VRE development, increasing flexibility needs and the role of electric energy storage

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1. VRE development

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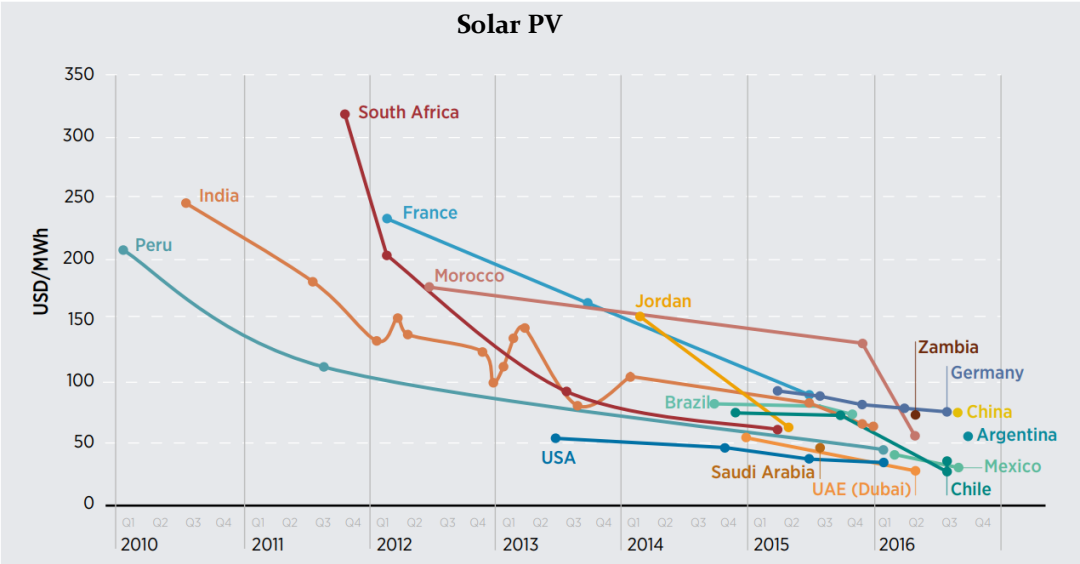
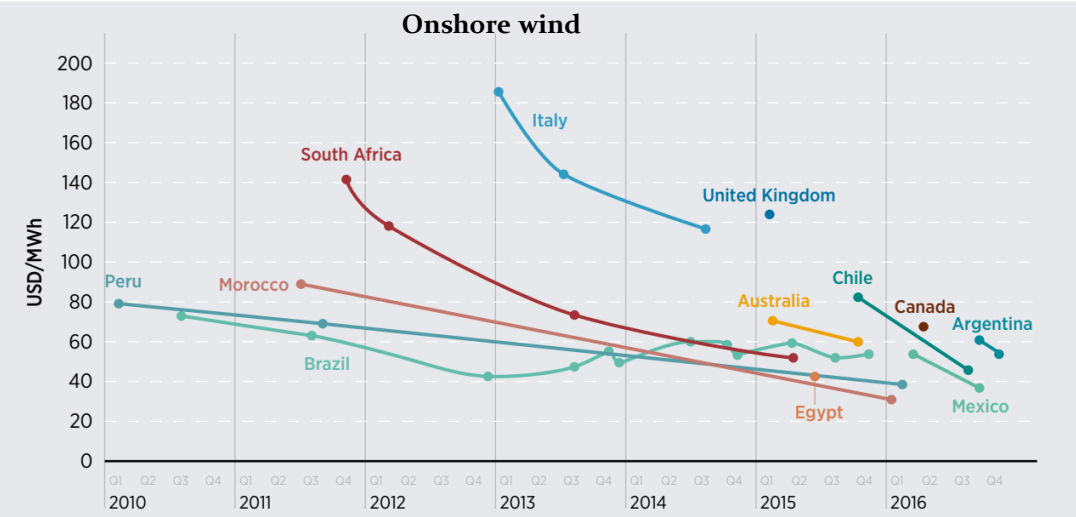
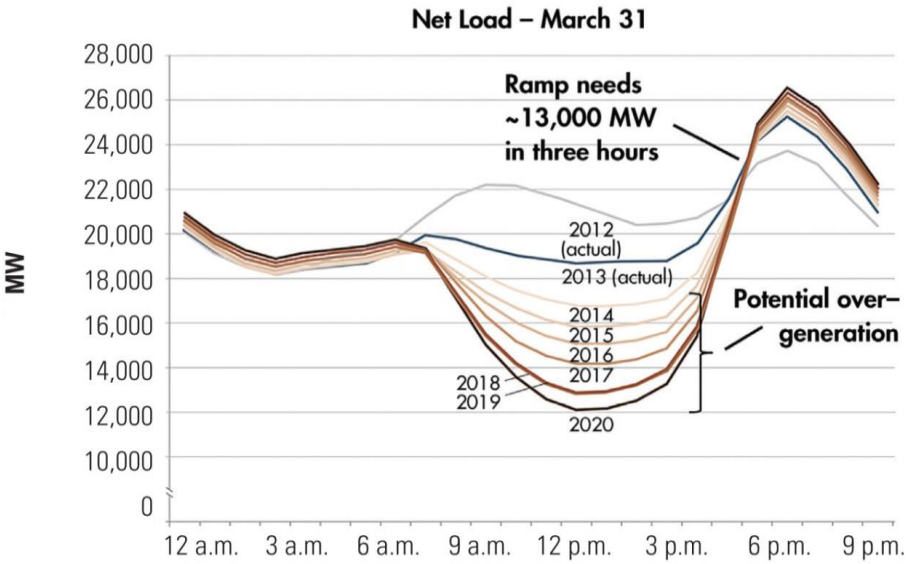
Evolution of average auctions prices for VRE technologies, January 2010-September 2016



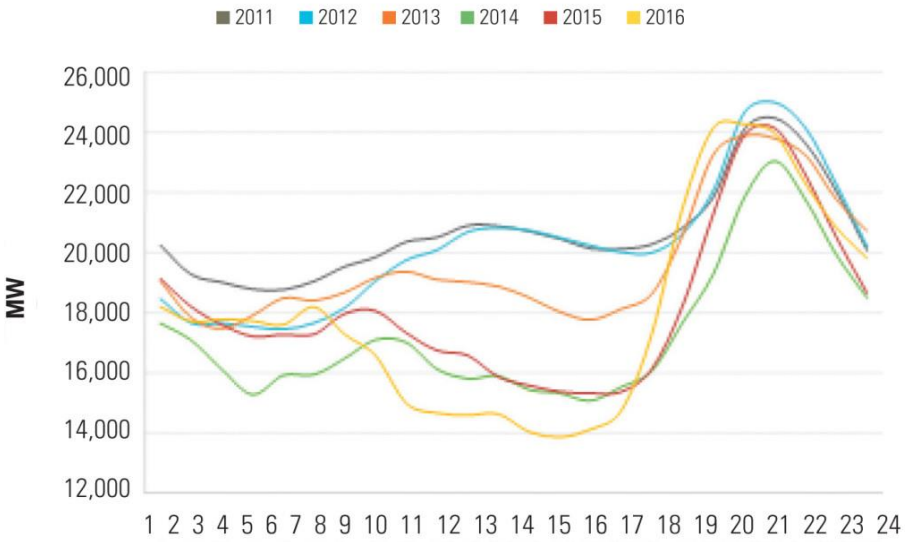


Source: IRENA 2017

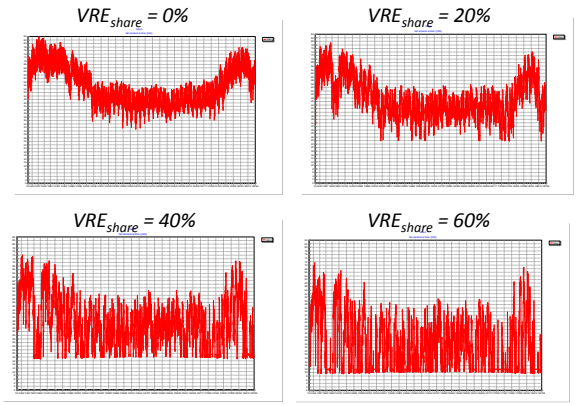
2. Increasing flexibility needs

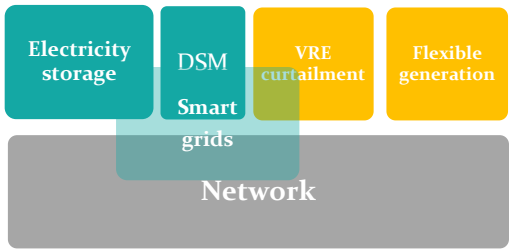


Duck curve. Source: CAISO 2013



Actual duck curve. Source: ScottMadden (October 2016)





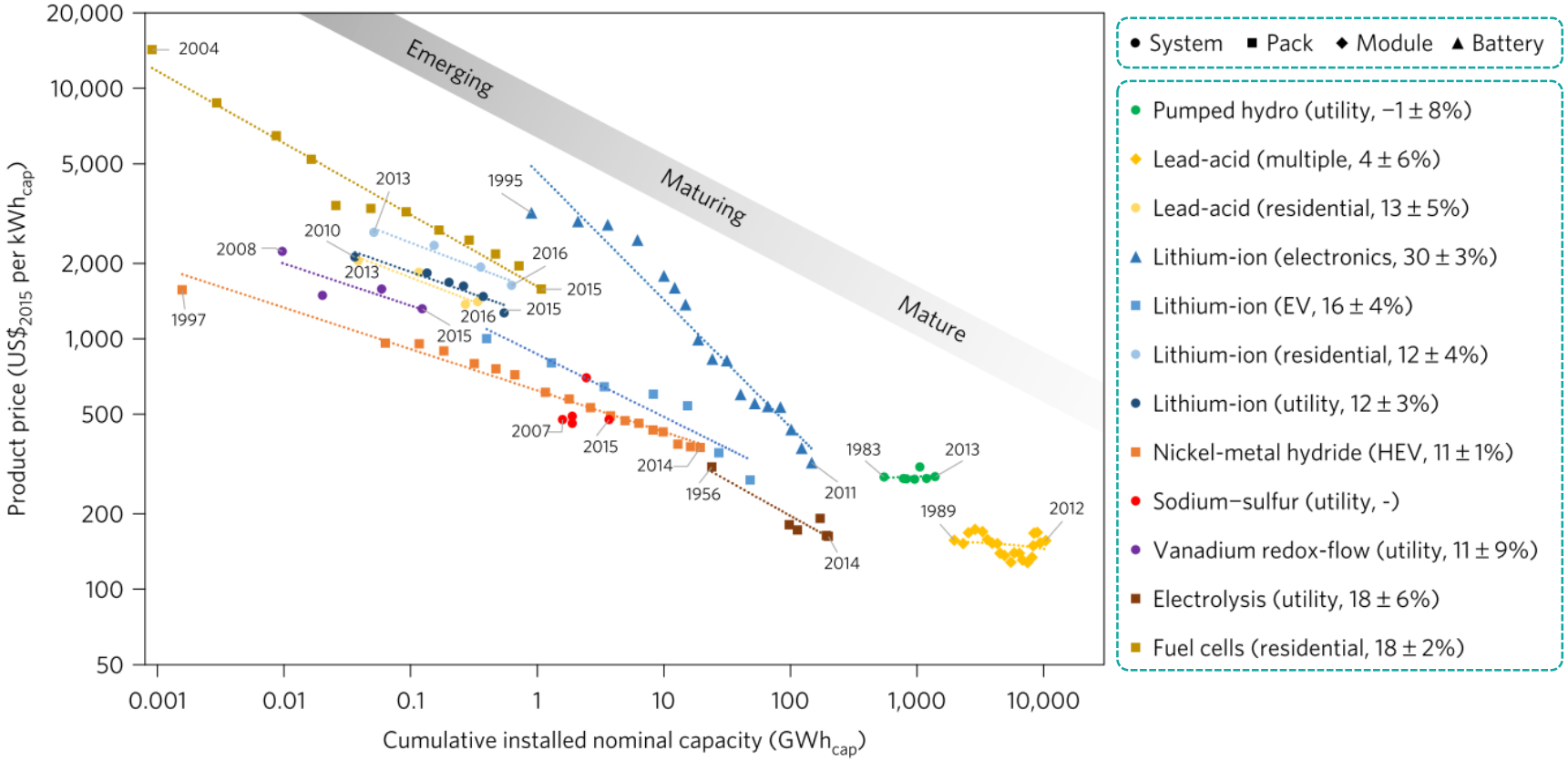
3. The role of electric energy storage

Kinetic energy			Potential energy		
Thermal technologies	Electrical technologies	Mechanical technologies		Electrochemical technologies	Chemical technologies
Hot water	Supercapacitors	Flywheels	Pumped hydro	Lithium ion	Hydrogen
Molten salt	Superconducting magnetic energy		Compressed air energy	Lead acid	Synthetic natural gas
Phase change material				Redox flow	
				Sodium sulfur	

Taxonomy of energy storage technologies. Source: Deloitte 2015

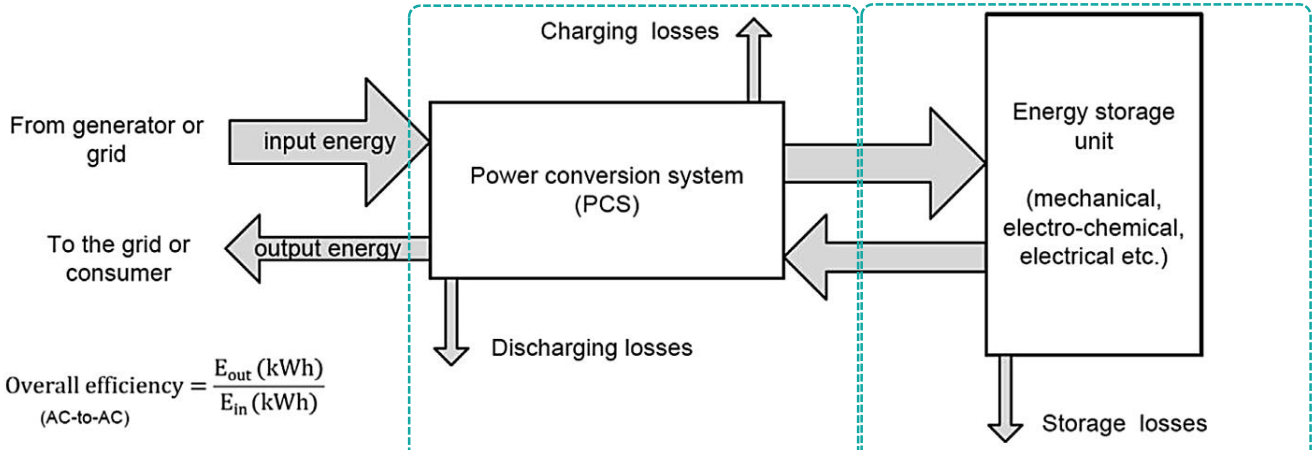
- *EES are a family of technologies using different energy conversion systems*
- *Each technology has its own technical characteristics making them more or less suitable for different applications (see appendix for further details)*

3. The role of electric energy storage



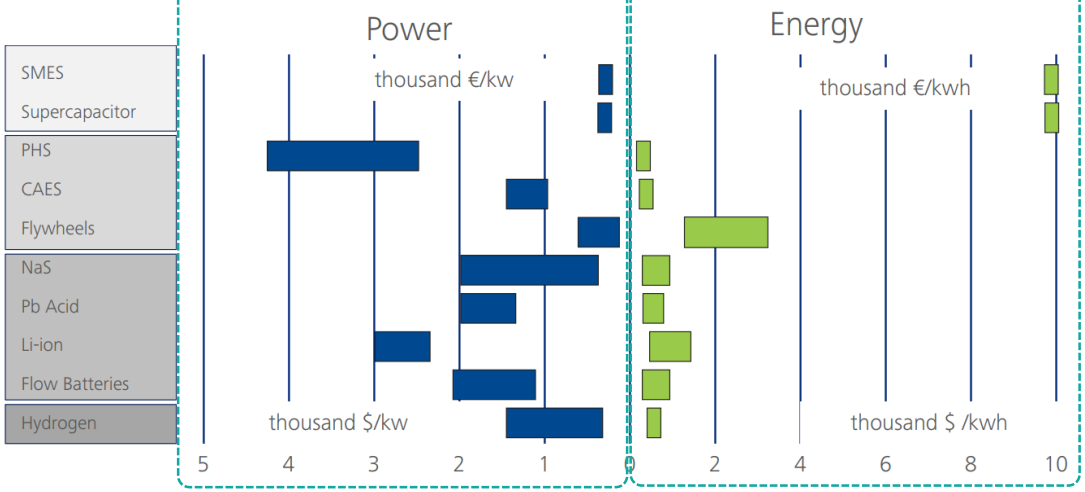
Learning curves of some EES technologies. Source: Schmidt et al. 2017

3. The role of electric energy storage



$$\text{Overall efficiency} = \frac{E_{out}\,(kWh)}{E_{in}\,(kWh)}$$
(AC-to-AC)

Components and energy flows of EES technologies. Source: Zakeri and Syri (2015)



Cost ranges of energy storage technologies. Source: EPRI (2010) and SANDIA Labs (2011)

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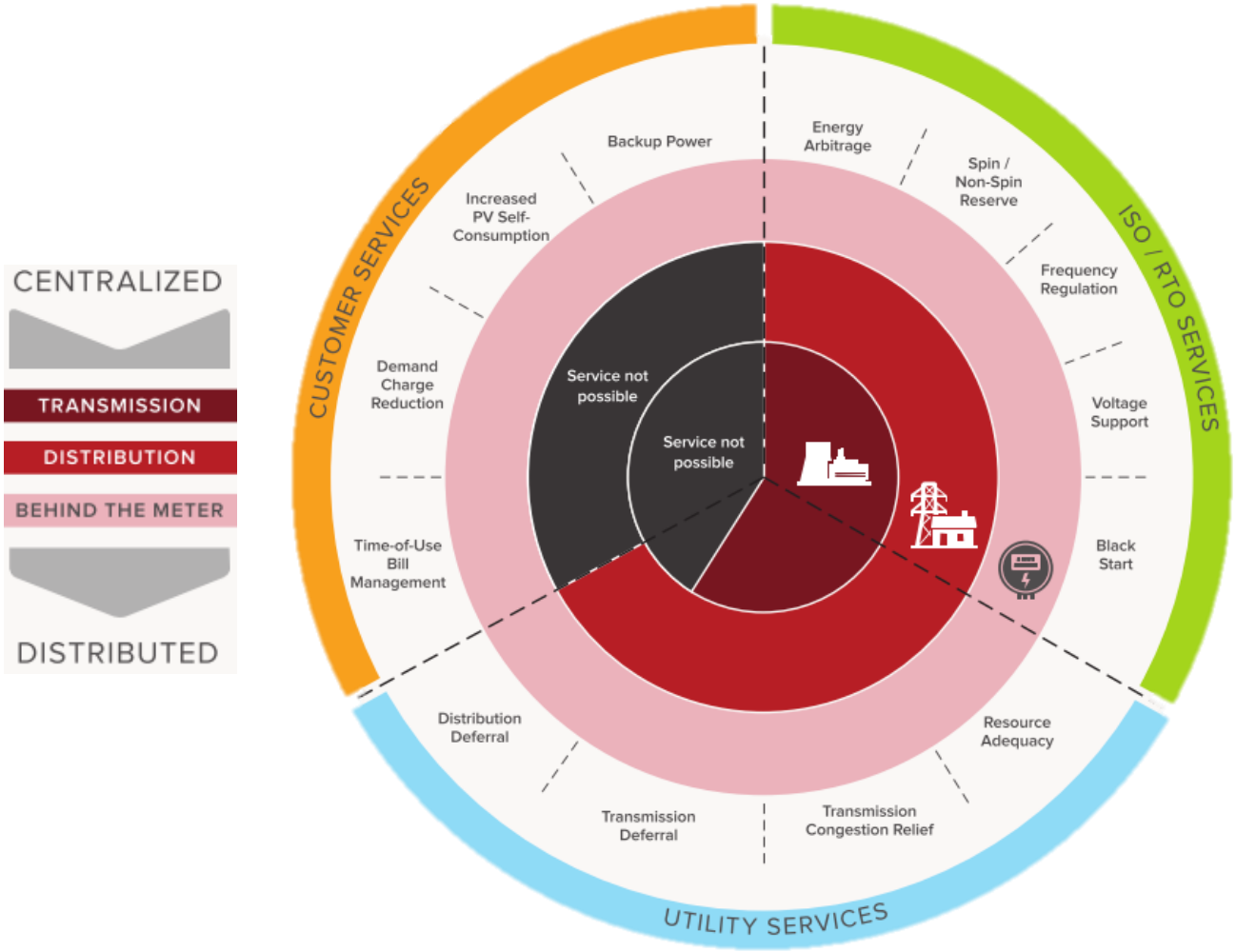
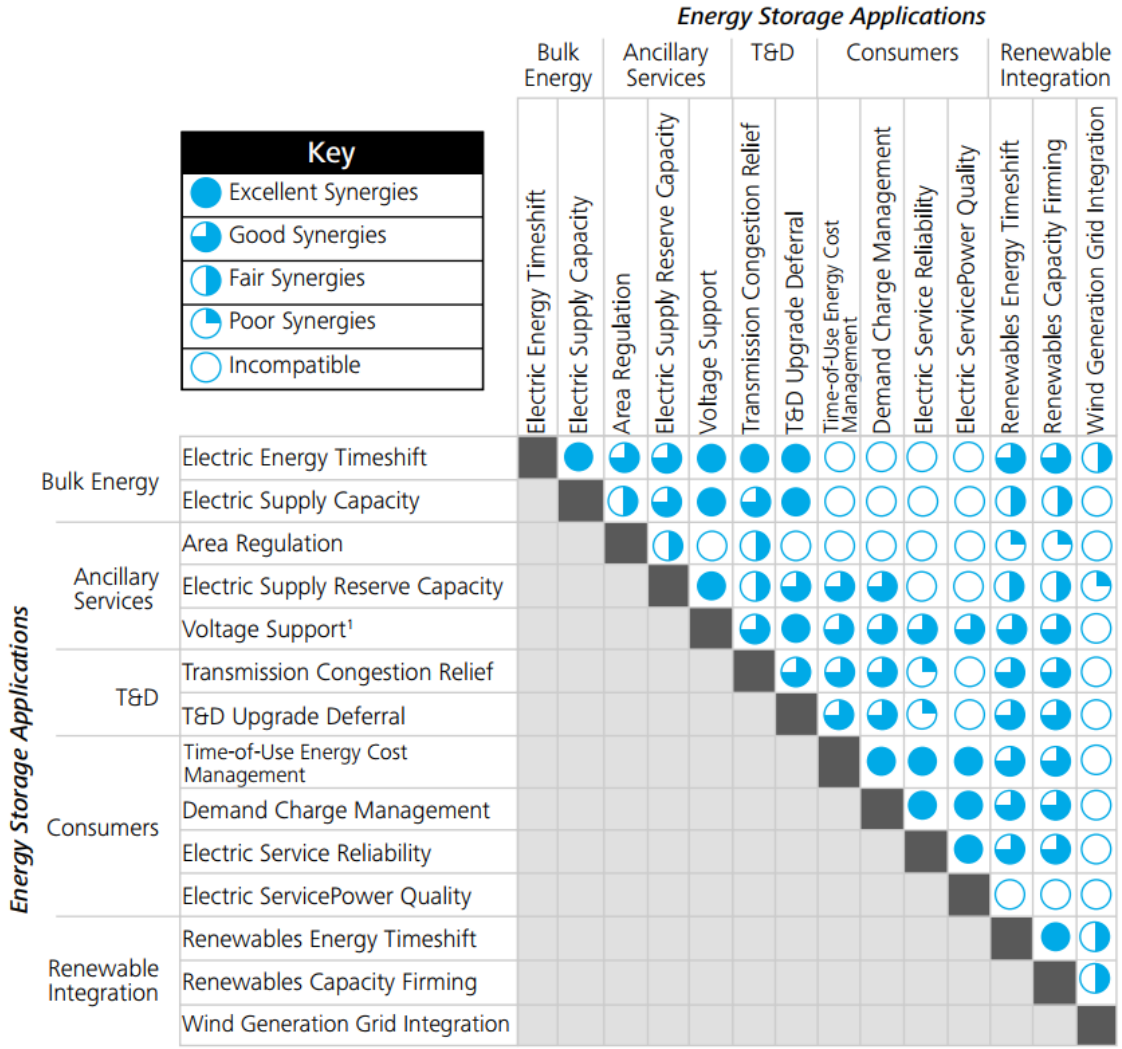
The system benefits of storage capabilities



Services that can be provided by EES technologies. Source: Fitzgerald et al. 2015 (RMI)

3. The role of electric energy storage



Complementary energy storage application. Source: Eyer and Corey 2010 (Sandia lab)

4. Regulatory and market considerations

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- **The case of EES on isolated systems (microgrids and islands):**

It is currently the niche market for EES and « smart grid » solutions but also it is a open-air laboratory for prove of concepts. In such systems EES are being successfully deployed and operated (e.g. EDF SEI managing near 80% VRE systems in the Ile de Sein, Ile de Mafate, isolated villages in Guyana, etc.).

⇒ There is only a regulated entity across the hole value-chain of electricity supply.

⇒ The EMS is the key part of the system (i.e. "self-dispatch")

⇒ Proved technical and economical feasibility

- **The case of EES on interconnected systems:**

There is a growing need for flexibility as VRE penetration increases (e.g. CA, Hawai, South Australia, UK, Germany, PJM, etc.), so business cases of EES are improved and they start to take a place in the SyS markets. Nevertheless, there are still important market barriers and regulatory issues to be overcome for large-scale development.

⇒ The wholesale markets results on optimal schedules (MO) and then "central-dispatch" is operated by TSOs.

⇒ Taking advantage of learning-by-doing effects from isolated systems

⇒ Companies are taking stakes and preparing for the right incentives to go (e.g. The 27/03/2018 Electricity Storage Plan of EDF, the move of Total towards electricity business and the SAFT acquisition, etc.).

4. Regulatory and market considerations

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Some issues being addressed:

- **Electrification is at the center of the EU decarbonization goals**, and RES are perceived as the main mean for achieving them.
- **The new EU Network Codes (2016-2017) points to the right direction** for considering new market-products with higher granularity and gate closures closer to RT, thus, improving the case for a market-based development of new flexibility options.
- **Negotiations on the « The Winter Package »** considering and supporting EES and "smart grids" solutions.

4. Regulatory and market considerations

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Some issues still to be addressed:

- **There is a lack of locational price signals for using EES for alleviating congestion**: Only System Operators (TSO-DSO coordination) are in the position for solving these issues (i.e. markets focusing to remunerate flexibility but there are no specific locational flexibility products).

- **Unbundling requirements in case of "non-wire" alternative to grid reinforcement** (e.g. The RINGO project): The Third Package legislation (Directive 2009/72/EC) foresees unbundling between generation/supply and transmission players based on different legal, functional and accounting degrees.

- **TSOs apply double grid fees to EES** while charging and discharging (but Germany, Austria and Ireland for PHS under specific conditions).

- **Lack of coherence between the purposes and outcomes of distribution grid fees regarding EES:** The Energy Efficiency Directive (Directive 2012/27/EC - Article 15) and the Renewables Energy Directive (Directive 2009/28/EC - Article 16 - Access to and operation to the grid) require that network tariffs aim at supporting an increased overall system efficiency (including energy efficiency), demand response and integration of renewables, which are the main capabilities of storage technologies.

Thank you for your attention.

Any questions?

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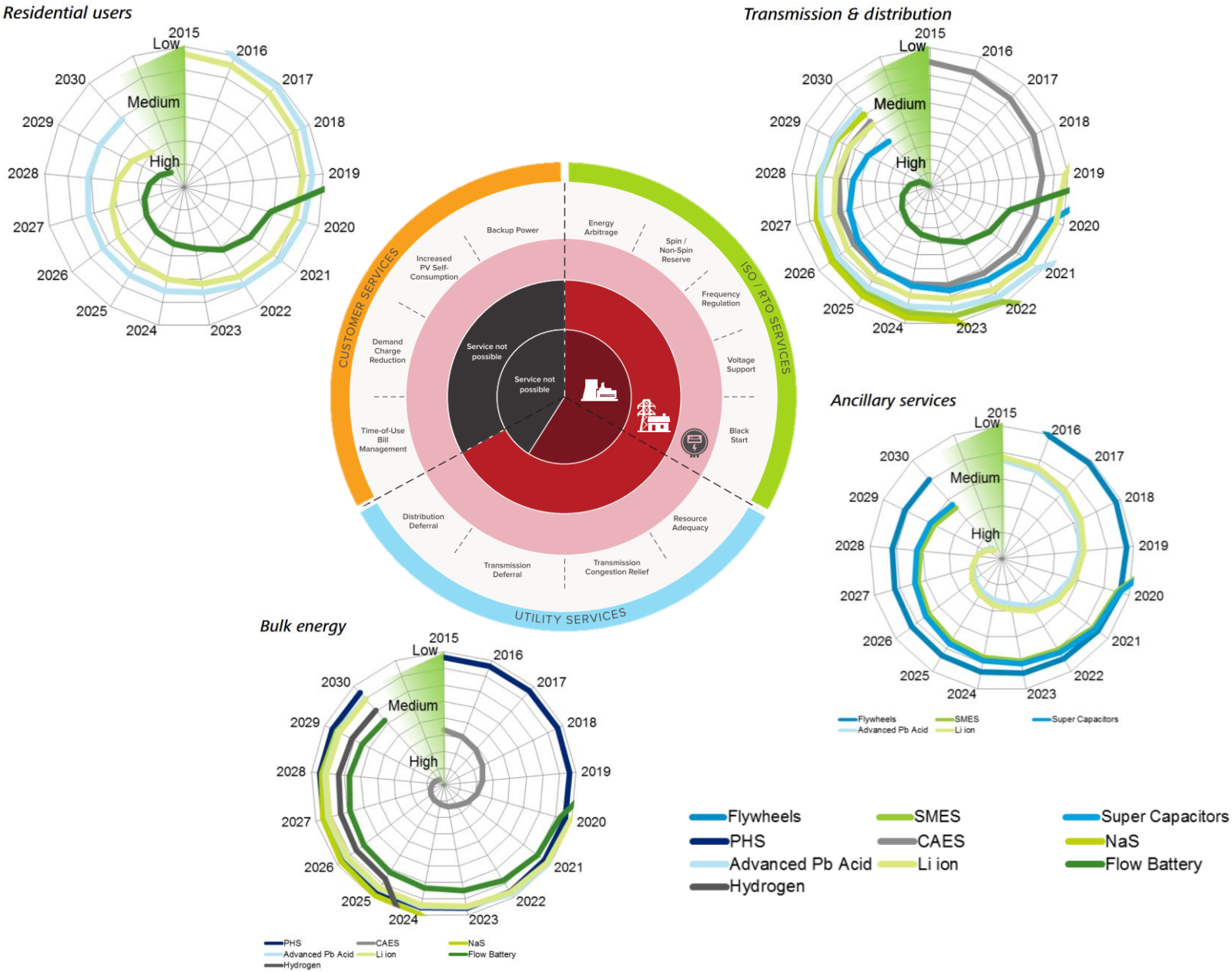
Motivation and research questions

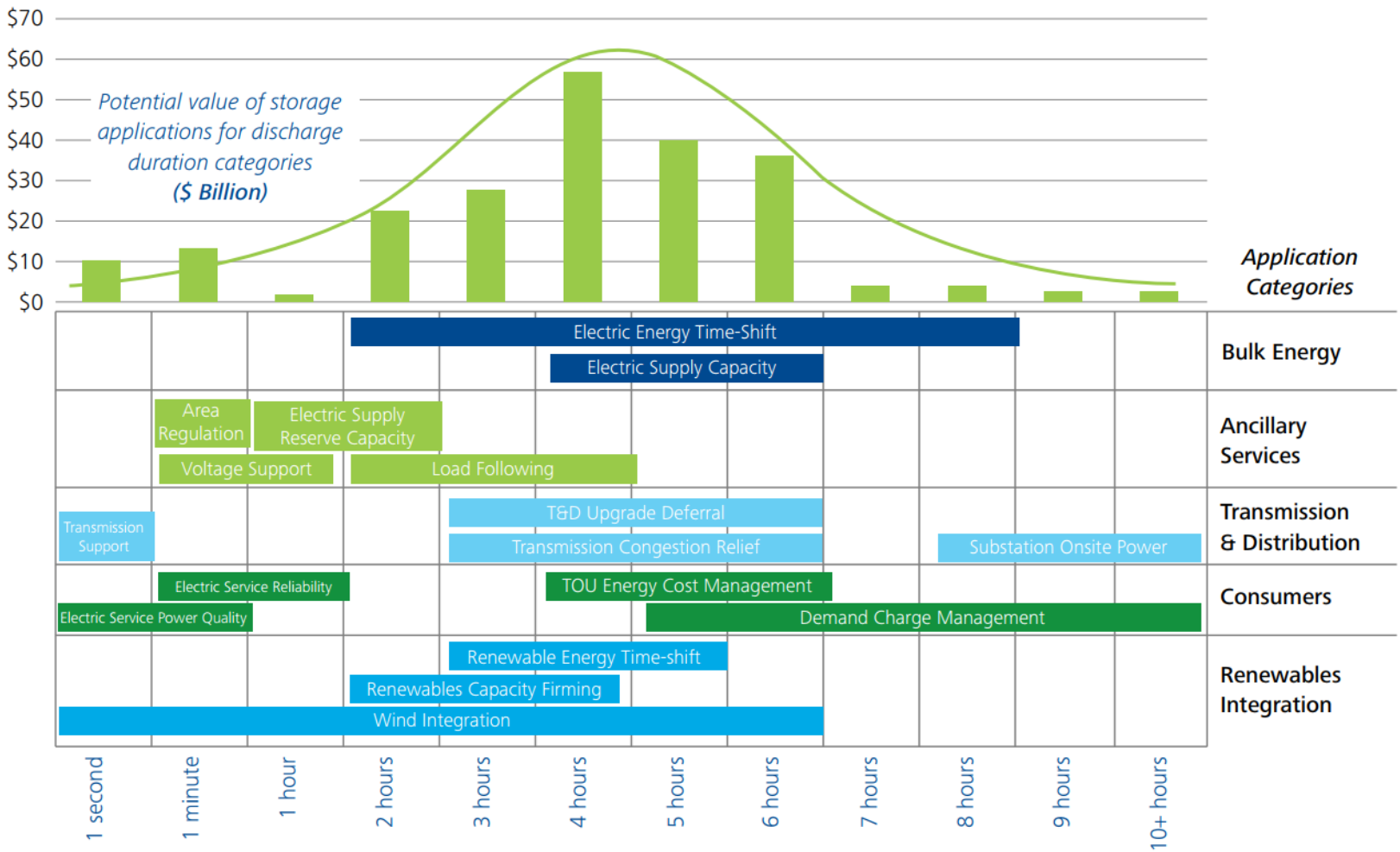


Technologies	Power rating (MW)	Storage duration (h)	Cycling or lifetime	Self-discharge (%)	Energy density (Wh/l)	Power density (W/l)	Efficiency (%)	Response time
Super-capacitor	0.01-1	ms-min	10,000-100,000	20-40	10-20	40,000-120,000	80-98	10-20ms
SMES	0.1-1	ms-min	100,000	10-15	~6	1000-4000	80-95	< 100ms
PHS	100-1,000	4-12h	30-60 years	~0	0.2-2	0.1-0.2	70-85	sec-min
CAES	10-1,000	2-30h	20-40 years	~0	2-6	0.2-0.6	40-75	sec-min
Flywheels	0.001-1	sec-hours	20,000-100,000	1.3-100	20-80	5,000	70-95	10-20ms
NaS battery	10-100	1min-8h	2,500-4,400	0.05-20	150-300	120-160	70-90	10-20ms
Li-ion battery	0.1-100	1min-8h	1,000-10,000	0.1-0.3	200-400	1,300-10,000	85-98	10-20ms
Flow battery	01-100	1-0h	12,000-14,000	0.2	20-70	0.5-2	60-85	10-20ms
Hydrogen	0.01-1.000	min-weeks	5-30 years	0-4	600 (200 bar)	0.2-20	25-45	sec-min
SNG	50-1.000	hours-weeks	30 years	negligible	1,800 (200 bar)	0.2-2	25-50	sec-min

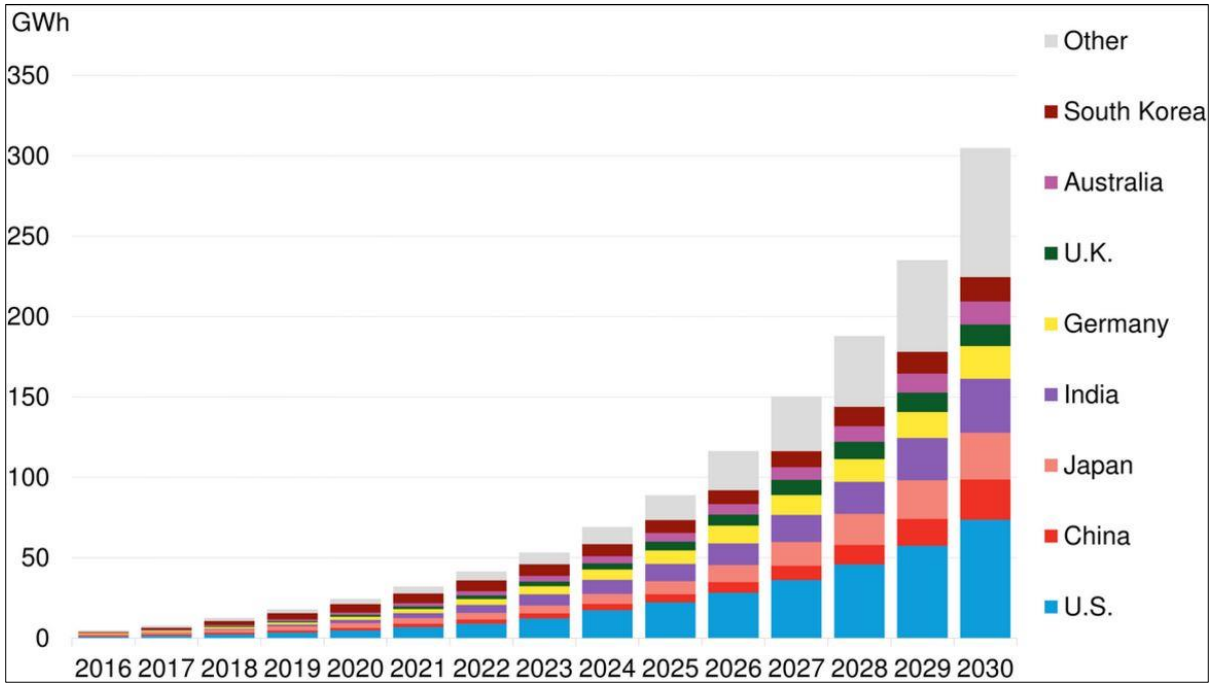
Electrical Mechanical Electrochemical Chemical

Characteristics of energy storage technologies. Source: Delloite 2015

The role of electric energy storage



Energy storage applications and corresponding value for various discharge durations
Source: Eyer and Corey 2010 (Sandia lab)



Global cumulative battery storage market. Source: Bloomberg New Energy Finance 2017