Abstract

The underground solution is a unique option to store huge amounts of gas safely with two main applications:

- The storage of methane to gain flexibility in the gas distribution network and avoid any risk of shut down.
- The storage of energy in the form of hydrogen or compressed air to compensate for intermittence in solar and wind energy supply.

In both cases, the principle is to store the energy when the energy supply is greater than the demand and to release it as needed. For methane we have strong feedback in Europe and North America with more than 70 years of experience. For energy storage, the approach is more innovative with only a few cases of hydrogen storages around the world and one case of compressed air storage in Germany.

Israel will soon be faced with the need to store methane and energy in huge volumes and safely: (1) the national methane gas network is growing quickly to distribute the gas coming from the recent Levant Basin discoveries and (2) the intermittent energy (solar and wind energy) should reach 13% of energy generation by 2025, and at least 17% by the end of 2030. Considering the geological potential of Israel, the underground storage would be a serious option for a gain in flexibility, reduced cost, and increased safety.

For methane storage and energy storage, the best options are injection in depleted hydrocarbon fields, in deep saline aquifers, in leached salt cavities and in mined cavities. These solutions allow for storage of huge volumes (a few billions of cubic meters in aquifers and a few tens of millions cubic meters in salt cavities)in deep depth and an anoxic environment to avoid any risk of fire or explosion. Costs are much lower than storage in tanks on the ground: 0.15 to 0.30 €/m3 in aquifers and depleted fields, 0.40 to 0.80 €/m3 in salt cavities and 125 to 600 €/m3 in mined cavities, in comparison with 600 to 900 €/m3 in GNL tanks.

We propose to share our European experience in gas storage to evaluate the Israeli technical-economic potential for underground gas storage / energy storage.

Feedback on European Experience in Underground Gas Storage (UGS)

Israel Energy & Business Convention, Tel Aviv, Dec 2019

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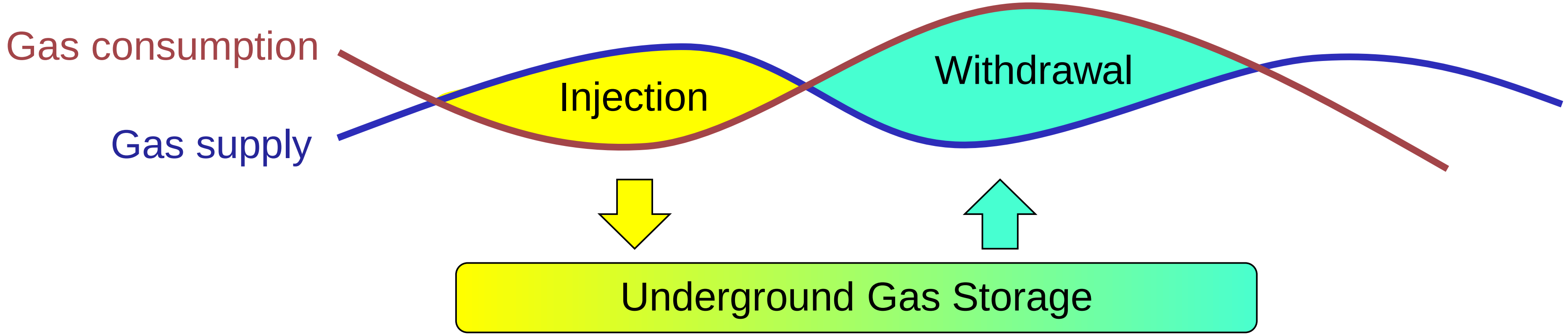
Bio

- ✓ Christophe Rigollet, Mines Paris, PhD
  - ✓ Geologist
- ✓ Background
  - ✓ TOTAL
  - ✓ Gaz de France (ENGIE)
  - ✓ BRGM (French Geological Survey)
  - ✓ SGS Netherlands
- ✓ Since 2016
  - ✓ CVA consulting, Geosciences Manager
  - ✓ GEODENERGIES, Managing Director

- ✓ Carlos GOMEZ MONTALVO
  - ✓ Engineer
- ✓ Background
  - ✓ VINCI
  - ✓ Praxair
  - ✓ Cegelec
- ✓ Since 1994
  - ✓ GEOSTOCK, Director Sales & Marketing

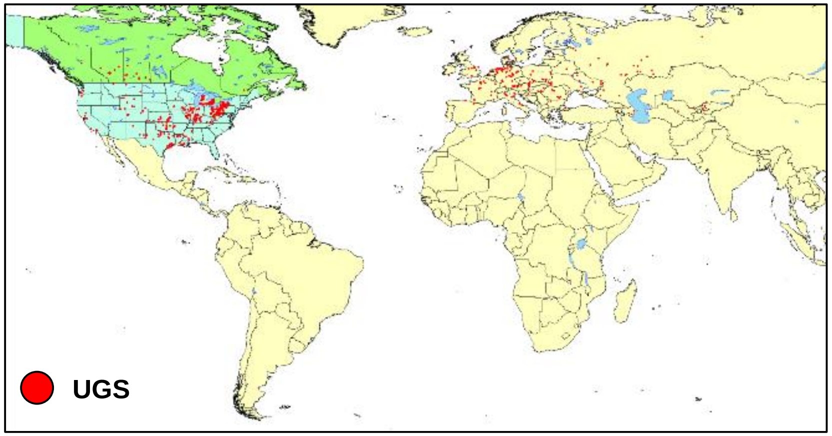
Why store natural gas?

- ✓ **Ensure gas supply** – in case of gas supply interruption, the underground gas storage (UGS) takes over the failing gas provider system. *In France, underground gas storage has been regulated since 1973: following a general gas supply interruption in France, the State required oil and gas companies to have two to three months hydrocarbon reserves.*
- ✓ **Ensure public safety** – an underground storage confines the gas at deep depth (more than 1000m) in an anoxic environment, without risk of combustion or explosion.
- ✓ **Smooth supply to demand** – during periods of high gas consumption, underground gas storage allows to smooth the supply to the demand peaks, quickly and over time.

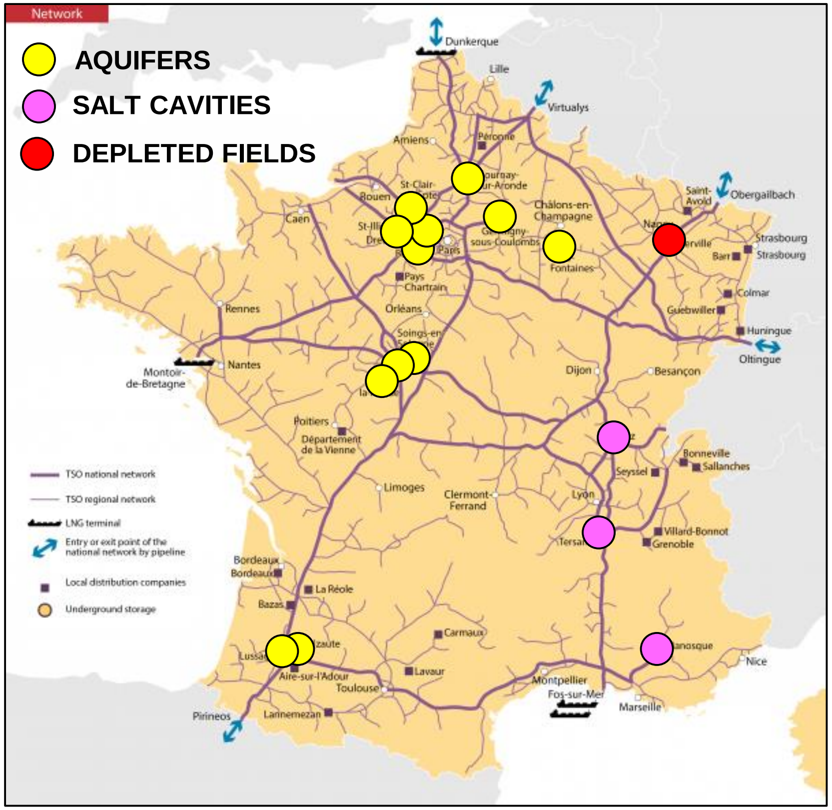


French feedback (19 UGC facilities)

- ✓ There are 671 underground gas storage facilities in operation in the world, mainly in the USA, Canada, Europe, Russia and China.
- ✓ The global UGS capacity is around 415 bcm.

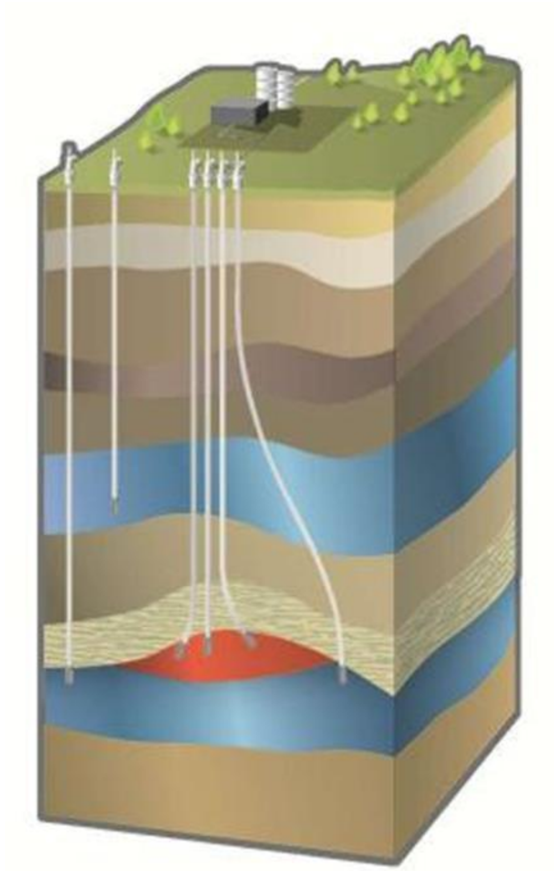


- ✓ In France, there are 19 UGS facilities, operated by STORENGY, TEREGA and GEOMETHANE:
  - ✓ 12 in aquifers
  - ✓ 1 in depleted gas field
  - ✓ 6 in salt caverns (78 caverns)
- ✓ The French UGS capacity is around 12 bcm, equivalent to 26% of the annual consumption.

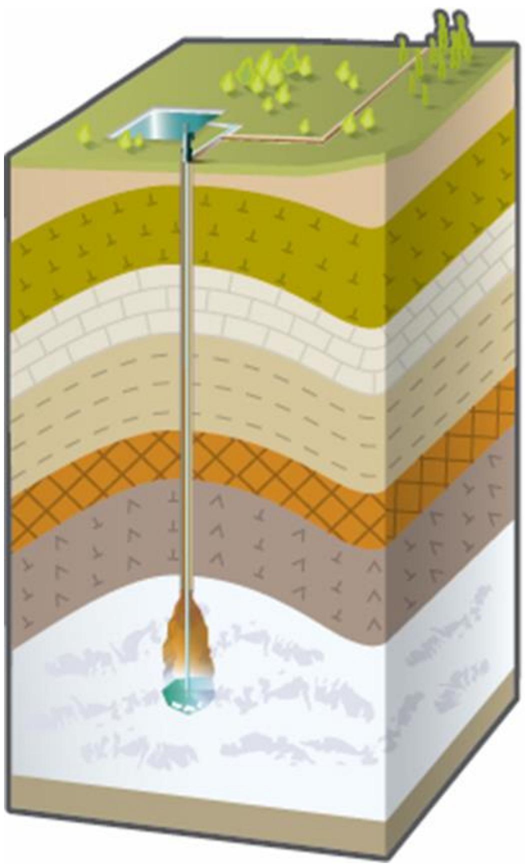


Natural gas storage techniques

- ✓ There are two main types of underground gas storages for natural gas:
  - ✓ In aquifers and depleted réservoirs
  - ✓ In leached salt caverns



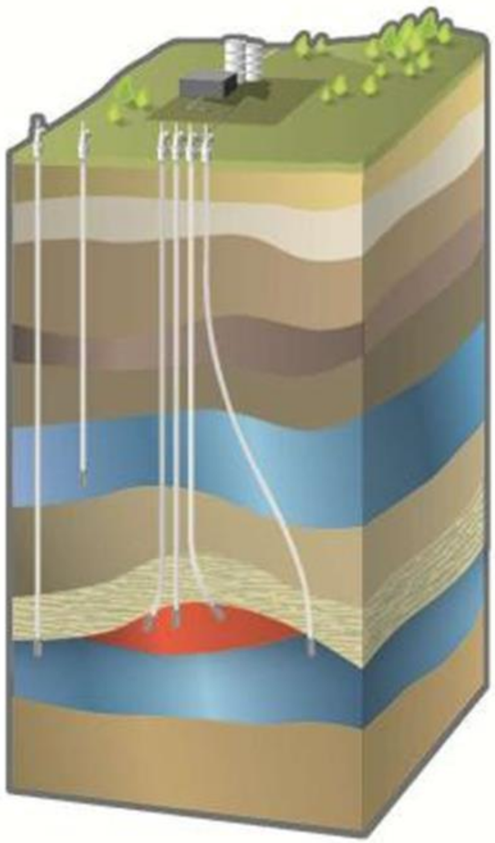
aquifers and depleted reservoirs



leached salt cavities

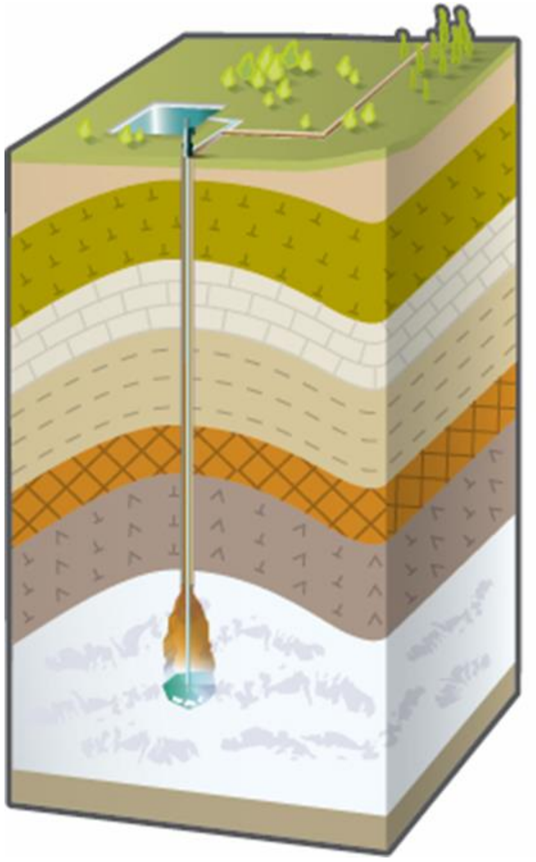
Aquifers and depleted reservoirs

- ✓ Principle: Use the natural porous space of the porous geological formation
- ✓ Depth: > 450m
- ✓ The sealing of the storage is provided by an impervious layer just above the porous formation
- ✓ The aquifer and depleted reservoirs are the main type of underground gas storage in the world, 56% in France
- ✓ Pressure: near in situ natural hydrostatic pressure
- ✓ Storage capacity: a maximum of 7bcm in France (Chemery)
- ✓ Advantages:
  - ✓ Huge volumes (many billions of cubic meters)
  - ✓ Strong technical feedback over a period of 70 years (1916 in USA and 1956 in France)
- ✓ Disadvantages :
  - ✓ High inertness (seasonal injection- Withdrawal cycles)



Leached salt caverns

- ✓ Principle : Create artificial cavities in salt formation by leaching
- ✓ Depth: between 200 and 2000 m
- ✓ The sealing is the salt formation itself – the salt is an impervious rock
- ✓ The salty caverns are the second main type of underground gas storage in the world, 26% in France
- ✓ Pressure: 180 bar
- ✓ Storage capacity: typically 90MNm^3 of gas in a cavity of 500 000 m^3
- ✓ Advantages :
  - ✓ Possibility to store all types of products inert with salt
  - ✓ Big volumes (up to 1 million of cubic meters/cavern)
  - ✓ Strong technical feedback since 80 years (1940 in USA and 1967 in France)
  - ✓ High reactivity (high frequency of injection- Withdrawal cycles)
- ✓ Disadvantages :
  - ✓ Salt formations are not present everywhere
  - ✓ Requires a good salt formation (to be avoided: insoluble layers, hypersoluble layers, high-creeping salt)

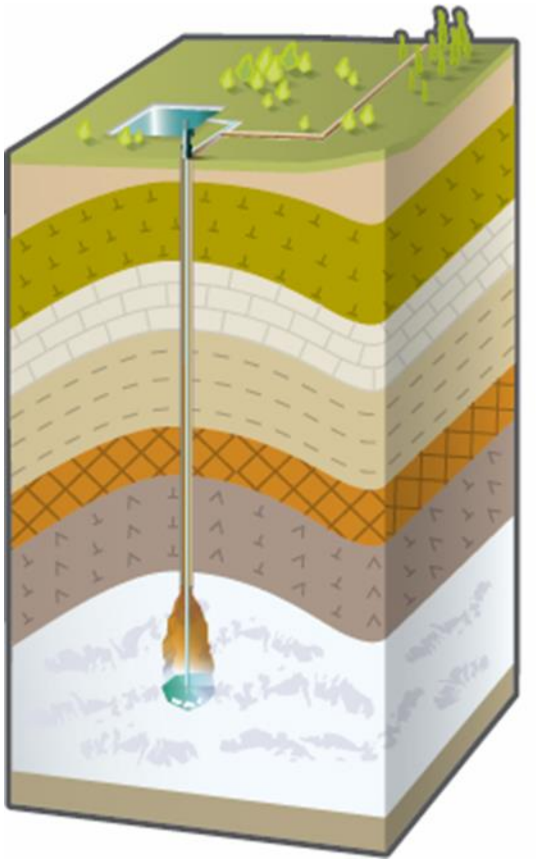


The costs

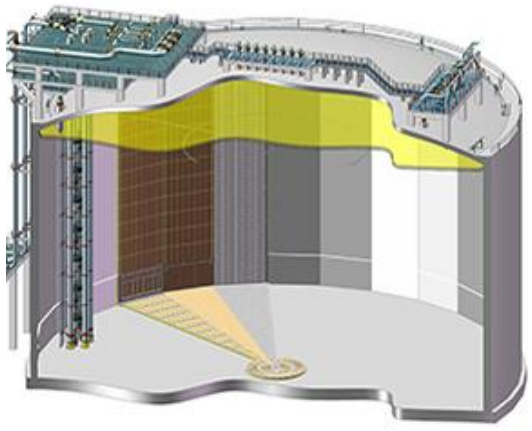
✓ UGS is significatively much lower than storage on the ground

In aquifers:
0,15 to 0,50 €/working Sm^3

In salt caverns:
0,40 to 1,50 €/working Sm^3



GNL in ground tank
600 to 1000 €/m^3 of LNG
(for comparison)

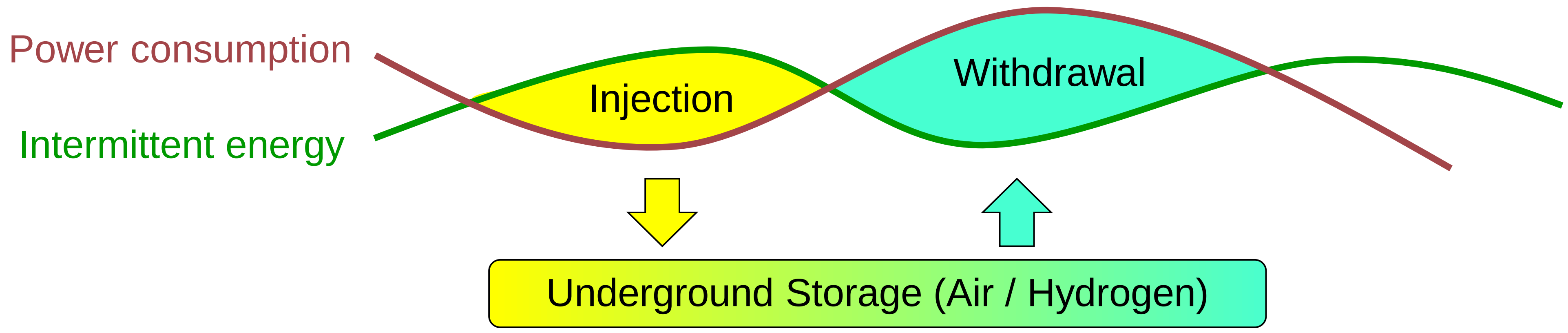


The risks

- ✓ Throughout the entire chain of production, storage and distribution of petroleum products, UGS is the least accident-prone link.
  - ✓ at depth, in the absence of oxygen from the air, gas cannot explode or burn;
  - ✓ at depth, gas is protected by several hundred meters of land from external attacks, tornadoes, fires, plane crashes, attacks; and they are not very sensitive to earthquakes.
- ✓ The rupture of the wellhead could lead to a complete emptying. In Europe, natural gas wells (caverns or aquifer) are equipped with an underground safety valve that is automatically activated in the event of a wellhead failure (fail safe valve).
- ✓ The most frequent accident is a defect in the metal casing or its cementation that allows the products to travel to the surface through the ground. In Europe, natural gas storage requires the presence of a second metal tube that forms an annular space with the cemented casing.

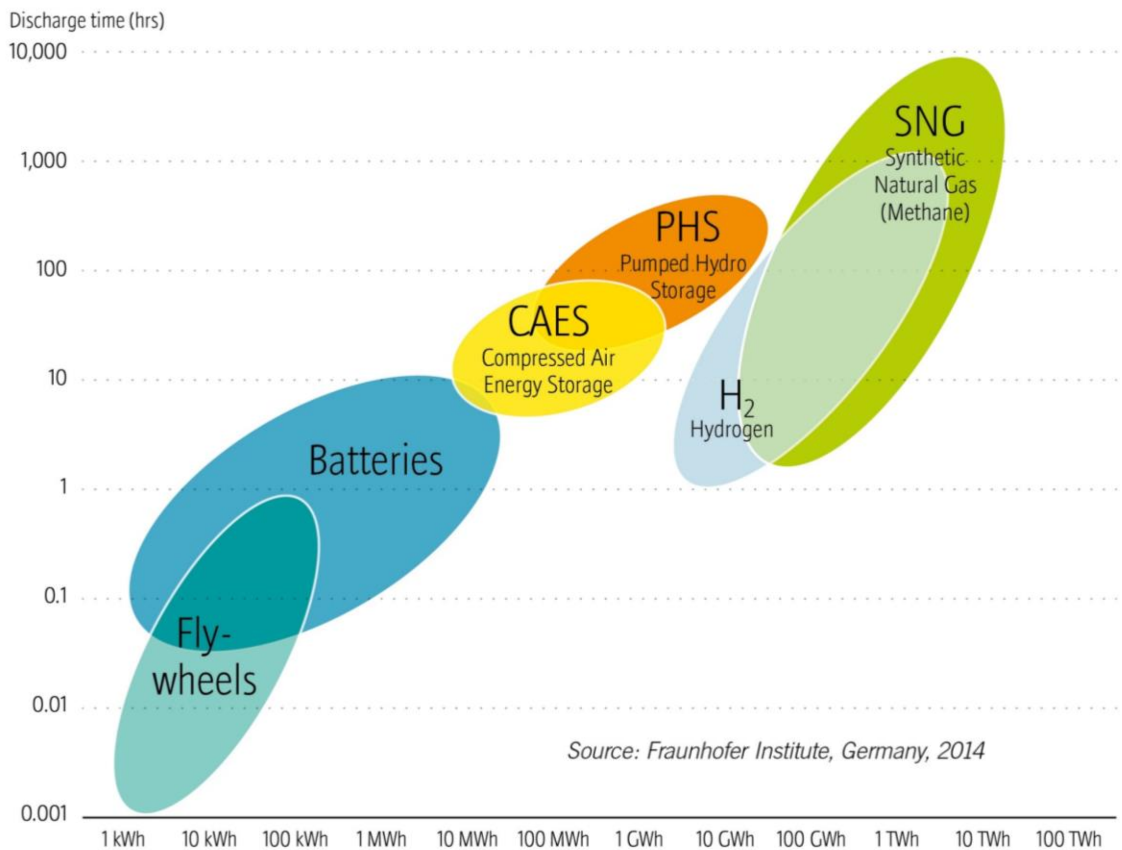
The future of underground storage

- ✓ The UGS technologies can be transferred to underground massive energy storage combined with intermittent renewable electricity production (solar and wind turbines)
- ✓ Principle: the excess of solar/eolian energy is converted into compressed air (CAES) or into hydrogen that can be stored in underground storage and removed as needed.
- ✓ Efficiency:
  - ✓ Hydrogen: 30-60%
  - ✓ Compressed air: 40-70% *Methane: 50-60% (to compare)*
- ✓ Investments costs:
  - ✓ Hydrogen: 8 to 11 €/kWh
  - ✓ Compressed air: 10 to 120 €/kWh *Batteries: 100 to 1800 €/kWh (to compare)*



The future of underground storage

✓ The underground massive energy storage of compressed air (CAES) or hydrogen (H_2), for huge volumes of energy, is more efficient and cheaper than batteries



Underground Gas Storage in Israel

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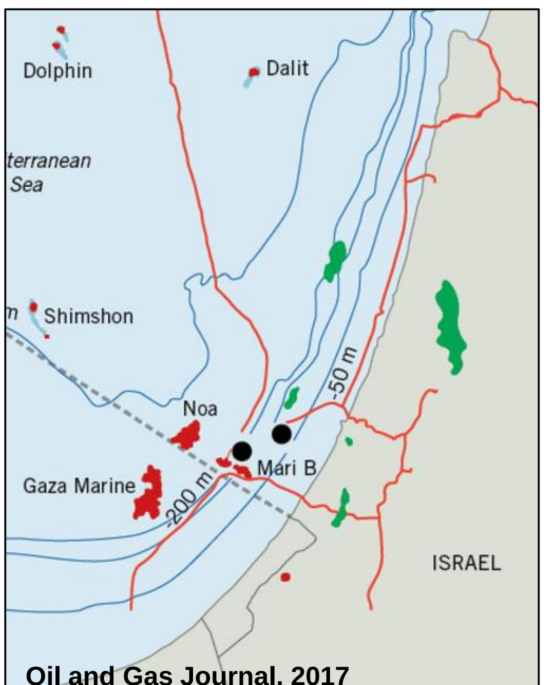
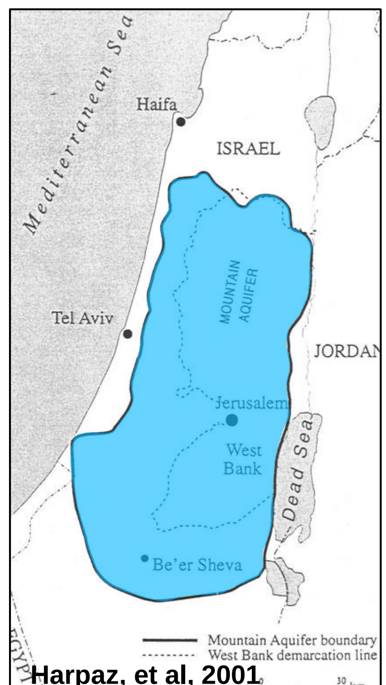
- ✓ Israeli geology is theoretically favorable to underground gas storage, in depleted onshore and shallow marine fields, deep saline aquifers and south Dead Sea salt formations.
- ✓ The potential of underground storage could be evaluated with available subsurface data coming from water, oil and gas exploration (wells and geophysical survey).

Oil & gas fields



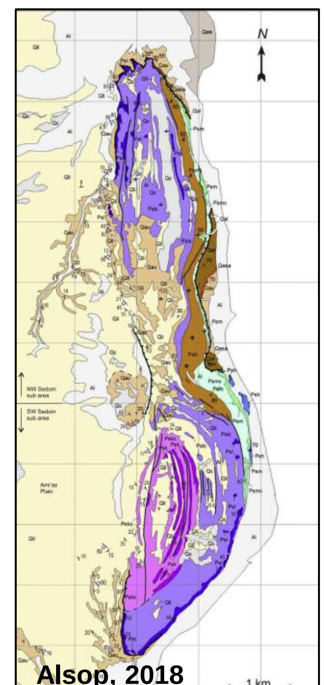
Oil and Gas Journal, 2017

Deep saline aquifers



Harpaz, et al, 2001

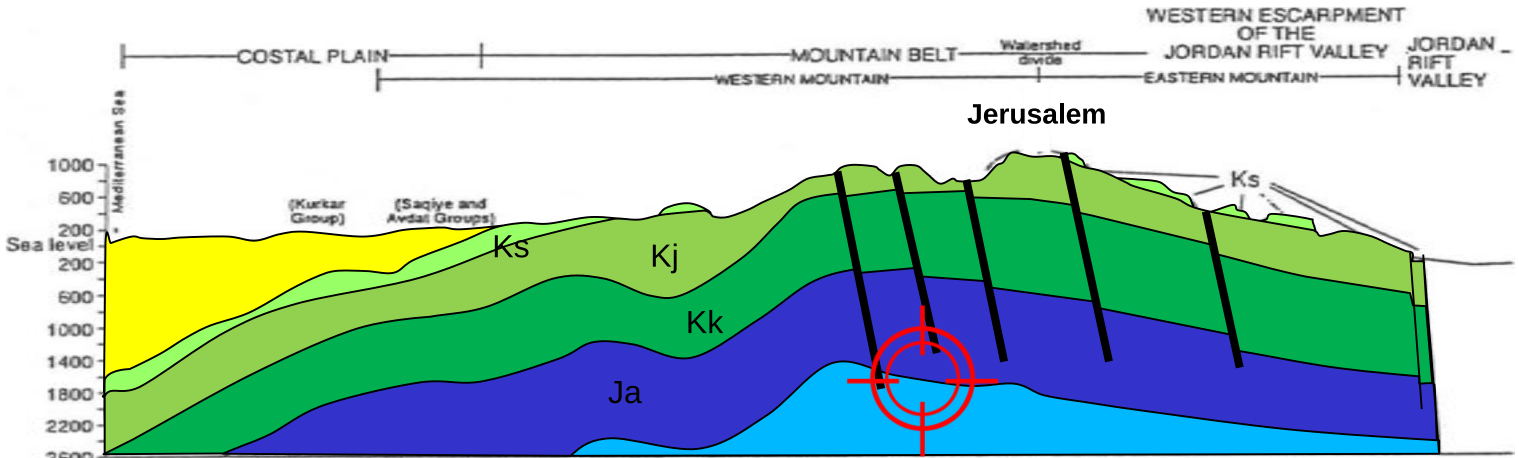
Salt formations (S'dom)



Alsop, 2018

Conclusions

- ✓ UGS is the most efficient solution to ensure natural gas supply and smooth supply to demand.
- ✓ UGS is the safest solution, due to depth of storage.
- ✓ UGS technologies are perfectly controlled, confirmed by 100 years of experience.
- ✓ UGS costs are very competitive in comparison with ground tanks.
- ✓ UGS technologies can be transferred to compressed air storage (CAES) and hydrogen storage for massive energy storage, combined to intermittent energy production.
- ✓ Israeli geology is theoretically favorable to gas storage in deep saline aquifers, depleted hydrocarbon fields and salt formations.



Harpaz, et al, 2001