Commercialisation of Energy Storage in Europe

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The study was authored by a coalition of over 30 organizations

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What is the objective of this study and why is it unique?

Objective of the study

- The objective of the study is to **assess the role and commercial viability of energy storage** (both power-to-power and conversion of electricity to heat and hydrogen) in light of the projected development of the European electric power system towards 2030 with an outlook to 2050
- The study is primarily intended for **policy makers, regulators, investors, OEMs and utilities**, to provide them with an understanding of
  - Role that energy storage can play in the European energy sector
  - The business case for individual energy storage services
  - Actions required to improve the competitiveness of energy storage
- The study was conducted with the assumption of **technology neutrality**

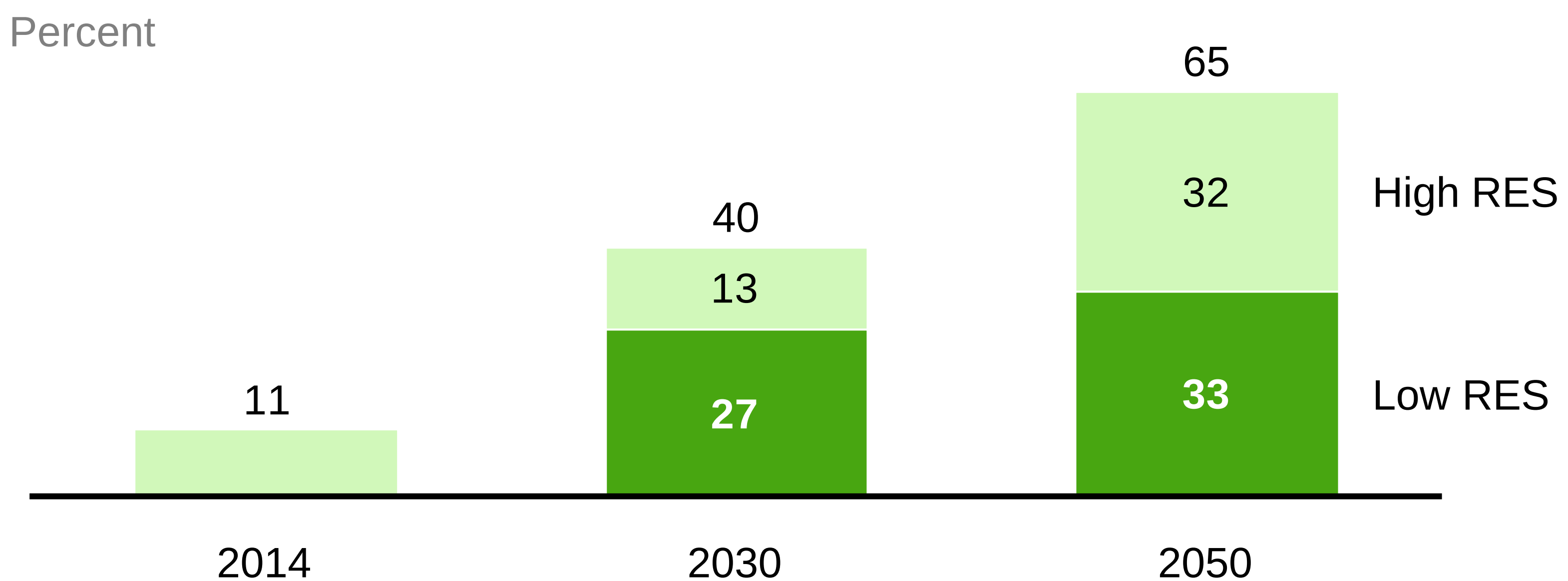
FCH-JU Energy storage study

Why is the study unique?

- Combines **multiple perspectives**:
  - Evolution of the energy system
  - Technology costs
  - Storage business cases
  - Regulation
- Considers not only power-to-power storage but **heat storage** and **hydrogen** for **use outside of power sector**
- Created by a **coalition of 30+ organizations** spanning the whole energy space

CONTEXT: The proposed growth in intermittent RES penetration will decrease predictability of the power system

Share of intermittent RES in power generation, EU27+2

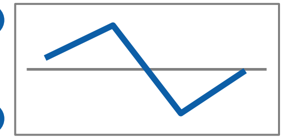
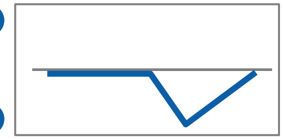
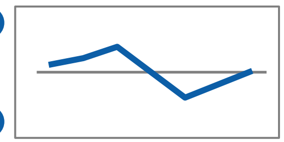
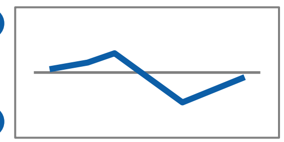
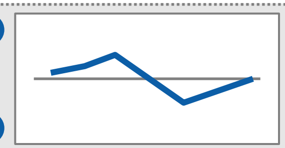
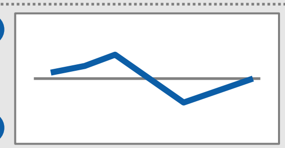
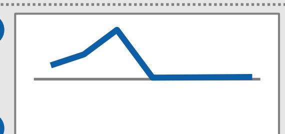


From …	Implication		… to
Demand led pattern	Predictability of required non-RES generation declines	»	Supply led patterns
>50% required non-RES generation[2]	Utilization of non-RES generation declines	»	~15% required non-RES generation[2]

1 Required fossil generation after RES and nuclear

2 Example of Germany

CONTEXT: There are 4 main options for integrating renewables, but all the options have significant limitations

RES integration solution		Deficit solved?	Surplus solved?	Residual load[1]	Limitations
0 Base case situation				Deficit ⊕  Surplus ⊖	
1 Dispatchable generation (hydro, bio-mass, fossil)		✓	✗	Deficit ⊕  Surplus ⊖	▪ Hydro and biomass quantity is limited ▪ Fossil fuels generate CO_2 emissions ▪ No utilization of excess energy
2 Transmission and distribution expansion		(✓)	(✓)	Deficit ⊕  Surplus ⊖	▪ Ineffective if RES production correlated over large area ▪ Hampered by permitting issues and long construction times
3 Demand side management		(✓)	(✓)	Deficit ⊕  Surplus ⊖	▪ Limited by amount of demand that can be shifted and time for which it can be delayed
4 Energy storage	Power-to-power	(✓)	(✓)	Deficit ⊕  Surplus ⊖	▪ *Focus of this study* ▪ *Technologies considered in the study included:* – *Batteries (Li-ion, NaS, Lead-acid, Flow-V)* – *Mechanical storage (pumped hydro, compressed air, liquid air)* – *Hydrogen power-to-power storage* – *Hydrogen for use outside of power sector* – *Heat storage*
	Conversion to heat and heat storage	(✓)	(✓)	Deficit ⊕  Surplus ⊖	
	Conversion to Hydrogen for use outside power sector	✗	✓	Deficit ⊕  Surplus ⊖	

1 Difference between demand and intermittent RES production

All of these option come at a cost to society

CONTEXT: Main methodology followed

It is …	… it is not
3 countries and 1 region	Europe modeled as a whole
Based on granular modelling of electricity supply-demand balance	Static capacity forecast
2 EC scenarios	New scenario modeling
Industry accepted storage and electrolyser cost projections	Independent review of cost projections
Top-down transmission & distribution constraints	Spatial modeling of transmission and distribution constraints

Two main questions addressed by the study

What role will storage play in long-term RES integration?

»1

To what extent will storage be able to help integrate intermittent renewables in the 2030-50 horizon?

What the short term opportunities for storage?

»2

What are the short term opportunities and early markets for energy storage and what actions are required to enable them?

Key findings

» 1 Demand for power-to-power (P2P) time-shift energy storage can grow up to 10x by 2050

» 2 Demand for storage will be highest in island systems and smallest in countries with large hydro reservoirs

» 3 Backup non-RES energy will still be required and substantial excess energy will remain even with 10x current amount of P2P storage

» 4 Conversion to heat and heat storage can reduce the required non-RES generation but will still leave excess energy. Conversion to hydrogen for use outside of power sector will be able to utilize practically all the excess with but cannot reduce the required non-RES generation.

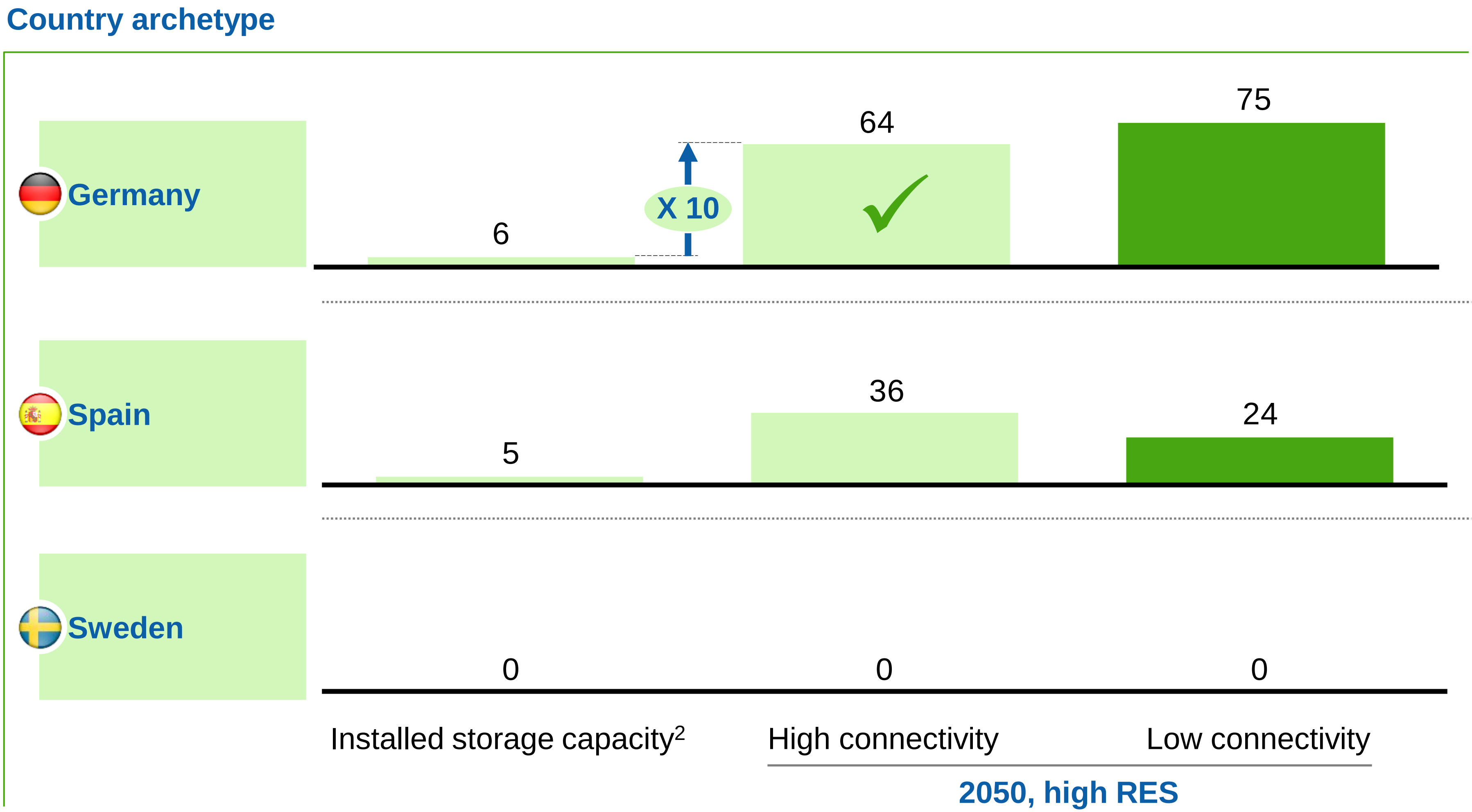
» 5 Commercially viable opportunities for storage will be available in the near term.

» 6 Regulatory change is key for a viable storage business case.

1 The economic demand for P2P storage in 2050 will be up to 10 times current installed capacity

✓ Used for explanation of core results

Economic demand for greenfield time shift storage, GW[1]



1 Amount of storage with 8:1 energy to power ratio and 80% efficiency that achieves benefit of EUR 65/installed kW per year
2 Predominantly pumped hydro storage

2 Demand for storage is highest in island systems, lowest in countries with large hydro reservoirs

	Representing archetype	System description	Implications for time-shift storage
Island systems	Greek island of Crete	▪ **Non-interconnected island system** with high installed wind capacity (~140 MW or ~60% of average load) ▪ Significant **curtailment of wind power** (44 TWh or ~9% of total wind production) due to must-run constraints ▪ **High cost of non-RES generation** due to fleet based on heavy fuel oil and diesel (marginal costs EUR 100-300 per MWh)	▪ Only archetype showing **positive greenfield demand for time shift storage in 2014** ▪ Positive business case for storage driven by **combination of curtailment and high non-RES generation** ▪ European areas with low interconnection and high RES penetration are **potential early markets for storage**
Hydro	Sweden	▪ Nordic country with **large natural hydro reservoir** (~33 TWh or ~800x German pumped hydro capacity) ▪ Hydro and nuclear together accounting for ~80% of power generation, resulting in **very low CO_2 emissions** ▪ **Low installed intermittent renewable** capacity (10% of total generation capacity and staying below 30% even in 2050 high-RES scenario	▪ **No demand for time shift storage** even in 2050 high-RES scenario ▪ **Reservoir hydro is a large natural energy storage**, which can be used for carbon-free provision of flexibility to the power system ▪ Because hydro is renewable energy, **no over-installation of intermittent RES is required** and hence no excess energy is generated

3.1 Backup non-RES energy will still be required and substantial excess energy will remain even with 10x current P2P storage

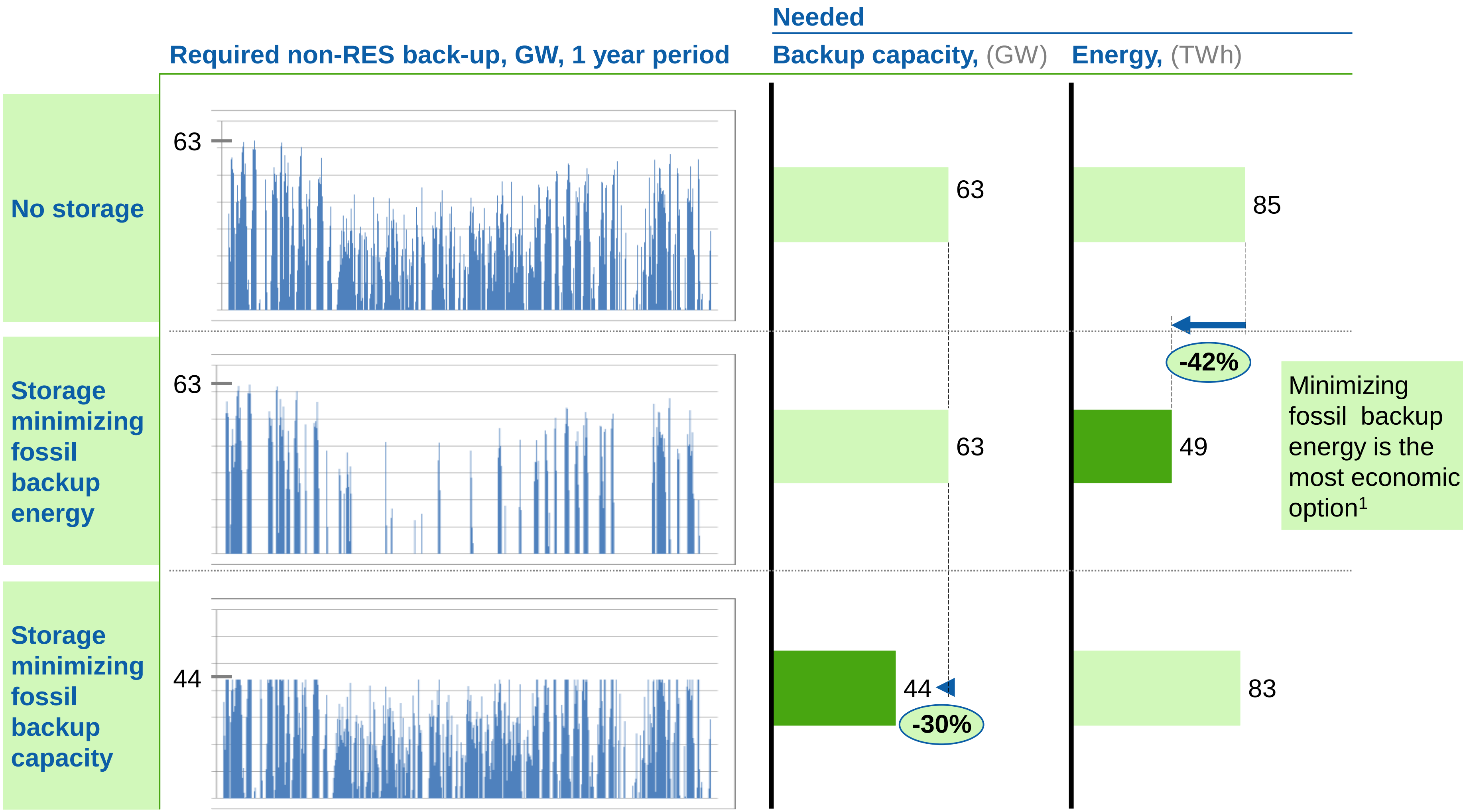
Germany 2050 High-RES case, TWh

No storage | **With 8-hour storage[1]** | **With 32-hour storage[1]**

1 64 GW, 0.5-2 TWh,90% efficiency

3.2 Storage can also be used to reduce the required backup generation capacity but this reduces storage utilization significantly

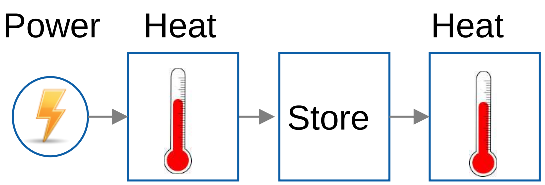
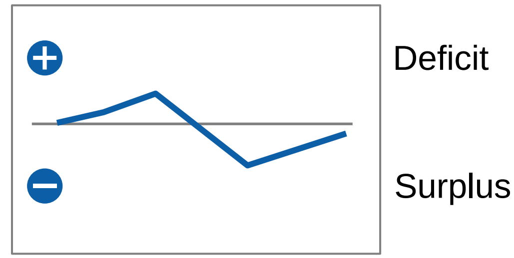
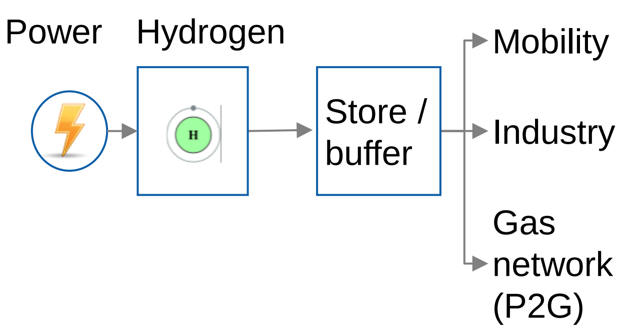
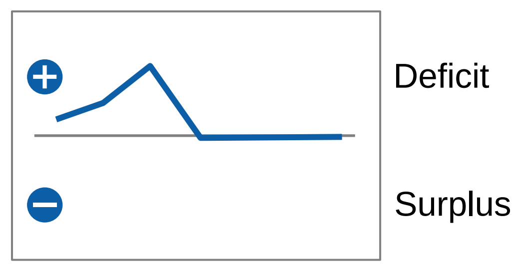
Germany 2050 High-RES case, 64GW/512GWh of storage



1 At the assumed fuel, CO2 and non-RES backup capacity costs 100 EUR/ton of CO2, 35 EUR/MWh of gas, 670 EUR/installed kW of non-RES capacity with 30 years of lifetime and 23 EUR/kW annual opex

SOURCE: Project modeling, IEA

4.1 Heat and hydrogen are two additional options for utilizing excess renewable energy

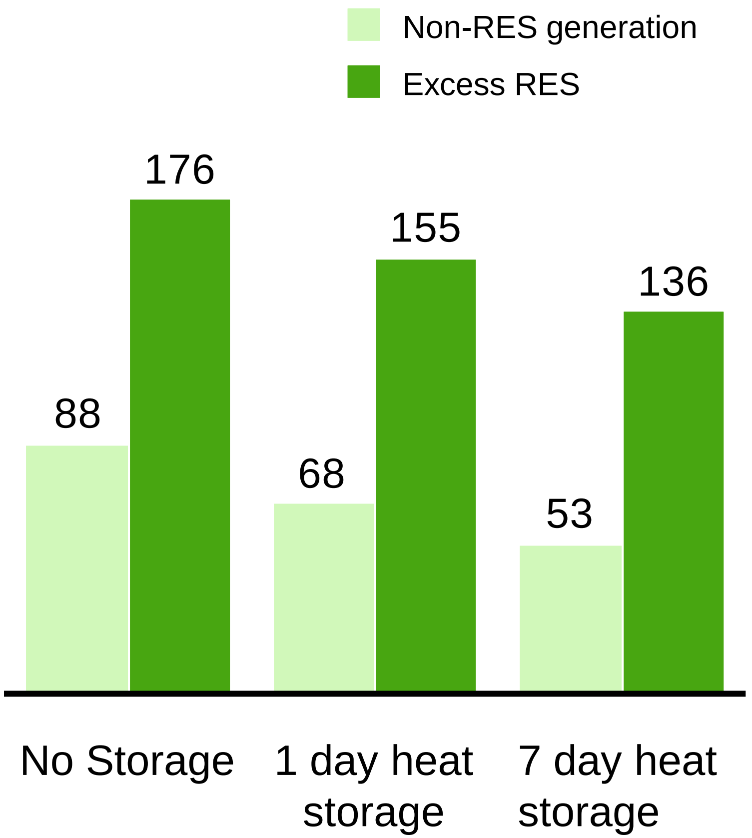
	Illustration	Role in RES integration: Residual load[1]	Role in RES integration: Limitations
Conversion to heat and storage of heat			Impact limited by electrified heat demand, its seasonality and amount of heat that can economically be stored
Conversion to hydrogen and its use outside of the power sector			Impact limited by the amount of hydrogen that can be used locally or economically transported to a demand center

1 Difference between demand and intermittent RES production

4.2 Conversion to heat and heat storage can reduce the required non-RES generation but will still leave excess energy

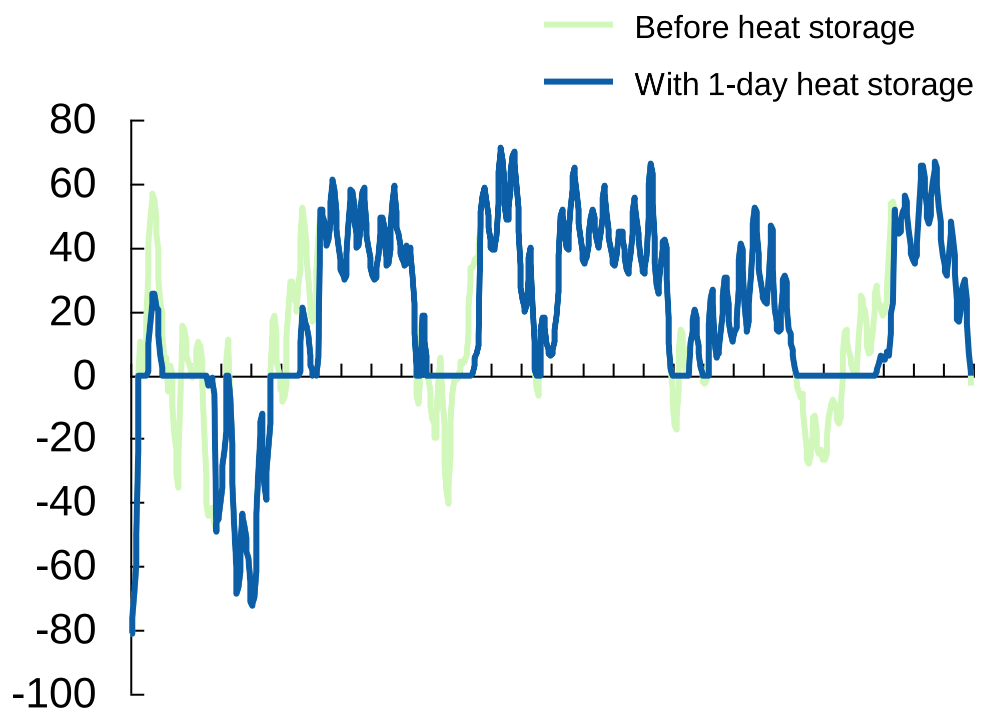
Required backup decreases…

German High-Res 2050 example, TWh



…but there are still long periods with excess RES and need for non-RES generation

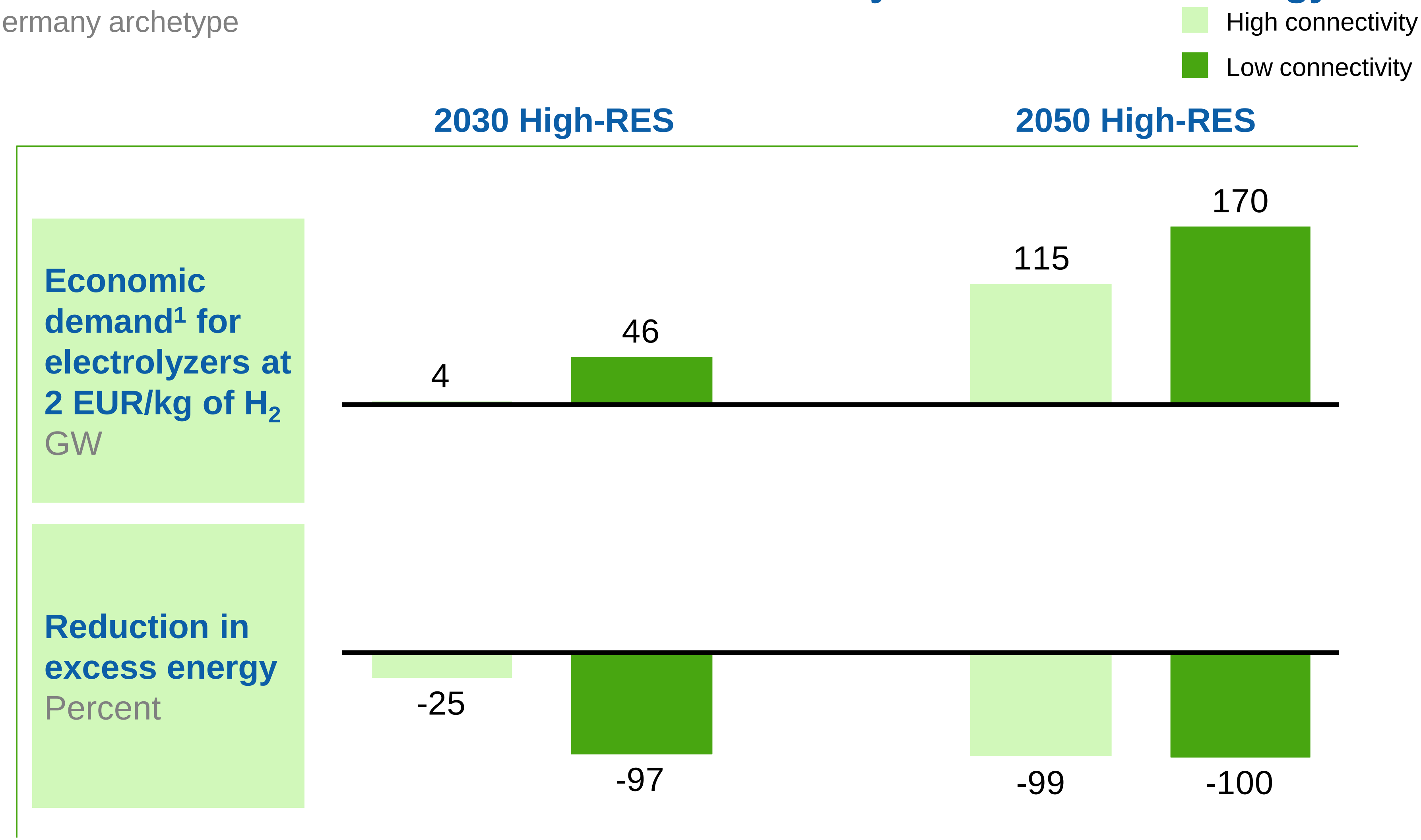
Residual load February 2050, GW



SOURCE: Project modelling

4.3 At 2 EUR/kg of hydrogen, large installed electrolyzer capacity would be viable and able to utilize nearly all excess RES energy…

Germany archetype



1 Installed electrolyzer capacity achieving 60 EUR/installed kW per year of benefits at given hydrogen plant gate cost – this corresponds to EUR 370/kW capex, 8% WACC, annual opex at 1.2% of total capex and 10 years lifetime (FCH-JU 2014)
Assumes no time-shift storage is in place.

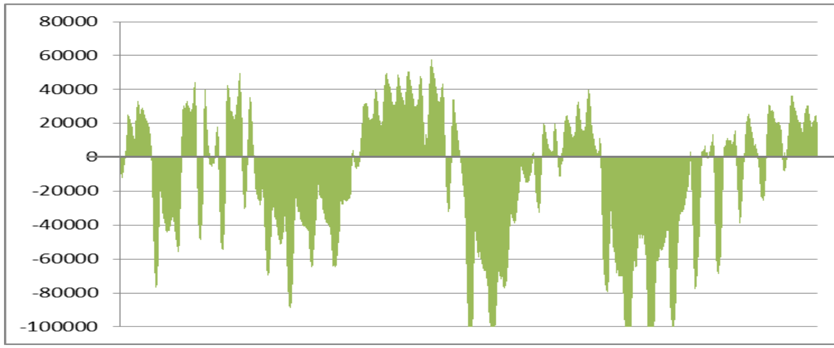
4.4 …as energy capacity is a softer constraint on electrolyzer utilization than for other P2P or heat storage

EXAMPLE

Germany; High RES; March 2050

Starting point – periods with excess energy and deficit

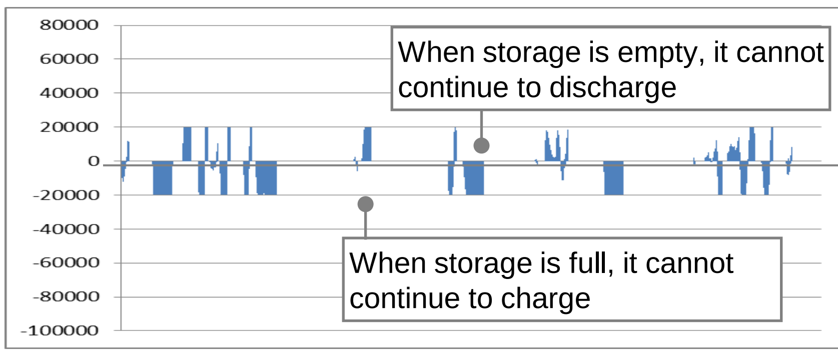
Load, MW



Deficit to be satisfied by backup generation

Surplus, to be curtailed

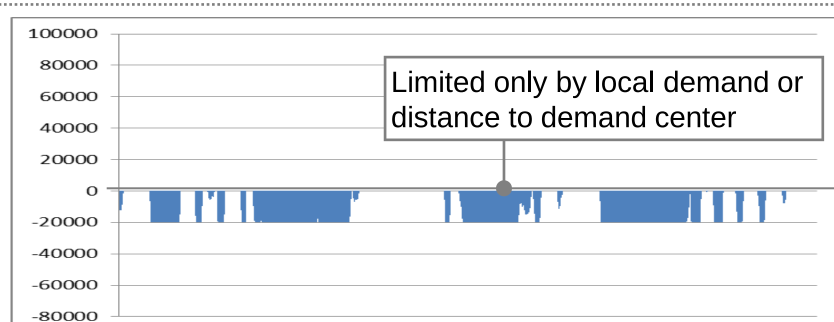
P2P storage with limited energy capacity[1] can only utilize part of the excess electricity…



Discharging

Charging

….while utilization is less limited for conversion to hydrogen



Charging and removing from the electricity system

1 1:8 power to energy example, 20GW power capacity

5 The emerging storage technologies have short-term, economically viable uses that can serve as early markets

2014
2030

1 P2P storage used for daily time shift

2 P2P storage providing secondary reserve

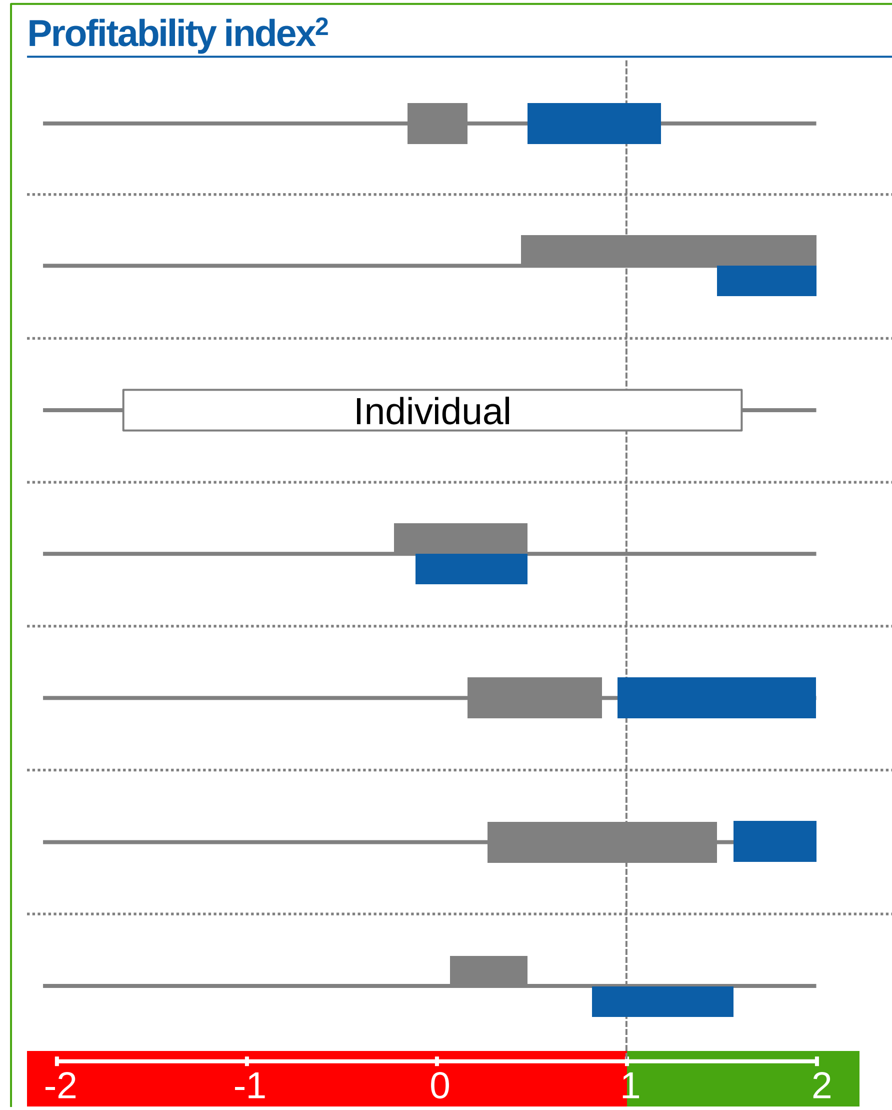
3 P2P storage providing T&D deferral

4 P2P storage reducing wind farm curtailment

5 P2P storage firming wind farm output

6 P2P storage integrating home PV

7 Electrolyser converting electricity to hydrogen



1 Assuming current network fees, WACC of 8%, electricity price development according to archetype modeling

2 NPV of project cash-flows excluding initial outlay divided by initial outlay. Profitability index greater than 1 denotes positive NPV, range based on values for different storage technologies

6 Regulatory change is key for a viable storage business case in the early markets

From …	… to
▪ **Little regulatory acknowledgement** of storage and hence a lack of storage-specific rules and insufficient consideration of the impact of new regulation on storage	▪ Storage acknowledged as a **unique and specific component of the energy system** and new regulation is explicitly taking impact on storage into account
▪ **Payments for curtailment to RES producers**, creating a disincentive to productive use of the curtailed electricity	▪ **Remove price signal distortions** caused by compensating curtailment (without necessarily reducing support for renewables)
▪ **Lack of clarity on the rules under which storage can access markets** – in particular the inability of TSOs and DSOs to own and operate storage in some countries and lack of rules on access of storage to the ancillary services market	▪ Define **conditions**, under which **network operators can own and operate storage** or purchase T&D deferral service from market ▪ Define **conditions** under which storage can **participate in the ancillary services market**, including time for which service has to be pro-vided, minimum time before reactivation, etc.
▪ **Application of final consumption fees to storage**, even though storage does not constitute final use of the energy	▪ **Exemption** of storage from **final consumption fees** (taxes, levies) and double grid fees

Each of these regulatory changes has impact on multiple stakeholders and its overall costs and benefits need to be further analyzed

General Conclusions

Main questions	Main conclusions
» 1 To what extent will storage be able to help integrate intermittent renewables in the 2030-50 horizon?	In 2050, there will be demand for up to 10x current installed P2P storage capacity. However, this capacity would only partially decrease required non-RES backup energy as well as amount of excess RES energy Conversion to heat and heat storage can reduce the required non-RES generation but will still leave excess energy in the High-RES scenario. Conversion to hydrogen for use outside of power sector will be able to economically utilize practically all the excess
» 2 What are the short term opportunities and early markets for energy storage and what actions are required to enable them?	Short-term, economically viable uses in the power system can serve as early markets (time shift in island systems, T&D upgrade deferral, provision of frequency reserve, home storage coupled with PV) In these early markets, regulation should ensure storage can participate on a level playing field with other flexibility options

H2 specific conclusions 1: P2P through H2 could be viable for long term storage, for power and energy intensive applications

Overview of technology LCoEs for power and energy intensive applications

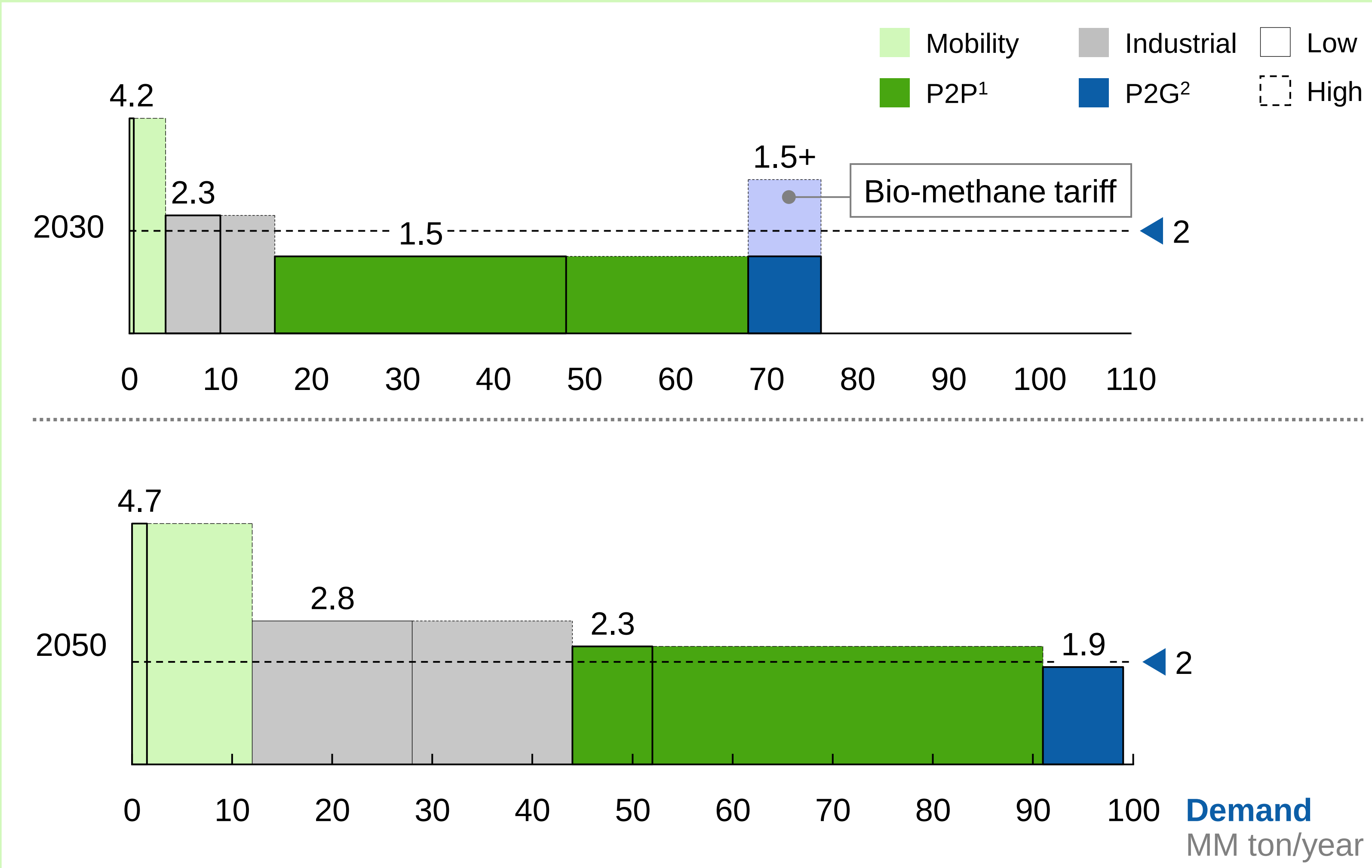
EUR/MWh

	Power intensive application example (1h of storage)				Energy intensive application example (8h of storage)				Long-term storage (2000h of storage)
	2013		2030		2013		2030		2030
	Low	High	Low	High	Low	High	Low	High	Low
Li-ion	138	573	38	106	181	754	76	218	1000s
NaS	N/A	N/A	N/A	N/A	196	269	42	68	1000s
Flow-V	155	238	57	97	148	239	50	96	1000s
Lead	211	379	59	110	114	262	39	98	1000s
CAES-A	27	N/A	19	N/A	49	N/A	37	N/A	1000s
LAES-A	40	82	32	66	71	166	57	133	1000s
PHES	18	28	18	28	24	42	24	42	>400
P2P H_2	Electrolyzer and CCPP with salt cavern storage considered for P2P H_2 - suitable for longer term storage								140

SOURCE: LCoE model; ISEA RWTH; 2012: Technology overview on electricity storage, coalition input

H2 specific conclusions 2: H2-mobility to develop quite early, industrial second follower, P2P and P2G only if costs significantly decline

EUR/kg of hydrogen, maximum plant gate prices to access market[1], EU27



1 Maximum hydrogen prices based on substitution of incumbent fuel. Prices do not take into account additional infrastructure costs (eg. reelectrification facilities for P2P) 2 Assuming all electricity storage demand is covered by hydrogen, 3 Assuming 5% of natural gas replaced by hydrogen

SOURCE: Study calculation, HyUnder study, FCH-JU Electrolysis in Europe study

H2 specific conclusions 3: Hydrogen could be produced at below 3 EUR/kg when grid fees are taken out by 2030

EUR/kg of hydrogen[1]

	2013		High-RES 2030		
Capex (EUR/kW)	**Alkaline (1100)**	**PEM (2090)**	**Alkaline (580)**	**PEM (760)**	**SO[2] (625)**
Capex	2.02	4.05	0.99	1.22	0.91
Opex	0.20	0.27	0.10	0.08	0.12
Wholesale electricity	1.32	1.39	1.64	1.54	1.41
Sub total	**3.54**	**5.71**	**2.73**	**2.84**	**2.45**
Grid fees and levies	3.24	3.42	3.00	2.82	2.58
Total	6.78	9.13	5.73	5.66	5.03

Estimate for 2020-25 between 2.5-4 €/kg without grid fees

Grid fees and other levies are potentially the largest driver of overall hydrogen cost per kilogram, eliminating these costs can drive down hydrogen production prices to the ~2.7 EUR/kg range

1 10MW size, 50% utilization, 47-57% efficiency, 8% WACC, Fees & levies & wholesale electricity based on archetype modeling, for industrial users in 20,000-70,000 MWh (highest Eurostat band)
2 76% efficiency, can rise to 92% if free waste heat is available
SOURCE: Eurostat, E4Tech & Element Energy, Team analysis

H2 specific conclusions 4: What actions should FCH-JU take to support deployment of hydrogen-based energy storage?

	Research and development	Pilot/demonstration	Large scale deployment
Electrolyzer technology	▪ Support R&D for reduction of electrolyzer capex costs	▪ Demonstrate feasibility of delivering EUR 2/kg green hydrogen from curtailed renewable electricity ▪ Continue mobility demonstration and deployment projects	▪ Support P2G technical regulation (% of H2 by volume injected limits, installation of meters in the grid,…) ▪ Support EU-wide standards for "green" hydrogen eligible for feed-in tariffs
H2 storage & distr. technology	▪ Support R&D on geological effects of bulk H2 buffering / storage	▪ Demonstrate P2G, analyse effects on NG devices operating on H2-NG mixtures	▪ Support technical regulation for usage of H2-NG mixtures
Supply – demand "ecosystem"	▪ Continue research into suitable locations for possible production of hydrogen from curtailed renewables	▪ Demonstrate H2 from renewables providing grid services	▪ Advocate required regulatory changes to minimize hydrogen production costs (exemption from fees and levies, access to frequency reserve market) ▪ Support P2Gtechnical regulation (% of H2 by volume injected limits, installation of meters in the grid…) ▪ Support EU-wide standards for "green" hydrogen eligible for feed-in tariffs

Final steps for study

- Launch event late ’14, early ‘15
- Study to be available at FCH-JU website
  http://www.fch-ju.eu/page/publications
- Happy to support initiatives for the dissemination of the study

THANK YOU FOR YOUR ATTENTION!