POWER-TO-GAS AND ADVANTAGES OF ELECTRICITY STORAGE THROUGH CHEMICAL ENERGY

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9ª Conferenza Nazionale Chimica & Energia
"Quale energia al 2030 con l'aiuto della chimica"
Milano, 16 novembre 2018

FEDERCHIMICA CONFINDUSTRIA
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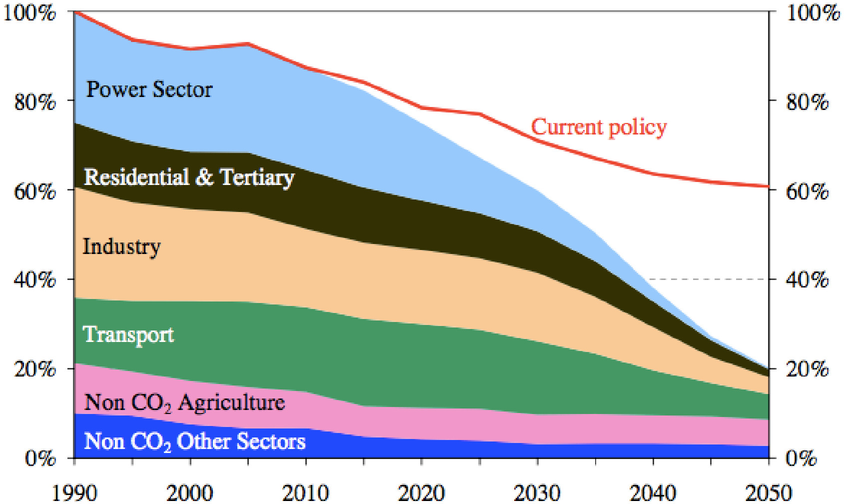
The EU Roadmap towards 2050

EU Commission, *Energy Roadmap 2050* :

Reduction of GHG emissions (primarily CO_2) 80% below 1990 levels within 2050

- Transition to a “low carbon economy”
- Actions required in all fields



«Current policy» = in line with EU energy strategy 2020

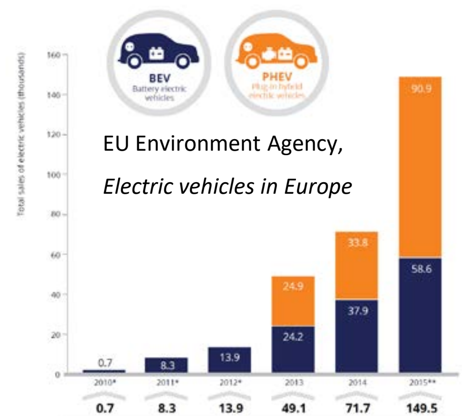
Main emitters (2015):

- Power 25%
- Transport 20%

Italy’s role: 10% of EU GHG emissions (EU-27)

- Need of more renewables (RES): PV, wind, biomass…

- Need of more clean vehicles: electric, H_2 , SNG…



EU Environment Agency, *Electric vehicles in Europe*

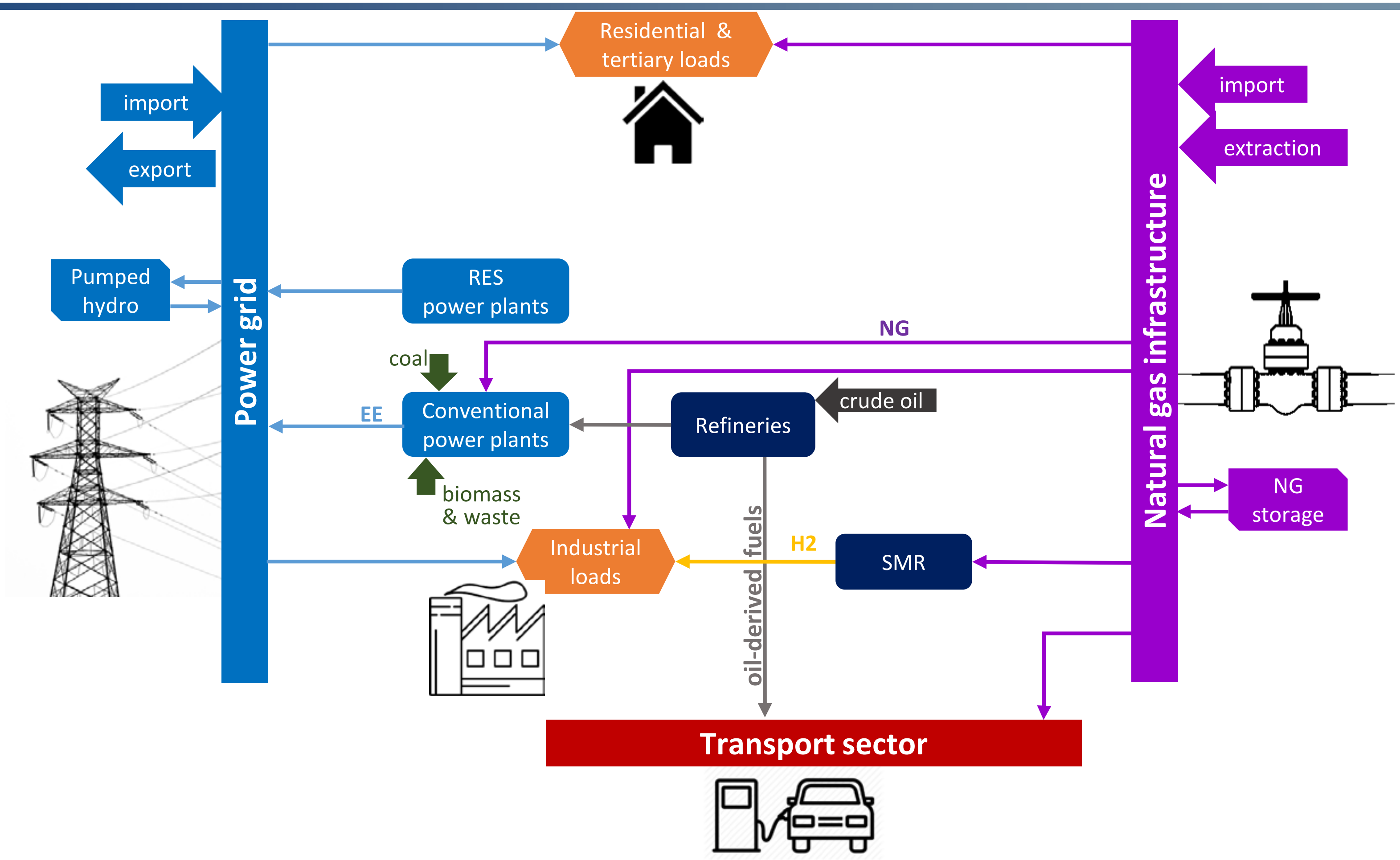
Issues and the role of energy storage

In presence of large (in the prespective 2030-2050, very large!) non programmable RES (wind, FV) there are increasing issues of control and stability of the electric grid:

- Load balancing
- Dispatch scheduling
- Energy losses and curtailment (grid congestions): the amount of energy which is lost increases with the installed non programmable RES.

➢ One of the key solutions (with power generation flexibility and demand-side management) is <u>energy storage</u>

The electric grid, the natural gas grid and the fuel-to-mobility infrastructure as they are today



- The three ‘energy infrastructures’ nowadays see easy-structured interactions
- Energy storage through pumped-hydro and seasonal NG storage

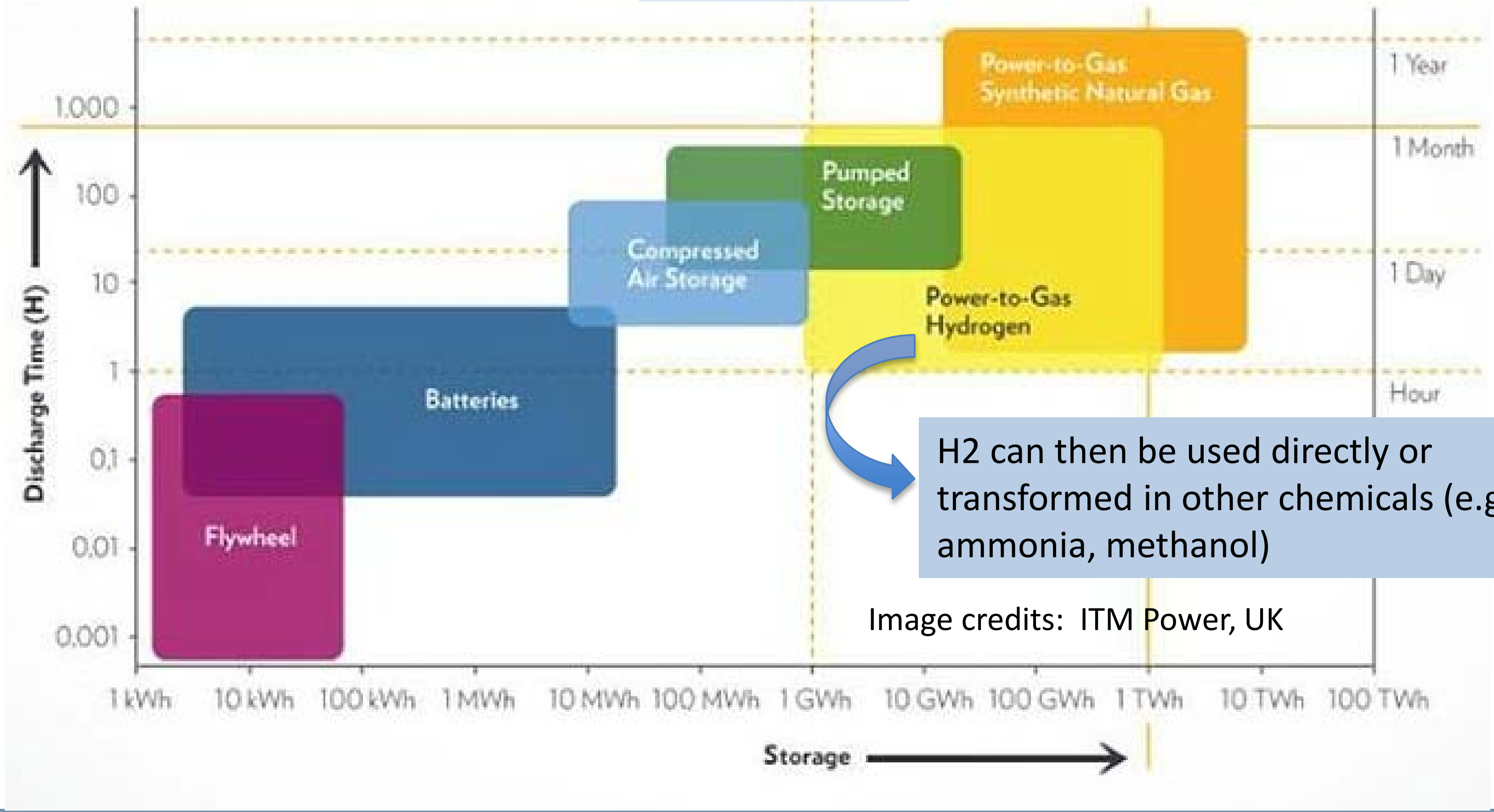
Energy storage and Power-to-gas (P2G)

- pumped hydro
- P2G, production of H_2 and synthetic natural gas (SNG)
- compressed air (CAES)

High energy storage allow long discharge time w. ~no losses

- flywheels, supercapacitors
- batteries (Ni-MH, Li-ion, redox..)

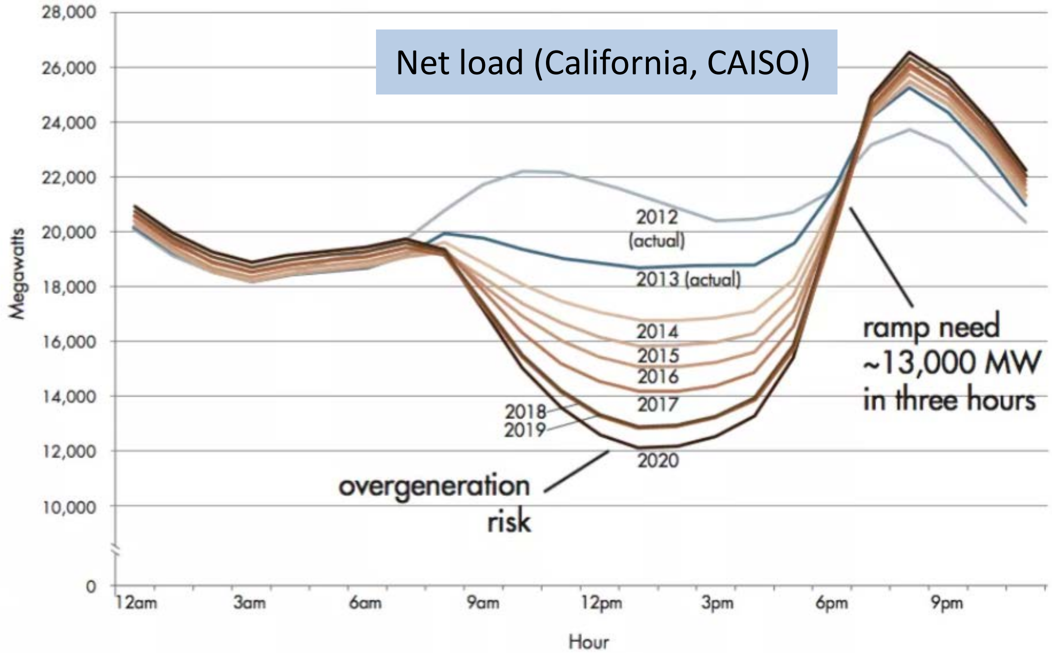
Low energy storage / fast discharge



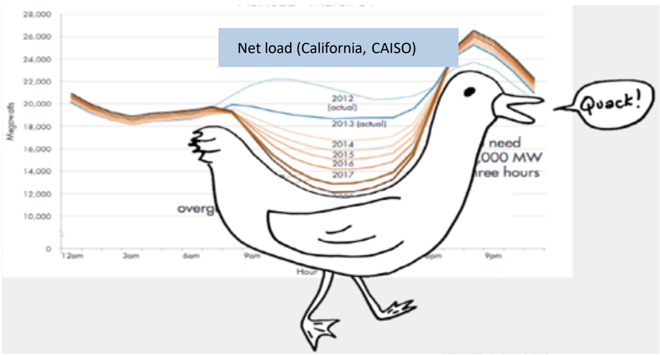
H2 can then be used directly or transformed in other chemicals (e.g. ammonia, methanol)

Image credits: ITM Power, UK

Large energy storage capacities are required, both on a daily and seasonal scale



- The «duck curve» of residual load (demand – RES production) in regions with high FV penetration



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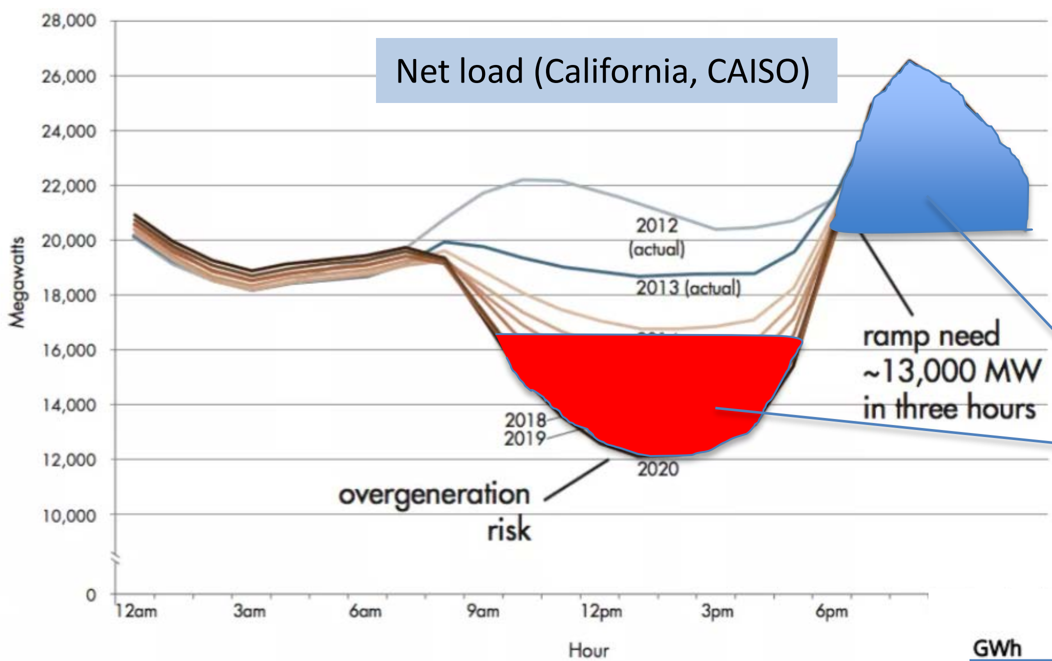
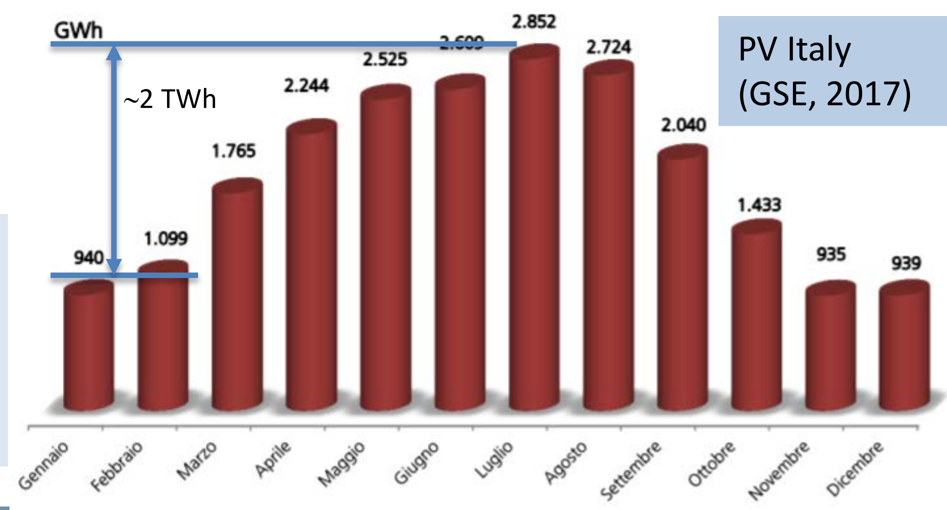


- The «duck curve» of residual load (demand – RES production) in regions with high FV penetration

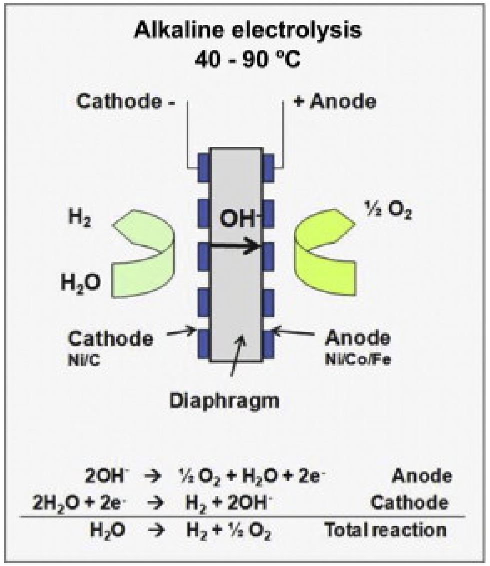
- The annual RES production profile (especially FV) has strong seasonal oscillations stagionali

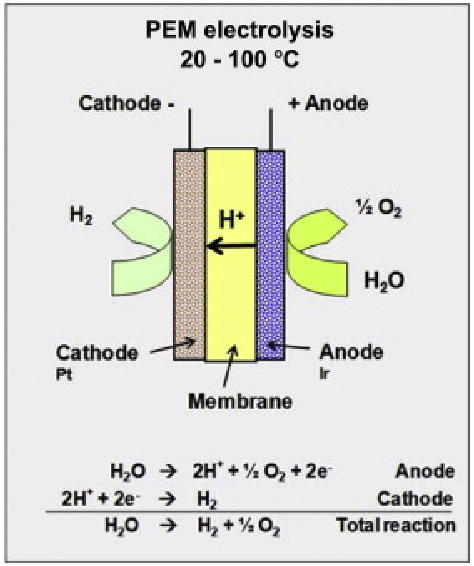
- Chemical energy storage tends to be the most competitive option for large energy capacities (TWh scale – perspective tens of TWh…)



Power-to-gas with hydrogen production

- The Power-to-gas concept aims at producing H_2 from renewables, using excess or dedicated electricity from PV, wind or other non programmable RES
- H2 is generated through electrolysis: $H_2O\ (l) + EE \rightarrow H_2\ (g) + \frac{1}{2} O_2\ (g)$ in alkaline or PEM cells (the latter showing higher compactness and wide dynamic capabilities)

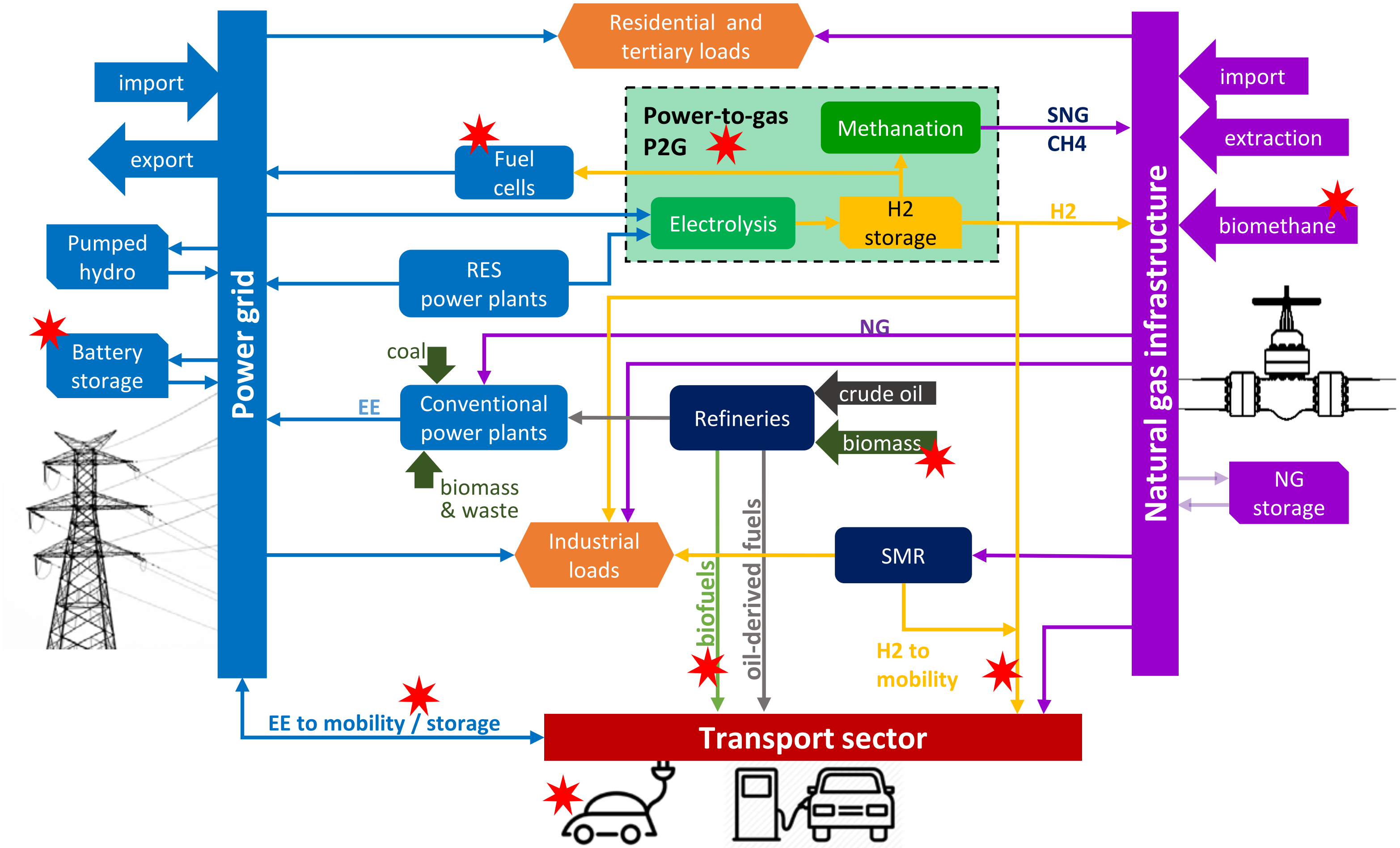




PEM electrolysis stack , 2 MW (ITM Power, WHEC 2016)

➢ **Electricity–to-fuel efficiency (rif. LHV): 65-75%**

Mid-to-long-term evolution: integration of power, transport and NG networks with *power-to-gas* and *electricity storage*

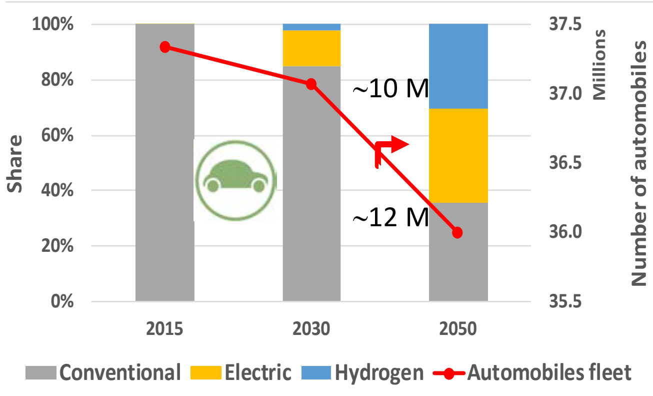


- **Electric-to-electric storage →** existing pumped hydro + newly installed batteries + plug-in EVs + others…
- **P2G to link networks → role of hydrogen as clean energy vector**
- Natural gas grid with blends of NG, biomethane, H_2

RES and mobility scenarios @ 2030-2050

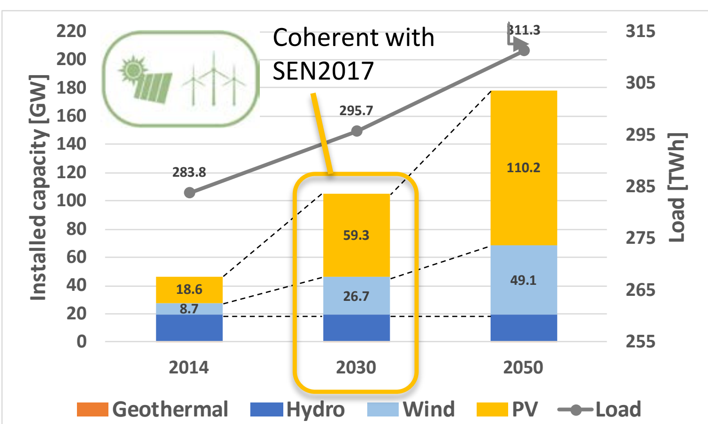
Mobility: 2050 IEA scenario *

High alternative automobiles penetration forecast



Electricity: 2050 RES technical potential scenario**

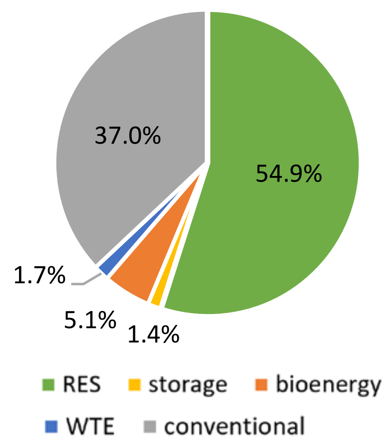
Maximum feasible PV & wind capacity ***(5-6 times vs current)***



* IEA, *H2&FC Technology Roadmap*, 2015 (% for EU4 – UK+D+F+ITA, scaled to ITA), ** P. R. Defaix et al., *Technical potential for photovoltaics on buildings in the EU-27*, 2012
RE-Shaping Project, *Long Term Potentials and Costs of RES*, 2011

- ➢ Through multi-nodal grid simulation models for countries or regions we can estimate the availability of H_2 from P2G, based on scenarios for RES deployment, grid demand evolution and clean mobility development with battery EVs and hydrogen FCEVs

Scenario Italy @2050: grid demand coverage (rete + EV)



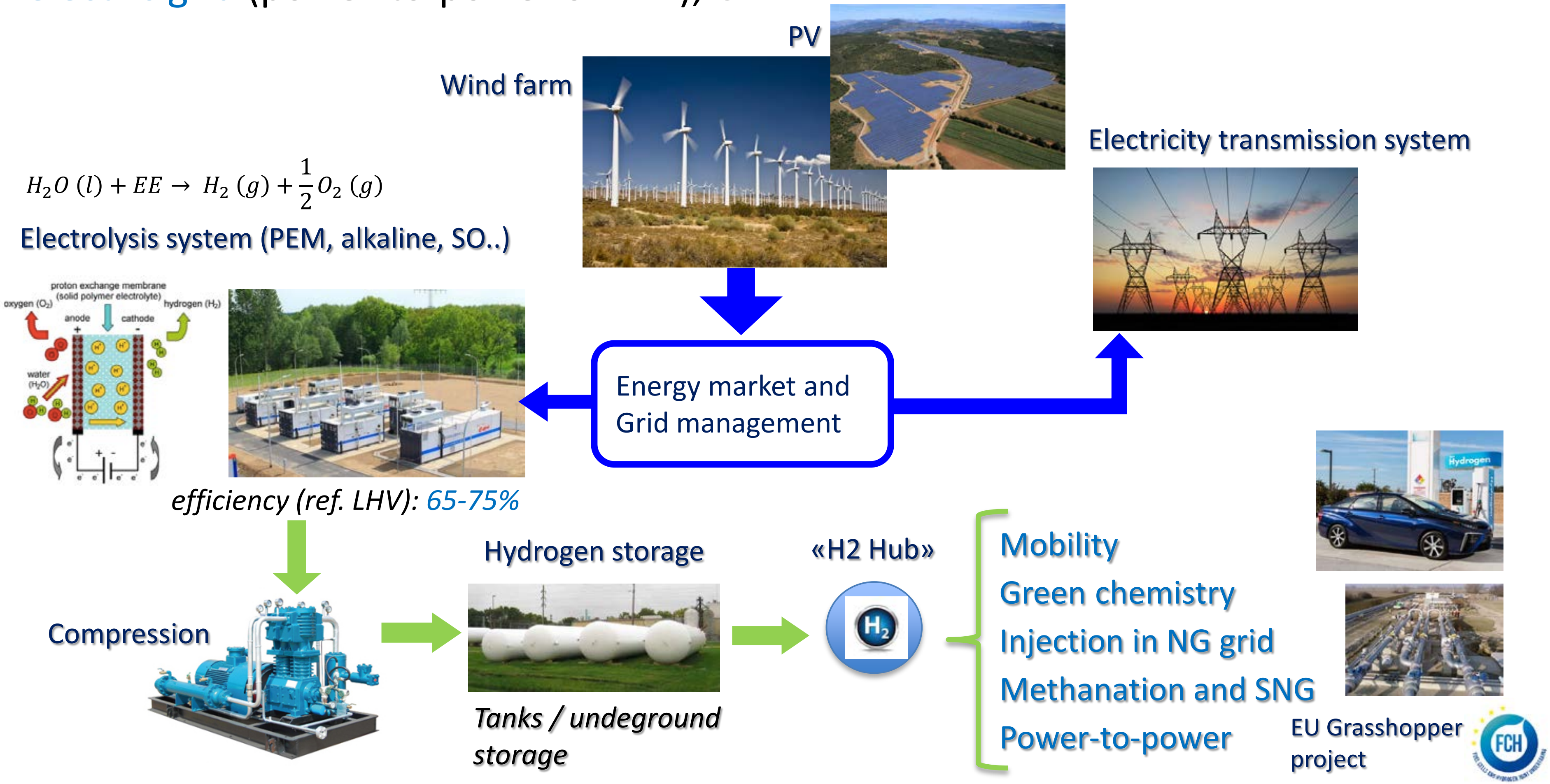
- ➢ Nearly 735 kt H2/year (81% of demand) can be covered by RES, with 26.2 GW P2G installed capacity

Note: the -80% target requires further efforts (other RES, CCS, nuclear…?)

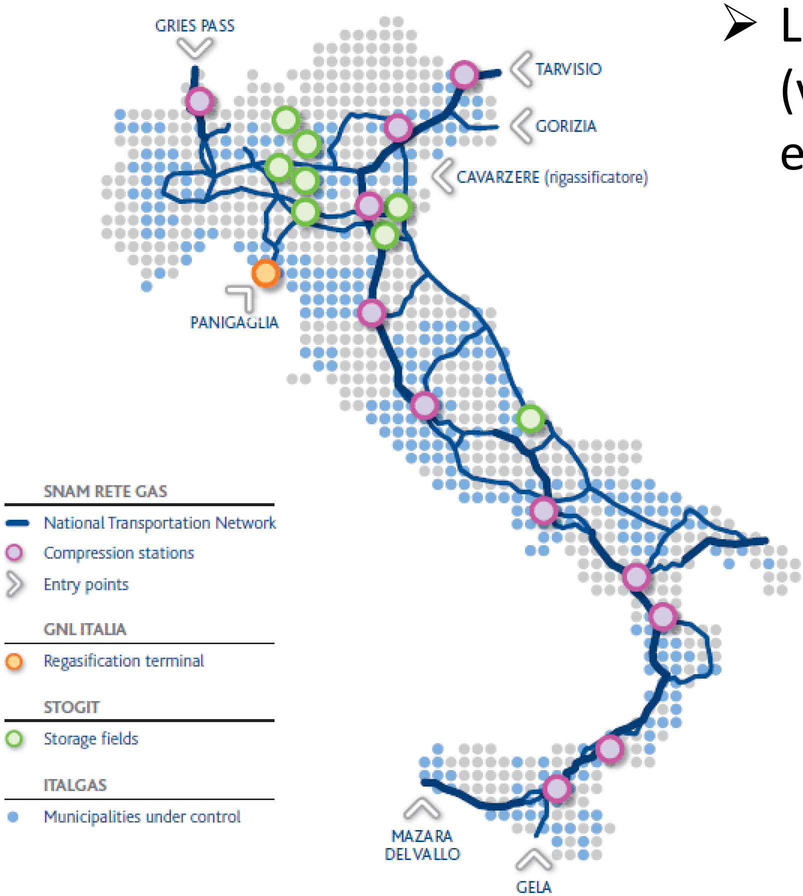
From: P. Colbertaldo, G. Guandalini, S. Campanari "Modelling the integrated power and transport energy system: The role of power-to-gas and hydrogen in long-term scenarios for Italy", Energy, Vol. 154, p. 592-601, doi.org/10.1016/j.energy.2018.04.089, 2018

Chemical energy storage with Power-to-gas and H_2 uses

✓ Hydrogen may work as «**energy hub**» for uses in industry (green chemistry, production of NH_3 / methanol), mobility, greening of natural gas, support to the electric grid (power-to-power or P2P), CHP



Examples: 1) Injection in the NG grid



SNAM RETE GAS (2017)
Transportation: 76 billions of Nm^3
Storage: 16 billions of Nm^3

- Large blending capacity: achieving a 10-20% H_2 (vol.) average requires nearly all today's electricity from PV and wind

	NG transported ($\times 10^9$ Nm^3/y)[1]	EE to P2G @ $10\%_{vol}$ H_2 (TWh_{el}/y)[2]	Total production from PV + wind (TWh/y)[3]
Germany	81	40.5	115
Italy	65	32.5	41.5
UK	77	38.5	61.5
USA	779	389.5	307

[1] data from BP Statistical Review of World Energy 2016
[2] with 60% efficiency ($H_{2,LHV}/E_{el}$)
[3] from AWEA, energytransition.org, BP statistical review, US Energy Information Administration, www.gov.uk/government/statistics, Italy's GSE.

- *Let's not forget that «city gas», used in Italy up to the '70-80 was ~50% hydrogen…*

Techological limits to grid injection

- H2+NG mixing has been studied in several specific projects (e.g. NaturalHy , EU FP6) through risk evaluations and experimental testing of pipelines and domestic appliances, showing good compatibility up to e.g. 20-30% H_2 (vol.)
- Adaptation issues for industrial uses (e.g. exisiting engine and gas turbine fleets) where - in absence of actions- the max tolerable quantity is limited to few % (3-5%)

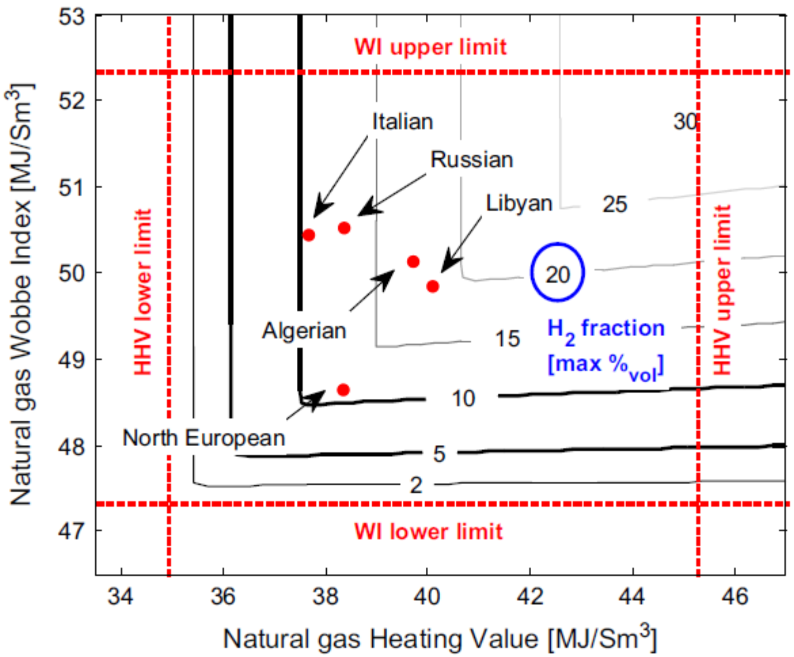
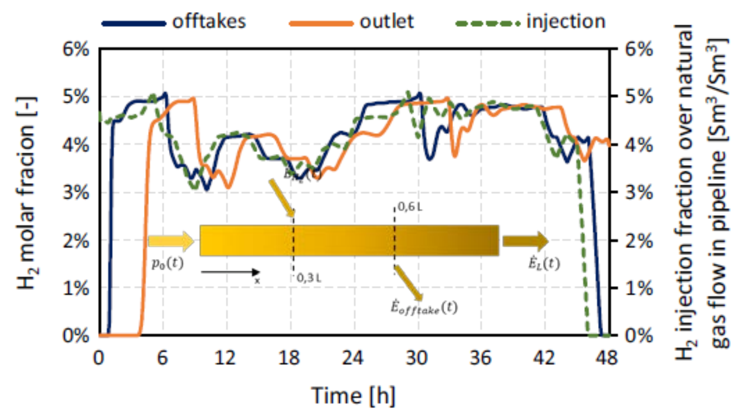


Fig. 3. Maximum allowed hydrogen volumetric fraction (%) in order to fulfill TSO requirements (dotted lines; values referred to Italy limits) as function of natural gas properties (HHV and WI); some NG types commonly present in the European grid are located as reference.

- Depending on NG origin, the max H_2 % changes to respect LHV / WI grid code parameters
- Issues of NG grid '*quality tracking*' in presence of variable injection and takeoff

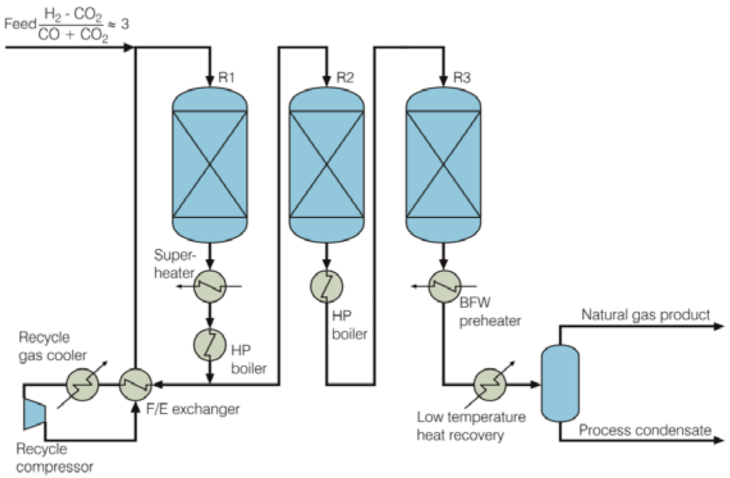


Da: G. Guandalini, P. Colbertaldo, S. Campanari "Dynamic modeling of natural gas quality within transport pipelines in presence of hydrogen injections", Applied Energy, 10.1016/j.apenergy.2016.03.006 , 2017.

2) The alternative of methanation with re-use of CO_2

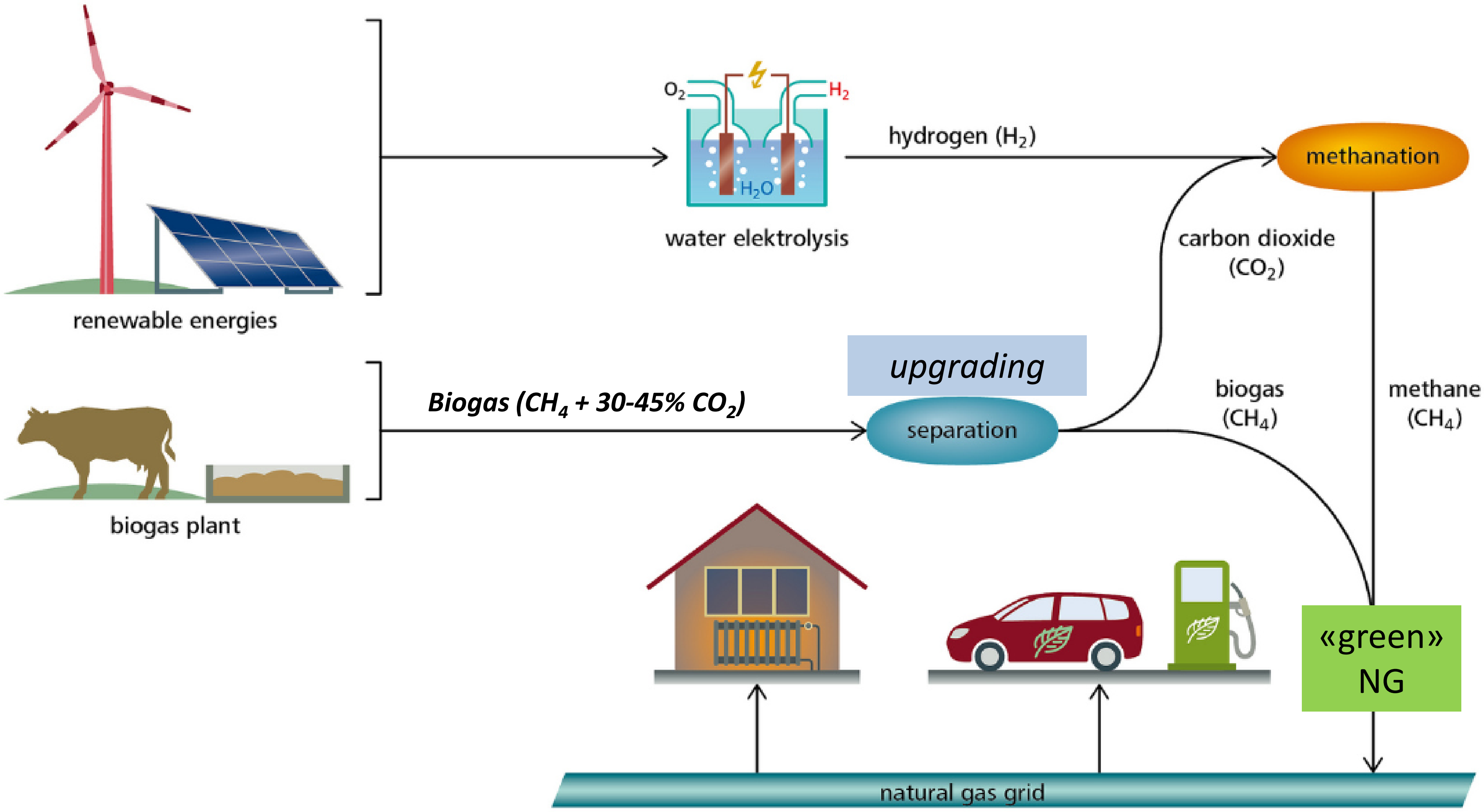
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad \Delta H^0_{298K} = -206.28 \text{ kJ/mol}$$
$$CO + 3H_2 \rightarrow CH_4 + H_2O \qquad \Delta H^0_{298K} = -41.16 \text{ kJ/mol}$$

- The ***Sabatier*** process allows methantion through CO2 and CO hydrogenation (Sabatier & Senderens, 1902)
- Exothermal reactions working at low temperature and high pressure (e.g. 300÷400°C, 40÷60 bar).
- Process efficiency ~80 % (LHV_{ng}/LHV_{syn}); generated heat can be recovered for high pressure steam production.
- ***The process aims at producing a synthetic natural gas (SNG) which respects grid code specifications and allows injection in the distribution grid.***



Es. layout of Topsoe TREMP™ processs; other process include HICOM (British Gas), Lurgi, CONOCO, Linde.

CO_2 may come from biomass , e.g. from biogas upgrading



3) Direct use of H_2 for mobility

Example of recent proposals for passenger cars

Toyota Mirai

- Fuel cell @ 114 kW (153 CV)
- Two hydrogen tanks, 5kg H_2 @ 700 bar (tank weight 87.5 kg), driving range 500 km
- With batteries for braking energy recovery
- Can generate electricity to feed the grid in case of black-out

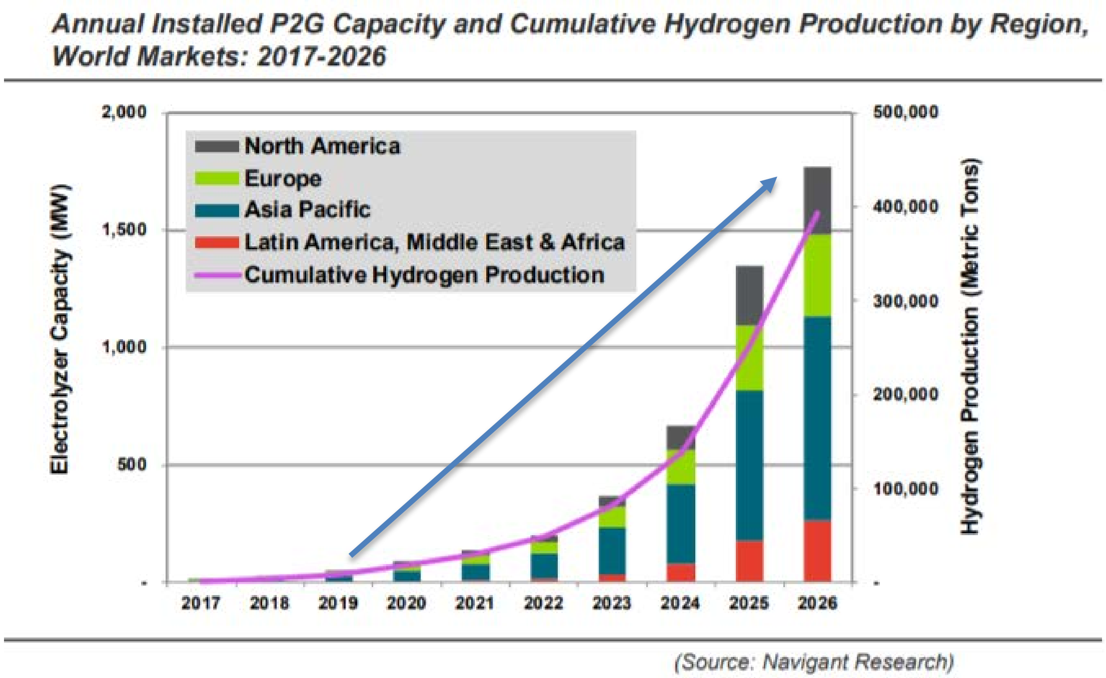
Leasing 36 months
@ 499 $/month
Or purchase 57 k$
(Japan / USA)

Hyundai Nexo

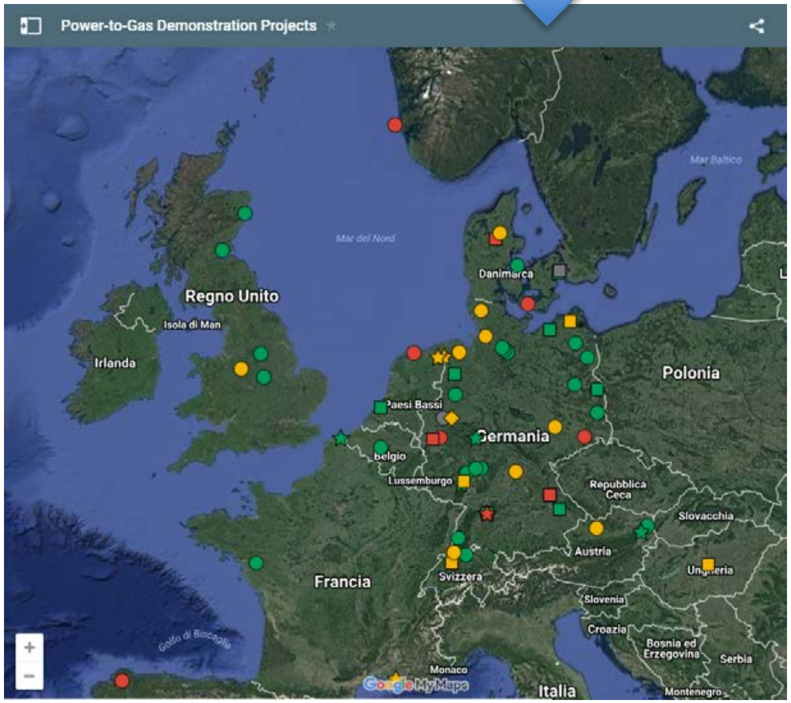
- Fuel cell @ 120 kW (163 CV)
- Three H2 tanks, 6.3 kg H_2 @ 700 bar, driving range 800 km

+ Many applications for bus and trucks

P2G in the world



Interactive map:
www.europeanpowertogas.com
/demonstrations



- Nearly 20 plants operating in 2015, 80 expected within 2018 (Germany, USA, Canada, Spain, UK, China,Japan, France).
- Some P2G plants are injecting H2 in the NG grid, e.g. Falkenhagen (2013), Werlte (2013, methanation), other feed refuelling stations or P2P systems.

One the first P2G plants

Falkenhagen Power-to-Gas Plant (Germany, Uniper)

Location: Falkenhagen, Brandenburg.
Initiated Oct. 2013, first grid injection 2014
PEM electrolysis (2 MW_{el})
Production: ~ 360 m^3/h H_2, injection in local distribution grid through a 1.6 km H_2 pipeline

Conclusions

- ✓ Electricity, NG and mobility energy networks will interweave significantly in future, with a central role for energy storage technologies
  - ➢ Issues have to be solved before a 100% RES electric system could be physically implemented, a parallel use of traditional (e.g. fossil fuel based) technologies is deemed necessary also in a medium-long term perspective.
  - ➢ **Hydrogen technologies and P2G would strongly help in facing the challenge**.

- ✓ P2G – H2 allows to recover over-demand RES power generation
- ✓ Mobility using FCEV + BEV scenarios has advantages vs. BEV-only or FCEV-only
- ✓ Italy: even at very high RES scenarios, best results still show ~50% primary consumption from fossils, far from goals → call for additional actions (more/other RES? CCS? Nuclear?)

Ongoing development

- Role of different storage technologies (H2, NH3/methanol, innovative batteries, CAES...) and grid interconnections improvement
- Economic analysis of infrastructure costs in the different scenarios
- Economic optimization of P2G + wind farm operation in selected case studies
- Extension of the analysis to heavy-load transport

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Thank you for your attention

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http://www.energia.polimi.it/ - http://www.gecos.polimi.it/

https://www.h2it.it/

2018
Stati Generali IDROGENO e Celle a Combustibile

Il ruolo dell'idrogeno nella transizione energetica e nella mobilità

28 novembre 2018, Politecnico di Milano

Dipartimento di Energia – Sala Consiglio – Via Lambruschini 4, Milano