1MWh electricity required to produce 200 sm3 hydrogen), potential access to a wide panel of uses, transportation and storage options.

3. Power to Gas (P2G); Hydrogen

Main applications of hydrogen as an energy carrier include:

- Use as a "clean burning fuel" (hydrogen combustion generates no CO_2) for:
  - Specific hydrogen Combined Cycle Gas Turbines
  - Fuel cells
  - Mobility

- Hydrogen can be injected and blended into the natural gas stream (ex. France, Dunkerque: GDF SUEZ Project GRHYD). GERG is preparing standards defining limits for the percentage of hydrogen acceptable.

- Power to gas: "Synthetic Methane Gas" from combination of hydrogen and CO_2 captured from an industrial user ($CO_2 + 4\,H_2 = CH_4 + 2\,H_2O$ at 350°C). This "green methane" produced from surplus electricity appears a unique opportunity to link the electric network and the gas grid (SMG is compatible with injection, transportation and storage in the natural gas infrastructure). Obstacle: low energy efficiency of the process (typically 10 to 15%).

- Conversion to Synthetic fuels (synfuels): kerosene, petrol, diesel, methanol

3. Power to Gas (P2G); Hydrogen. Storage options

- **Conventional pressure vessels, novel solid storage solutions (metallic hydride e.g.) answer needs for small size, distributed storage.**

- **The UGS option is only applicable for large size storage (100 GWh i.e. approx. 3000 tons or 35 Mm3 (n) hydrogen and above).**
  - One 500 000m3 cavern with a 120 bar operating pressure range (e.g. 180 to 60 bar) can accommodate (working gas):
    - 45 Mm3 (n) i.e. some 4000 tons Hydrogen or some 135 GWh
    - 60 Mm3 (n) Natural gas i.e. some 700 GWh

- **UGS is a less efficient process for hydrogen than for natural gas:**
  - For a same storage space and conditions, the working gas volume of natural gas will be greater than that of hydrogen
  - The energy content in a natural gas storage is 5 times that in a H2 storage.
  - Hydrogen compression will require 8 times more energy than natural gas (low density)
  - The high value of hydrogen (20 times that of natural gas) will impact cost of the trapped, non-recoverable gas and of the immobilized cushion gas.

3. Power to Gas (P2G); Hydrogen Storage

- **3 hydrogen salt caverns UGS in operation (+ one under construction) to store hydrogen as feedstock for the petrochemical industry:**
  - Teeside, UK (SABIC Petrochemicals), operating since 1971. 3 caverns each 70 000m3; 370 m depth; 4.5 MPa; working gas: 850 tons (28 GWh)
  - Clemens Dome, Texas, USA (ConocoPhillips), operating since 1983. Working gas capacity: 2600 tons (86 GWh)
  - Moss Bluff, Texas, USA (Praxair), operating since 2007. Working gas capacity: 3700 tons (122 GWh)
  - Spindletop project, Texas, USA (Air Liquide).

  (For the latter three sites, unit cavern volume is approx. 580 000 m3)

3. Power to Gas (P2G); Hydrogen The UGS experience

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- **What we know:**
  - Feedback from operating hydrogen storage in Salt Caverns
  - Coal gas storage experience in the 70's (salt caverns, reservoir)
  - Helium R&D storage projects (Russia, Gazprom)

- **Feasibility of Hydrogen storage in salt caverns considered proven for pure salt. Site specific evaluation needed for bedded salt.**

- **Main obstacles to be overcome (R&D):**
  - Fugacity (annulus of cemented wells)
  - Metallurgy (HIC)
  - Chemical activity (polymer seals)
  - Dissolution of hydrogen in brine or water
  - Compression technology
  - Hydrogen detection by existing chromatographs with He carrier gas
  - Safety issues (LEL and UEL 4 to 75%); low activation energy (rules to be defined; should be within those in force for natural gas)

ENTREPOSE

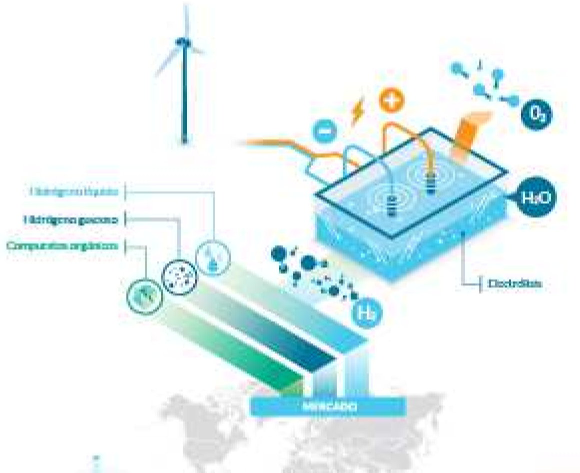
3. Power to Gas (P2G); Hydrogen The UGS experience

- **A few additional challenges for reservoir storage (showstoppers? Might then impact feasibility of large % H2 blending in the nat gas infrastructure)**
  - Contamination with reservoir fluids or minerals (pyrite)
  - Fugacity, interaction with caprock and vertical containment
  - High mobility, low viscosity: lateral containment & sweep efficiency
  - Bacteriological activity and biodegradation
  - Cost of trapped and cushion gas

- **Ongoing R&D effort**
  - Studies: InSpEE (Germany); HyUnder
  - Pilot Projects: Falkenhagen, Mainova (Thüga, Germany), HYCHICO (Argentina), Sun (RAG AG, Austria)

3. Power to Gas (P2G); Hydrogen
The UGS experience

- **The HYCHICO project (Patagonia; Argentina) considers test-injection in a depleted gas field of hydrogen produced from 7x0,9 MW windmills and 2 hydrolysers (total capacity: 120 Nm3/h H2; 60 Nm3/h O2).**



Source: HYCHICO website

3. Power to Gas (P2G); Hydrogen Conclusions

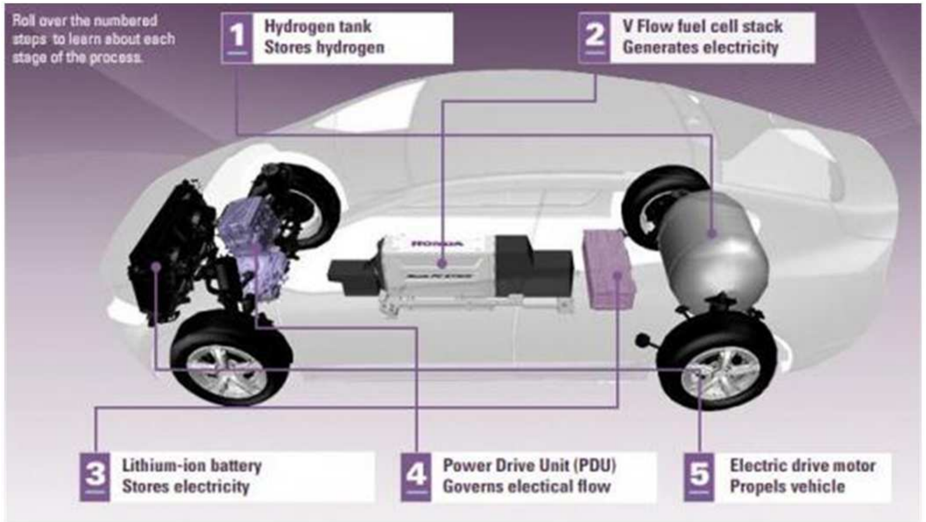
- **The UGS industry can contribute storage options for Hydrogen:**
  - Salt caverns: the most mature option
  - Reservoir: possible but…
  - Rock caverns: lined caverns deemed viable technically. Cost!!
  - Underground tubes (small size storage)

- **Constraints include:**
  - Large size storage volume
  - Suitable geology
  - Rather applicable for concentrated than for dispersed electricity production
  - Lined rock caverns or Underground located ‘’tubes’’ may relax the above constraints –at higher unit storage volume cost-

3. Power to Gas (P2G); Hydrogen Conclusions

- **Main obstacles to stabilization of electricity grids through hydrogen storage include:**
  - UGS requirement for large volumes entails need for large capacity hydrolysers (It would need some 15 years to fill the 50 MMm3 WG capacity of a 500 000m3 salt cavern with a 360 m3/h hydrolyser such as that of the Falkenhagen demonstration project). Technological breakthroughs are needed in the field of hydrolisers (performance, cost)
  - Use of hydrogen as such is the most efficient option, but requires dedicated transportation infrastructure
  - Injection of hydrogen in the gas infrastructure (hybrid grid) poses a number of challenges:
    - stability and quality of the blend
    - impact on pipelines, equipment, storage facilities, etc…
    - complex regulatory issues if cross border transportation.
  - Green Methane would relieve constraints, but energy efficiency is low
  - ECONOMICS…as of today, the P2G option cannot make it on its own. No market incentive for stabilizing intermittent electricity through storage, hence no driver for investment. Only economically viable business case is use for mobility (HyUnder, Fraunhofer Institute).

3. Power to Gas (P2G); Hydrogen Conclusions



FCX Clarity

Conclusions

- **The UGS Industry can claim a 100 years experience of safe and efficient UGS storage design, construction, operation and monitoring**
- **In the current energy transition period, Natural Gas is clearly a bridging fuel, which could allow balancing intermittent electricity production and demand (using in part existing infrastructure)**
- **The Gas industry can provide technical storage solutions (mainly CAES and Hydrogen storage) for surplus electricity production, provided quantities are large enough:**
  - Salt caverns (re-conversion or new caverns)
  - Lined rock caverns? Others?
- **What will the market needs be in the future?**
  - A few large storage facilities at '' sweet spots'' of the electricity grid
  - UGS deployment will largely depend on:
    - Intermittent electricity production: will it be concentrated or dispersed
    - Demand side management and demand volatility
    - Emergence of smart grids
    - New rules of the game and business models

Conclusions

- **It is anticipated that energy systems may change dramatically over the next 30 years. How many new (or novel) massive energy underground storage facilities will be needed by the market is unclear as of today.**

- **Besides providing UGS solutions for intermittent electricity storage, the UGS industry could take advantage of its current know-how (subsurface, well & completion, reservoir, environmental impact monitoring, surface and process, facility operation, permitting) to extend its field of services to other energy storage techniques:**
  - geothermal heat storage in aquifers or dry rocks
  - subsurface monitoring
  - in the wider perspective of a de-carbonated energy society CO2 storage

- **However the future evolves we are ready to face the change and to respond to the challenges ahead with a combination of experience feedback and technology driven innovation.**