Trends in Redox Flow Battery Technology and project REDOX2015

International Workshop on Energy Storage in the grid.

Barcelona, 9 January 2014

Luis Santos

Agenda

1. EDP in Spain
2. Conventional approach to storage: price arbitrage
3. New approach: grid services and reserves
4. Redox flow batteries are a promising option
5. Redox2015 project
6. Conclusions

1. EDP in Spain

#1 Portugal

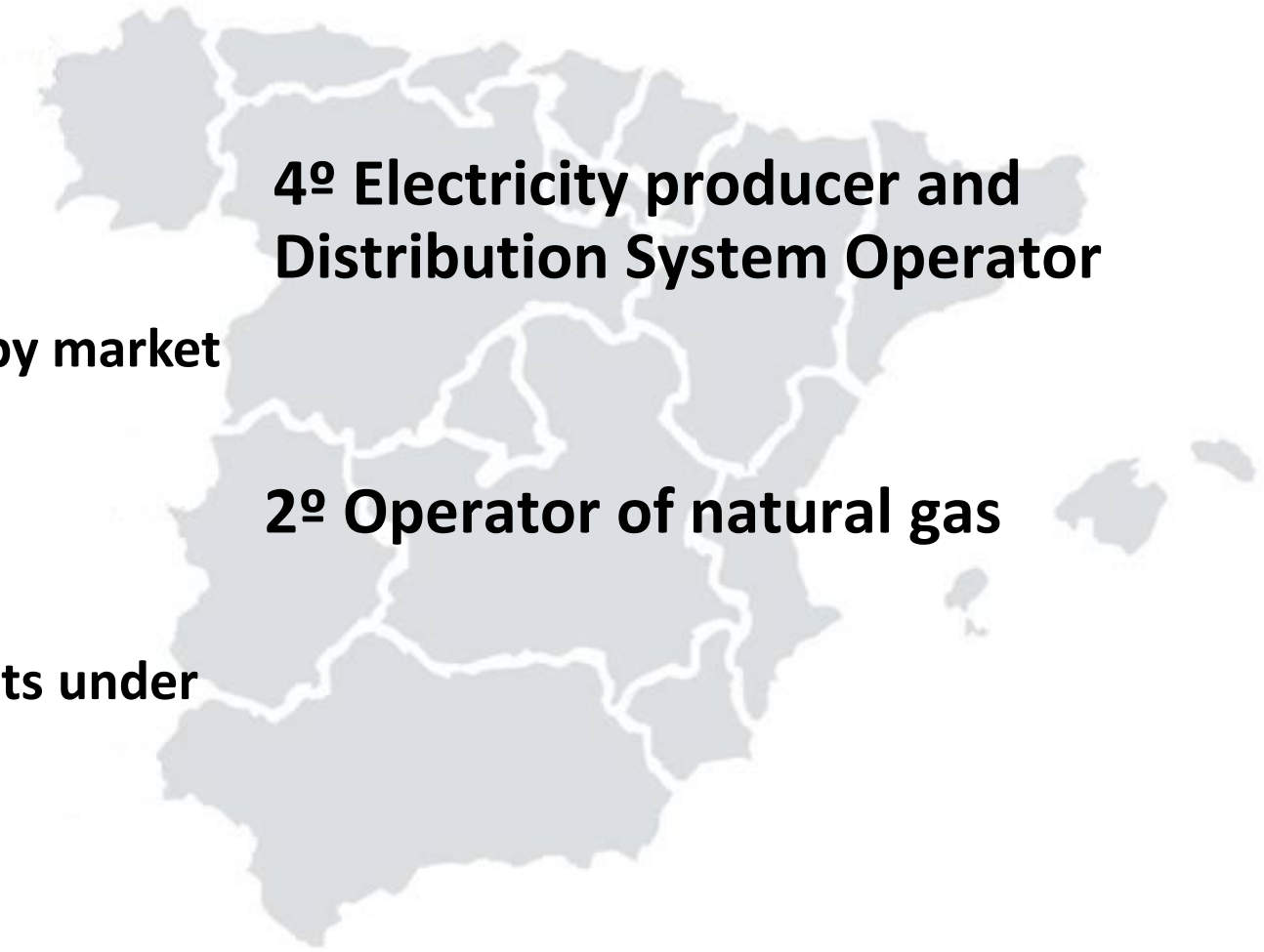
First Portuguese company by market capitalisation

#1 Europe

~ 3 GW of hydraulic projects under construction

#3 Worldwile

More than 6.4 GW of wind capacity



4º Electricity producer and Distribution System Operator

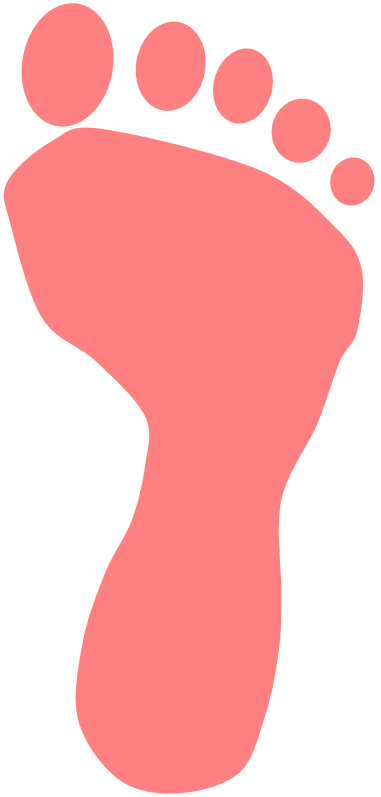
2º Operator of natural gas

1. EDP in Spain

Innovation strategic lines

Flexible generation and with high availability

Environmental innovation



Electric mobility

Grids and storage

Energy intelligence

Agenda

1. EDP in Spain

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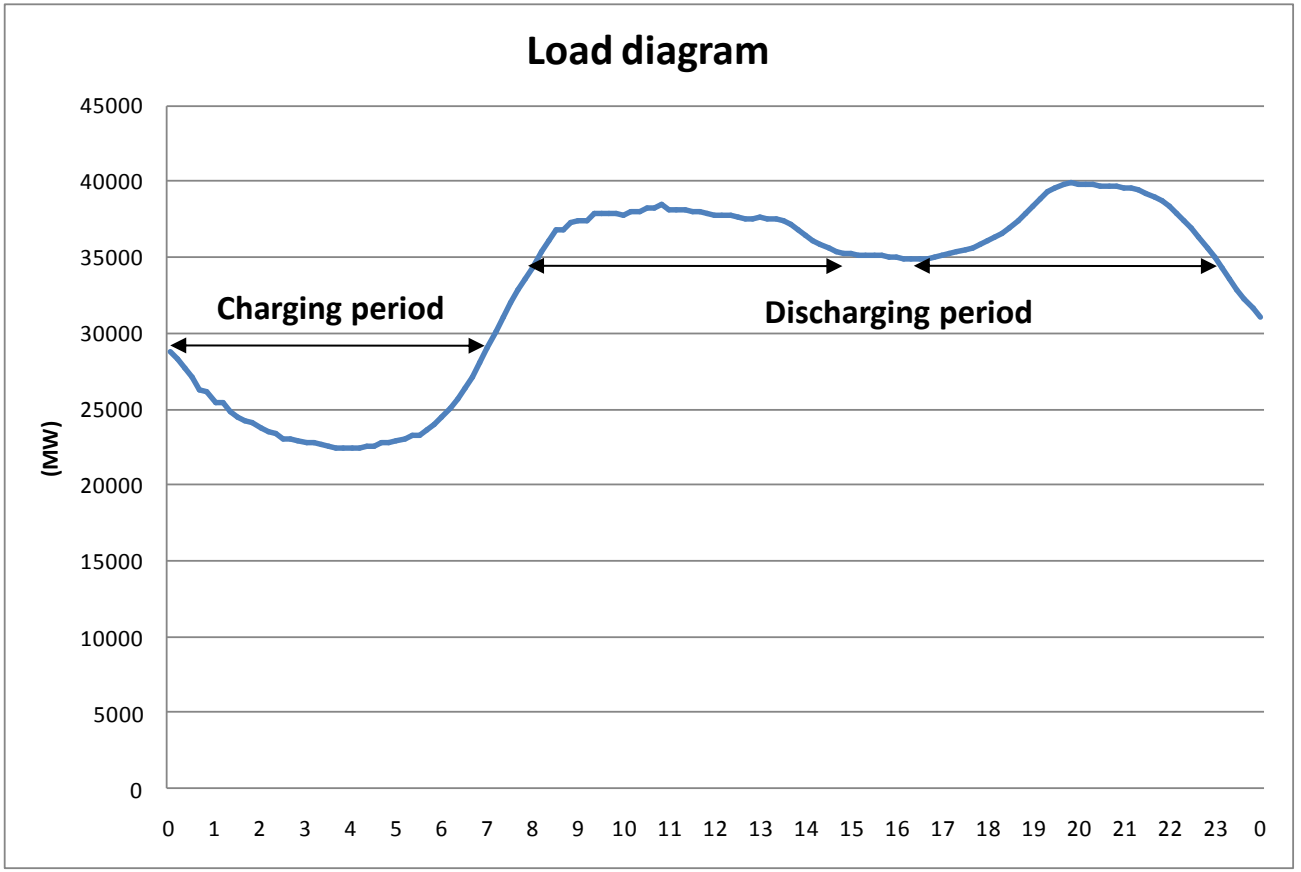
2. Conventional approach to storage: price arbitrage

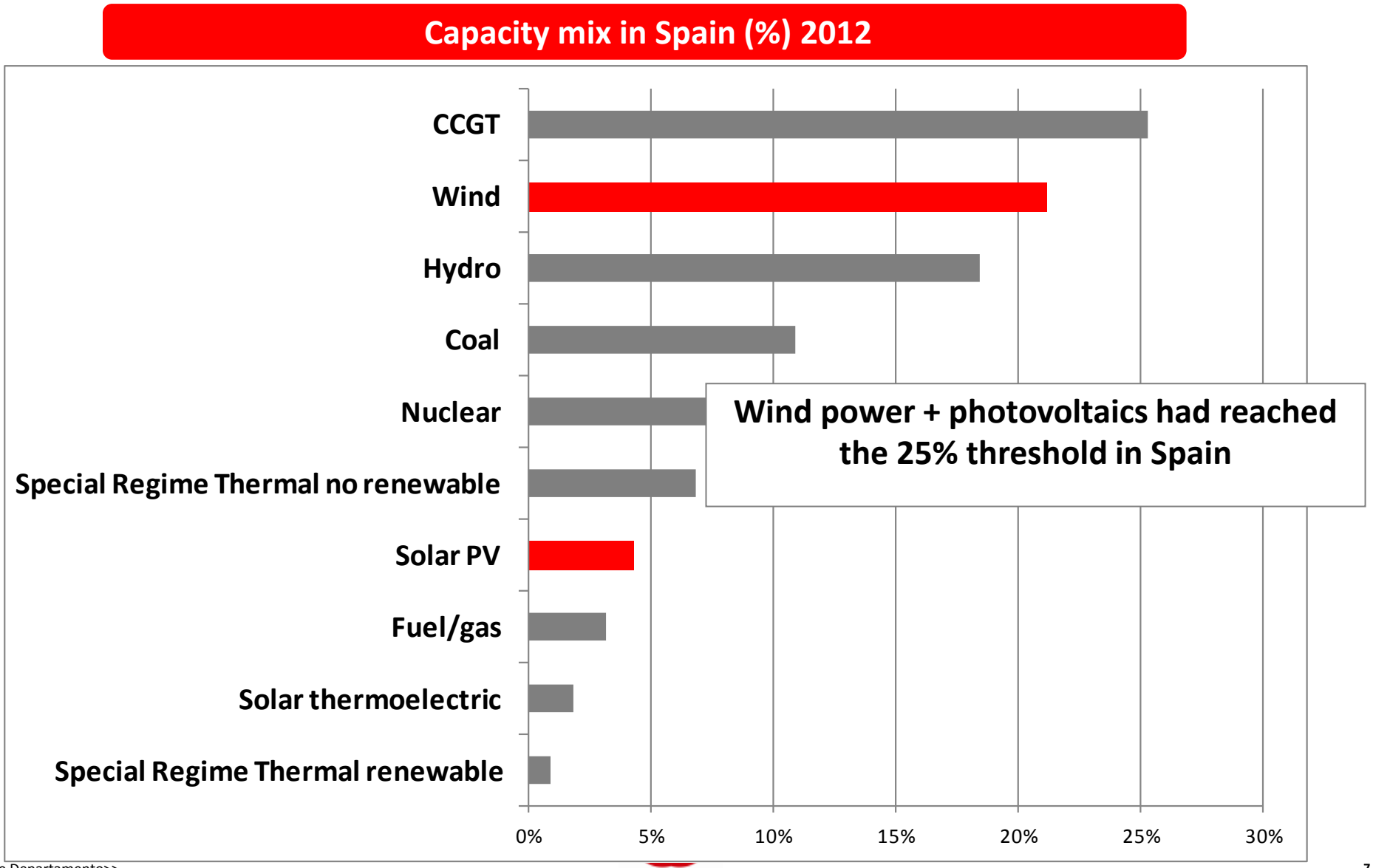
As a first approach, the economics of energy storage ar assessed by price arbitrage

Price arbitrage - charging during off peak hours and discharging at peak hours



2. Conventional approach to storage: price arbitrage

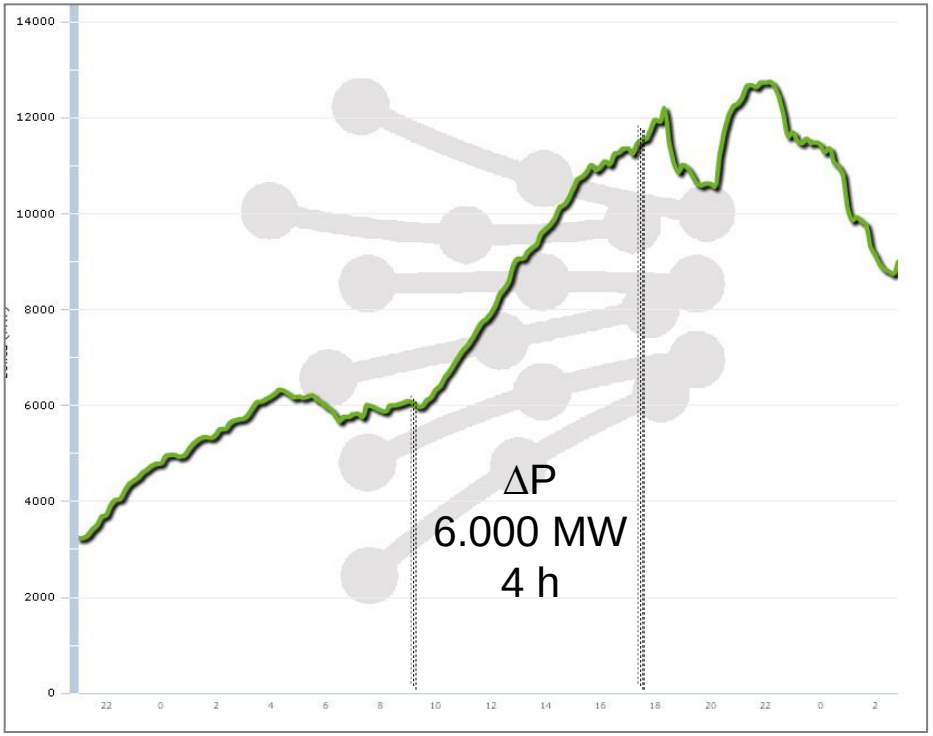
Wind power has grown dramaticaly in Spain over the past years



2. Conventional approach to storage: price arbitrage

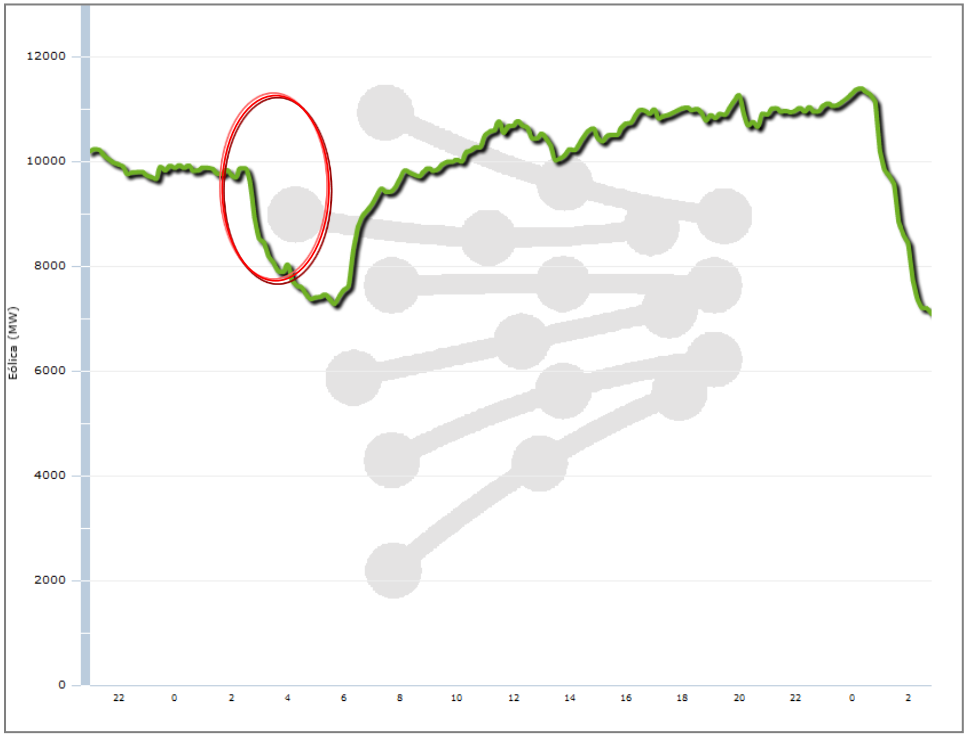
Now there is a Supply Side Management problem

Sometimes wind power grows a lot…



Wind power production in Spain 29.03.2010

…and has to be disconnected

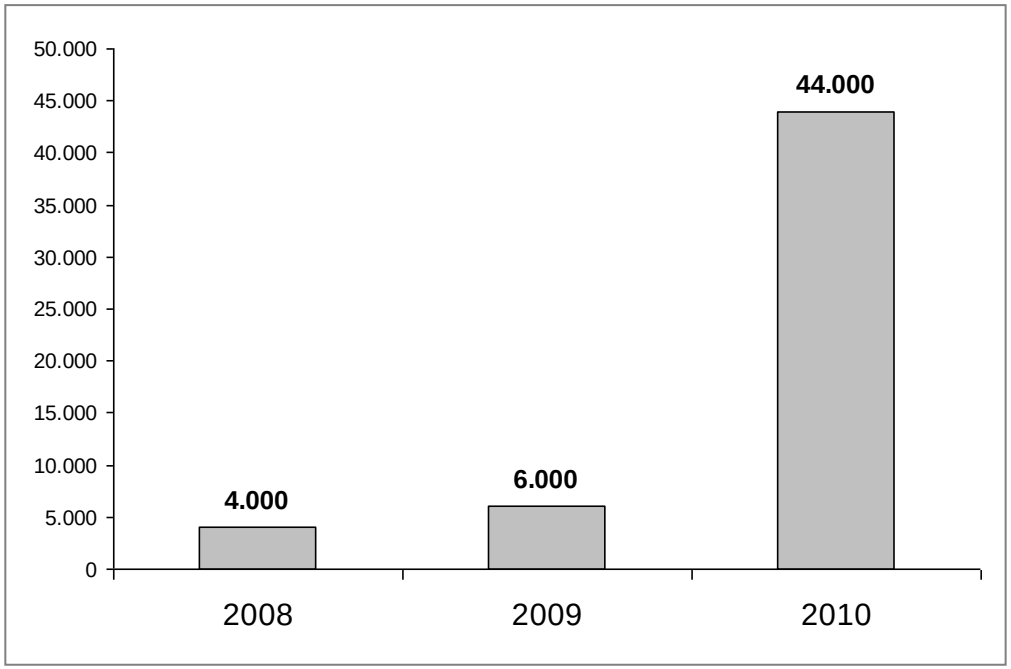


Wind power production in Spain 25.02.2010

2. Conventional approach to storage: price arbitrage

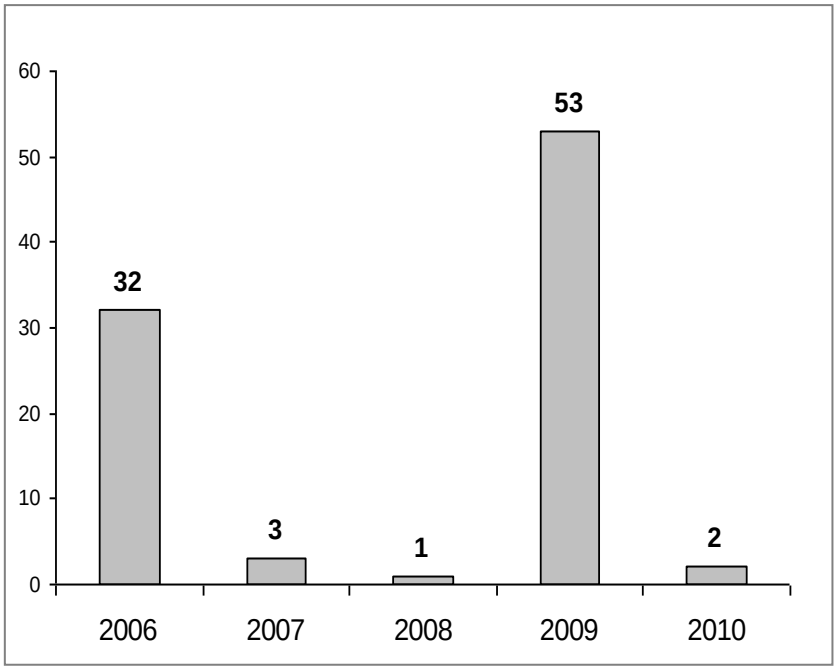
Supply “peak shaving” is the problem now

There is a lot of energy wasted…



Energy lost due to disconnection of wind (MWh) in Spain

…but other fuels also suffer

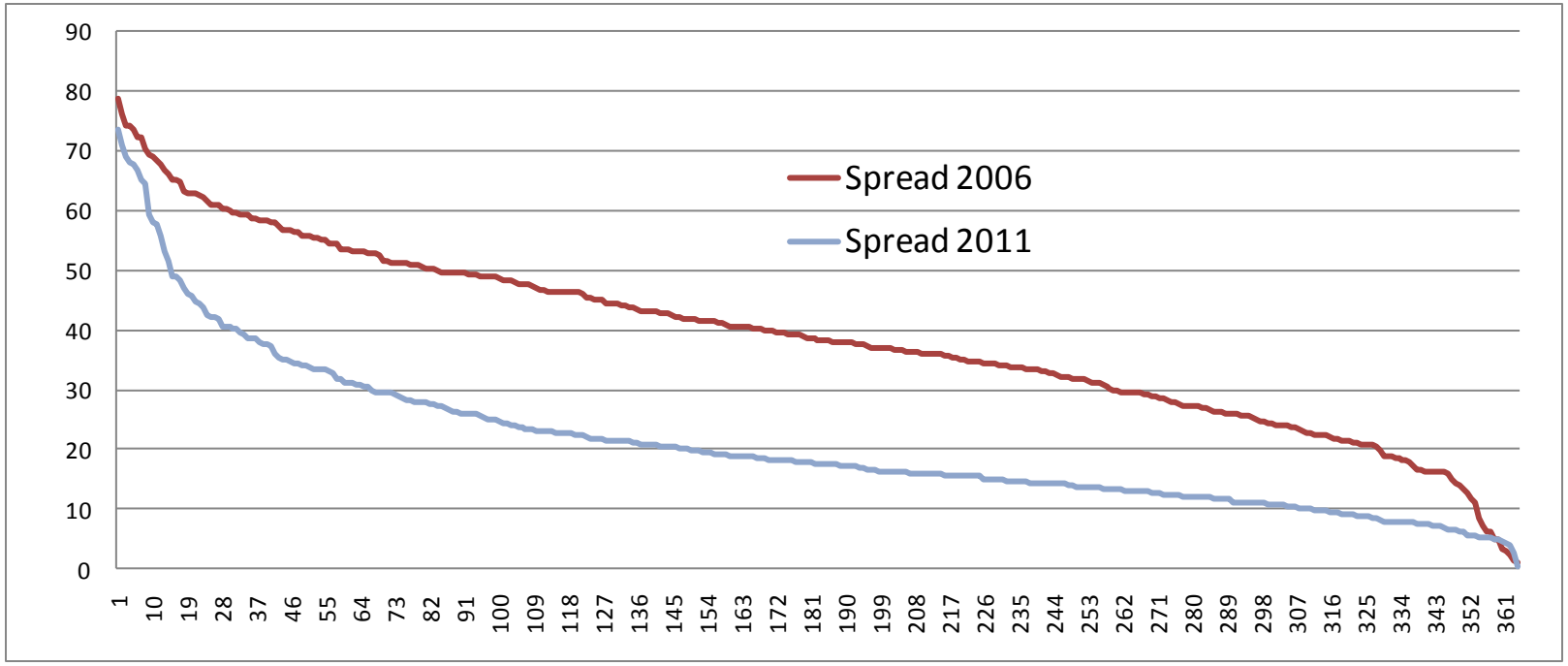


Thermal units disconnected to allow wind production in Spain

2. Conventional approach to storage: price arbitrage

Peak and off Peak prices are getting closer: the spread for price arbitrage is reducing

Spread (€/MWh) in Spain
(Peak - Off peak Prices)



- **Excess of capacity**
- **The number of days with a spread good enough to recover costs is reducing**
- **This puts more pressure on the economics of price arbitrage**

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3. New approach: grid services and reserves

Threats and opportunities for energy storage

Energy storage point of view

RES have reduced energy spreads

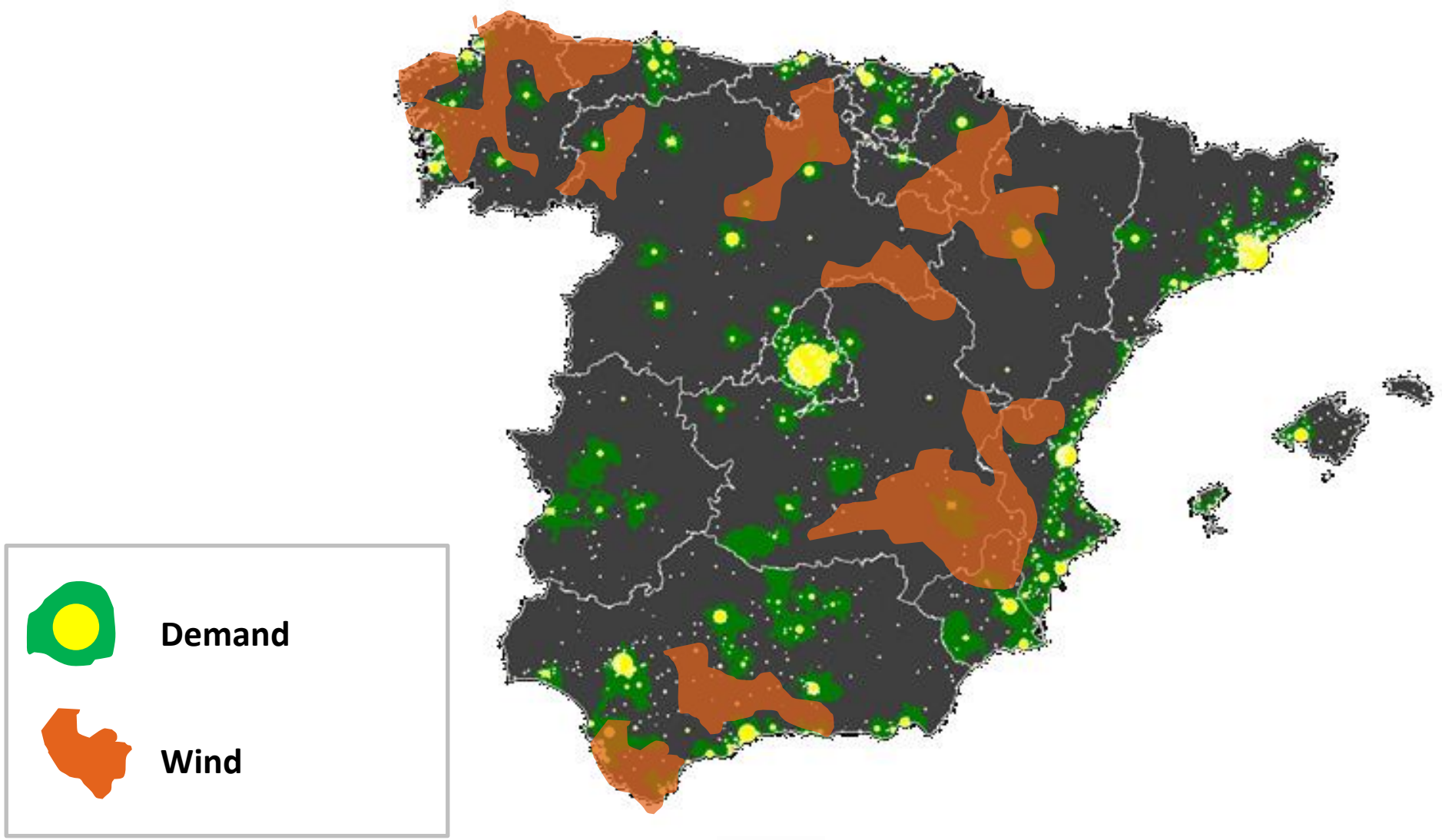
Grid Services

Need for **quicker** and **longer** reserves

Intermittent incontrollable generating capacity

3. New approach: grid services and reserves

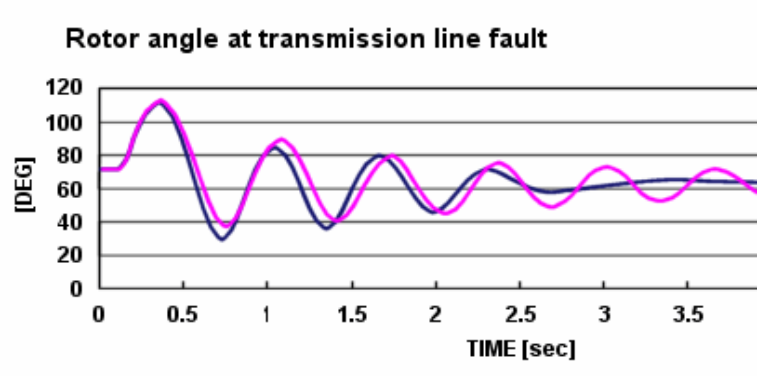
Wind farms are far away from demand: more grids are needed



3. New approach: grid services and reserves

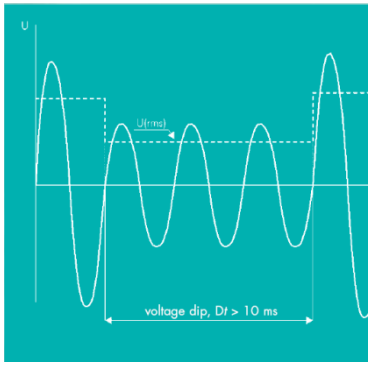
Services to transmission & distribution

Investment deferral

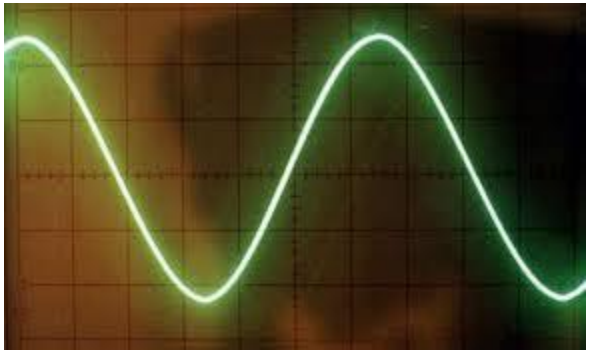


Grid stability

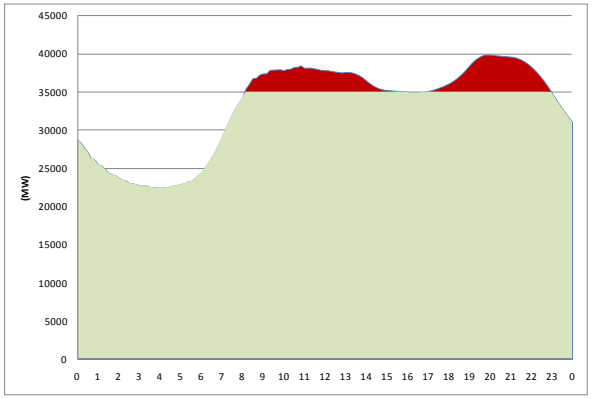
Contingency support



Voltage control



Frequency control



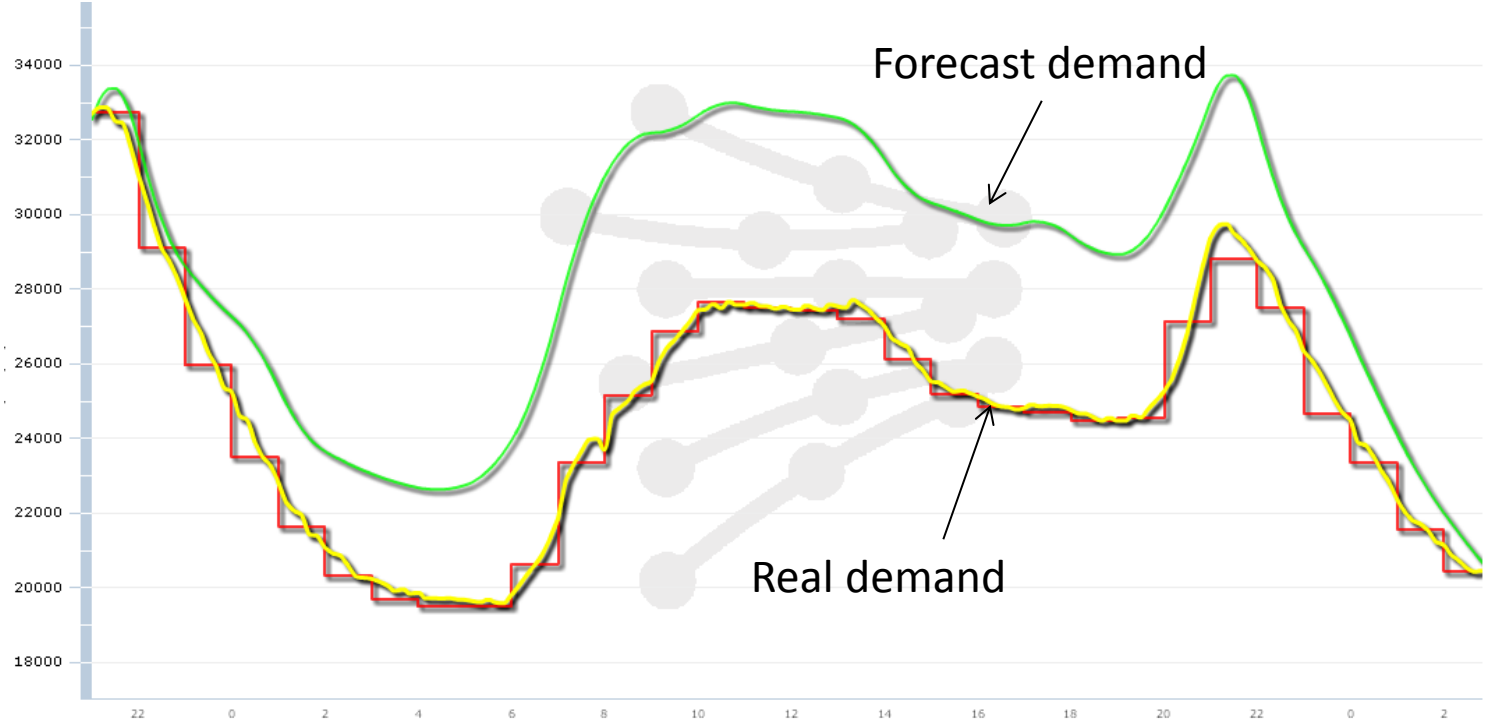
Charge management

But all these services deserve a proper retribution

3. New approach: grid services and reserves

Need for fast and longer reserves

1. **Future loads cannot be perfectly predicted**
2. **Generator ouputs can vary substantially in different time frames**
3. **Power system equipment can fail without notice**



Operating reserves: real power capability that can be given (upward) or taken (downward) to assist in generation and load balance and frequency control

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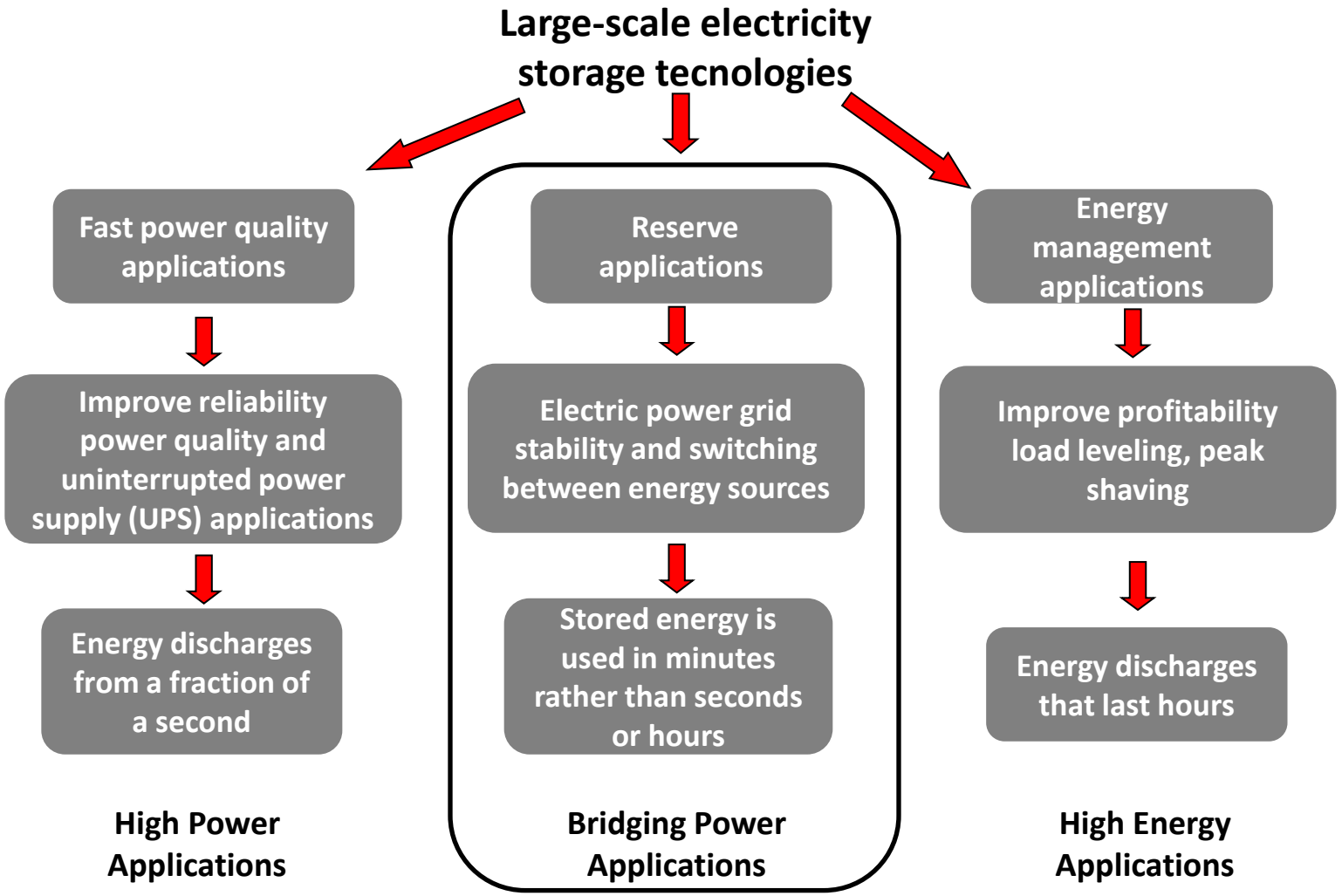
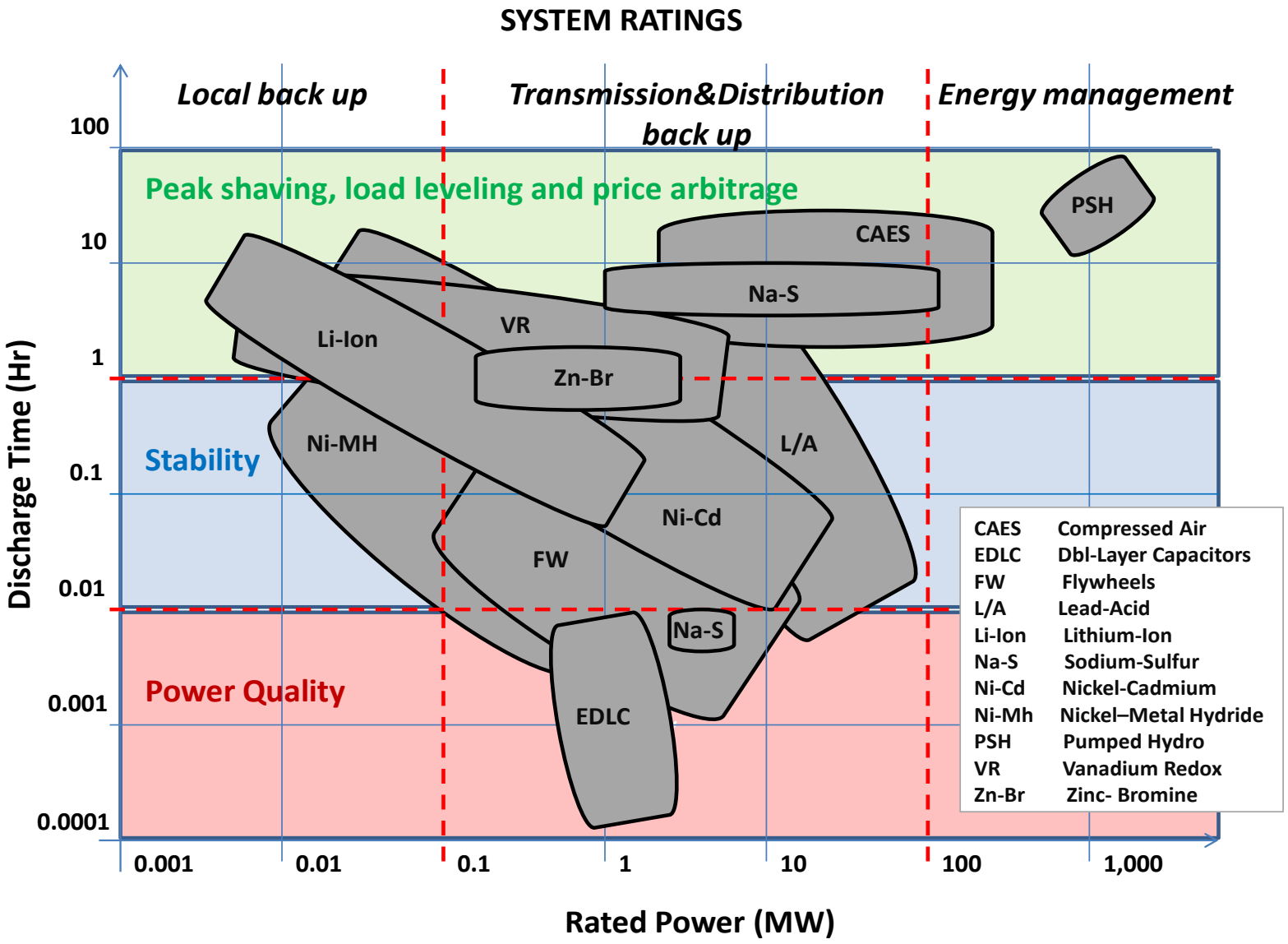
Different needs imply different technologies and approaches

What do you need storage for…?



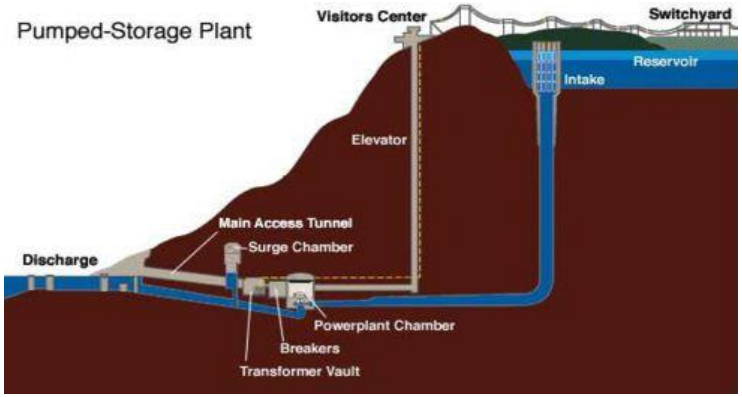
4. Redox flow batteries are a promising option

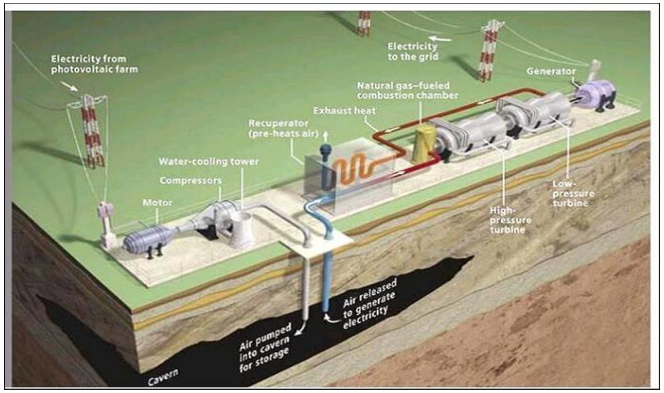
Power vs Capacity



4. Redox flow batteries are a promising option

Pumping and Compressed Air are for the lucky ones





Pumping hydro and Compressed Air Energy Storage fall apart from other technologies:

- Heavy reliance on geology (site dependent)

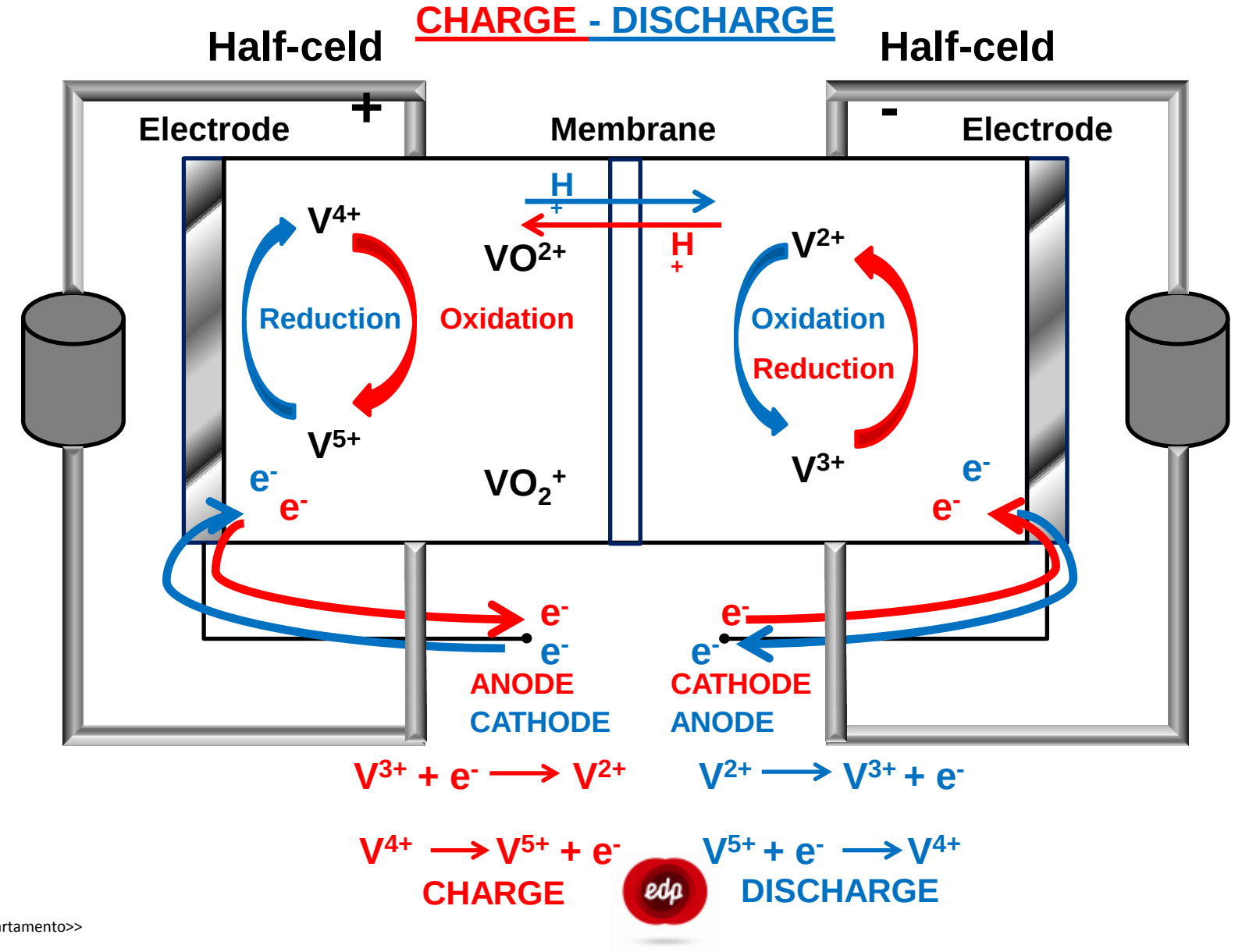
  (Portugal, Austria, Switzerland, Slovenia)

- Massive capital costs and long comissioning periods
- Mature technology
- Enviromental issues involved

Other technologies are needed to address the storage problem from a distributed & site-independent approach

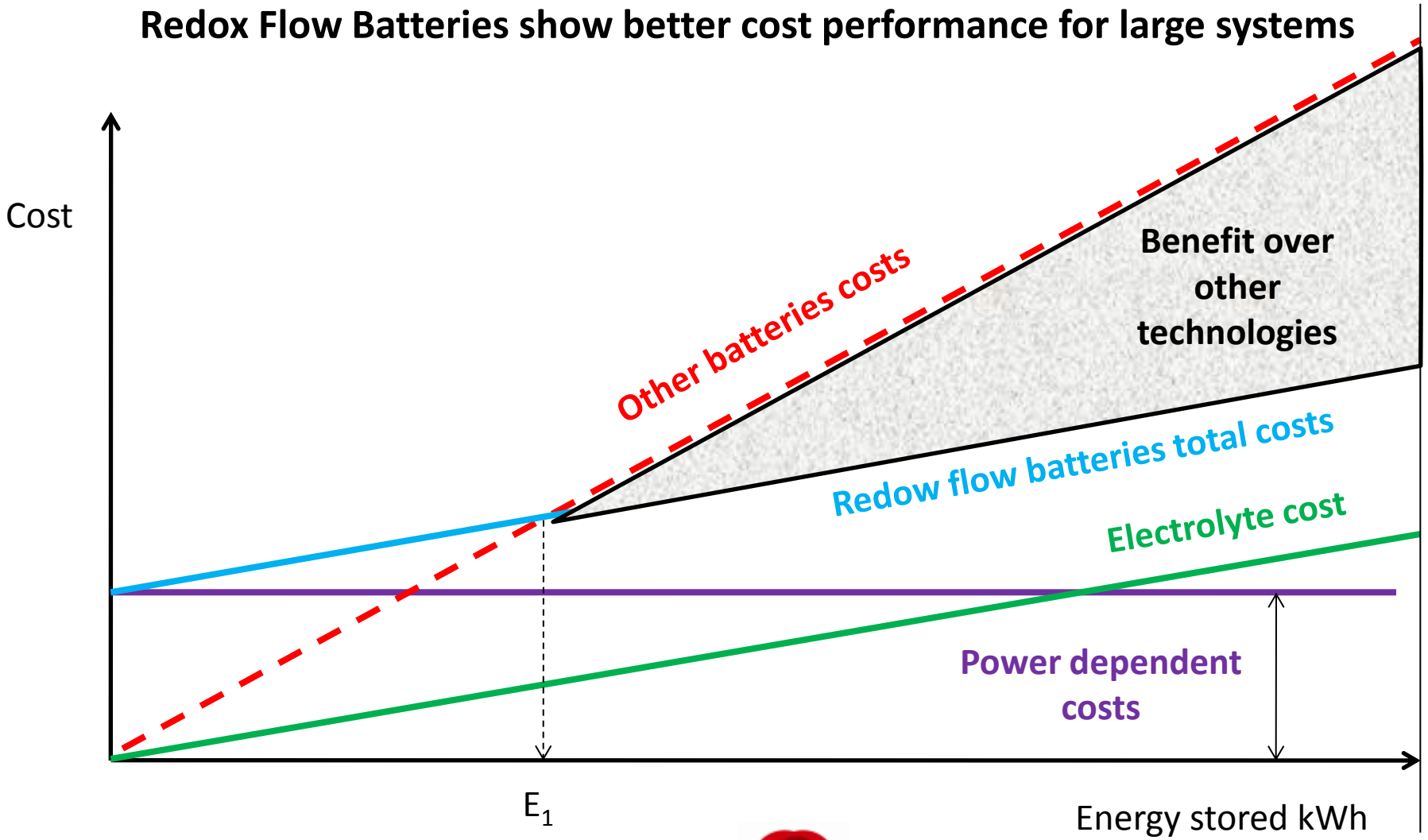
4. Redox flow batteries are a promising option

Redox flow battery



4. Redox flow batteries are a promising option

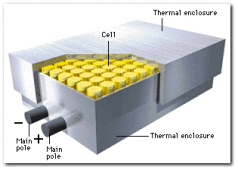
Capacity costs and power costs are independent



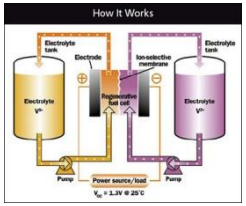
4. Redox flow batteries are a promising option

Redox flow batteries show more opportunities to bring costs down

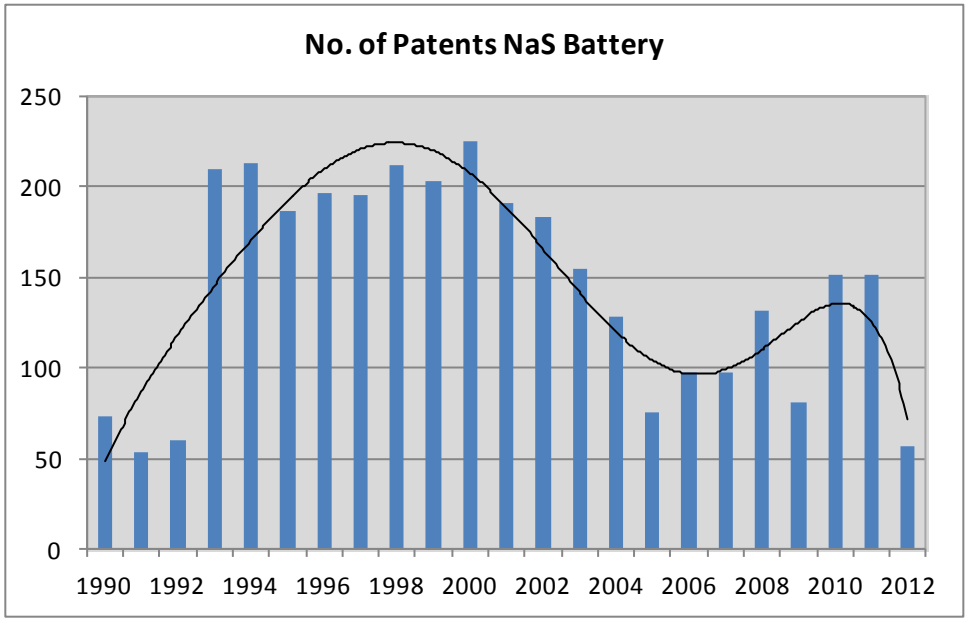
Tendency of published patents shows better perspective for Redox Flow Batteries

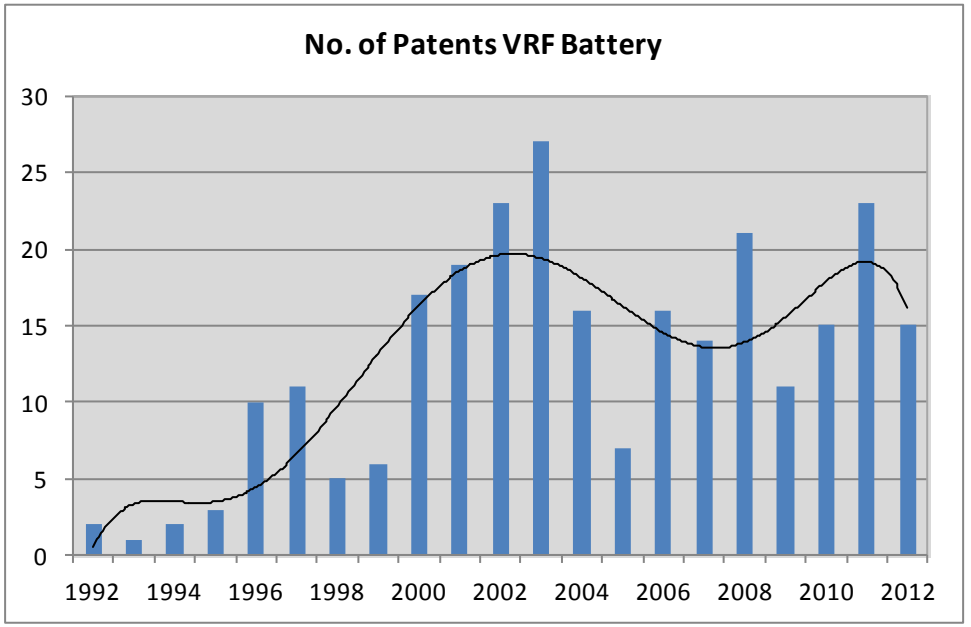


NaS battery



VRF battery





From a fire incident in 2011 NGK has asked nearly every customer to suspend the use of NAS batteries or restrict its use

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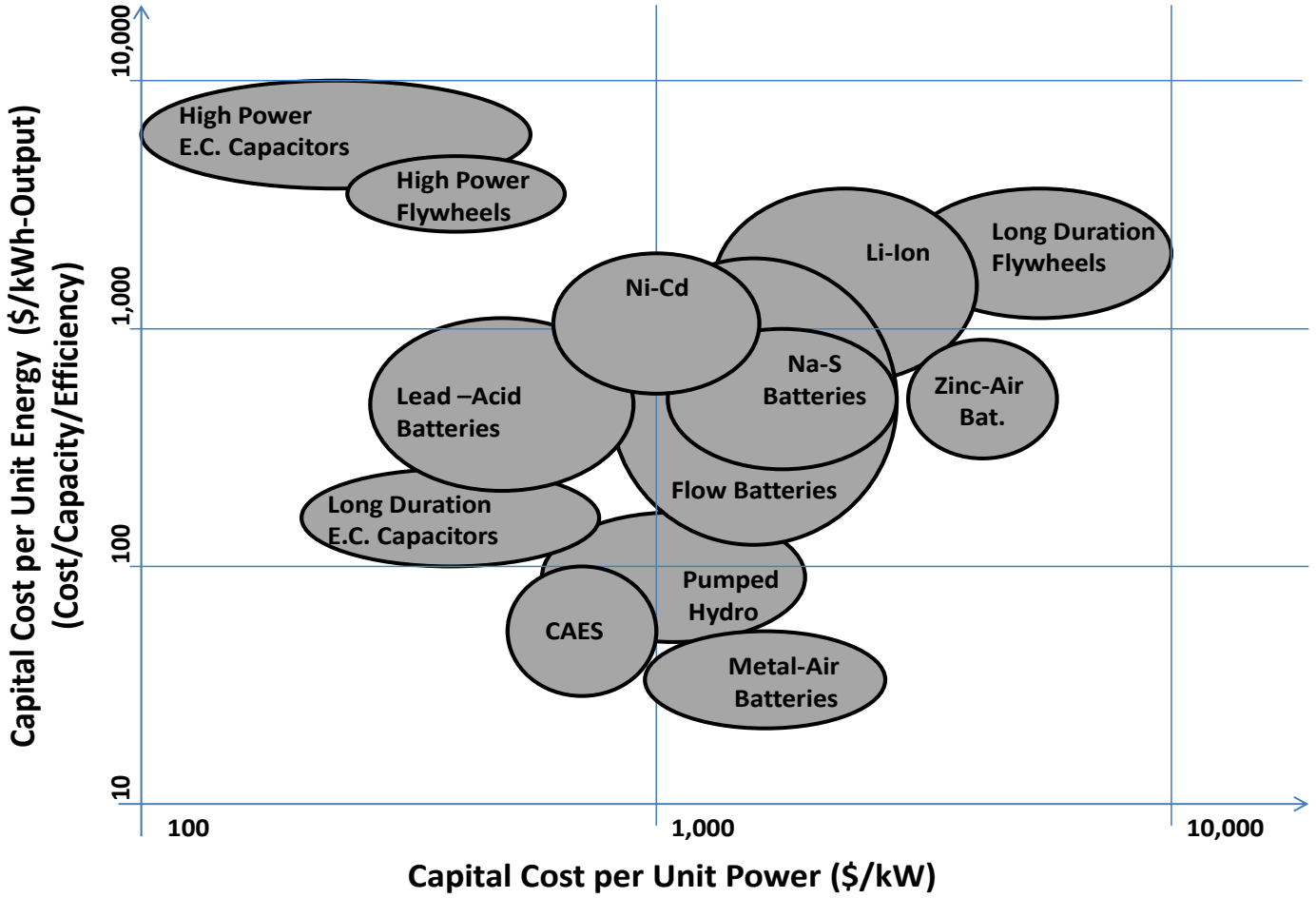
Consortium and funding

- Objective: develop a Vanadium Redox Flow Battery by spanish partners
- Budget :2,7 M €
- Project length: 27 months (2011-2013)

Funded by the Economy and Competitiveness Ministry of Spain with FEDER funding from the European Commission
(IPT-2011-1690-900000)

5. Redox2015 project

Questions to answer by the project: metrics to evaluate



Cost metrics

- **capex** in €/kW and €/kWh

Performance metrics

- **real efficiency**
- **ciclability stability**
- **calendar and cycle lifes**

5. Redox2015 project

Findings so far

	Service	Required power		Required discharge time	Required response time	Frequency of use	MV connection					LV connection			
							A	B	C	D	E	F	G	H	I
Distribution	Capacity support	MV	500 kW – some MW	2 – 10 h	Minutes	Occasional (peaks)	●	●	●	●	●	●	●	●	●
		LV	hundreds kW												
	Local voltage control	MV	100 kW – some MW	2 – 10 h	Minutes	Occasional (peaks)		●	●	●	●	●	●	●	●
		LV	10 kW – hundreds kW												
	Contingency support	MV	100 kW – some MW	2 – 10 h	Minutes	Unusual	●	●	●	●	●	●	●	●	●
		LV	10 kW – hundreds kW												
	Island mode	MV	100 kW – 10 MW	4 – 10 h	20 ms	Unusual	○	○	○	○	○	○	○	○	○
		LV	10 kW – 1 MW												
	Reactive compensation	hundreds kVar – some MVar.			Minutes	Daily	○	○	○	○	○				
Generation	Peak capacity	More than 1 MW		1 -10 h	Minutes	Daily	■	■	■	■	■	■	■	■	■
	Local generation support	More than 1 MW		variable	Variable	Variable	□	□	□	□	□	□	□	□	□
	Services to DER	hundreds kW – 2 MW		20 min. – 1h30	15 30 seconds	Continual	●	●	●	●	●			●	
Transporting	Frequency control	More than 1 MW		20 min. – 1h30	15 – 30 seconds	Continual	●	●	●	●	●				
	Frecuency stability on island	More than 1 MW		Tens of seconds	Less than 1 second	Unusual	■	■	■	■	■				
Consumer. Managing peak demand		0,5 – 10 MW		1 -10 h	Minutes	Daily			●		●		●	●	●

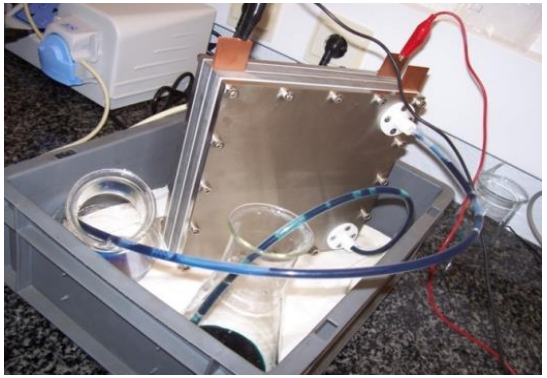
	Feasible	•	High value for storage (■ specific for island mode)
	Inappropriate	○	Other applications are feasible (□ specific for island mode)

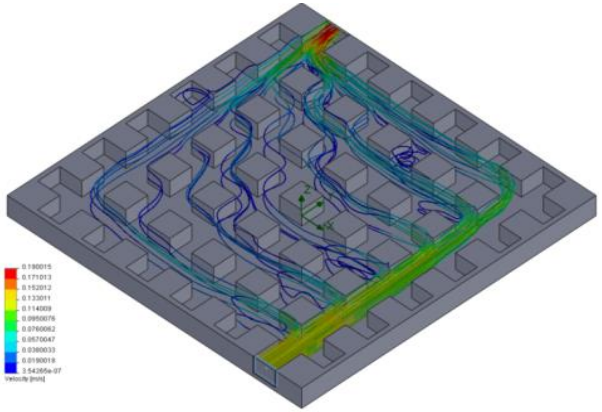
5. Redox2015 project

Findings so far

SIMPLE CELL DESIGN

1. Components screening
2. Cell design
3. Charger/Discharger prototipe
4. Flow dynamics modelling
5. Single cell optimizing tests
6. Stack development





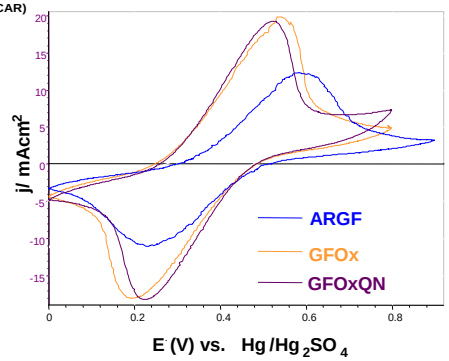
5. Redox2015 project

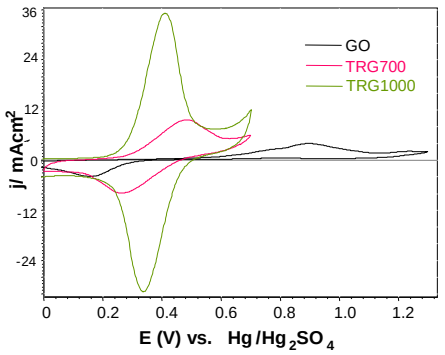
Findings so far

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
INSTITUTO NACIONAL DEL CARBÓN (INCAR)

redOx 2015

ELECTRODE ACTIVE MATERIALS SCREENING FOR VRFB



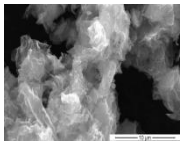


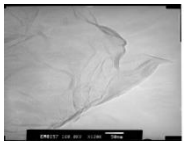
GO: Graphite Oxide

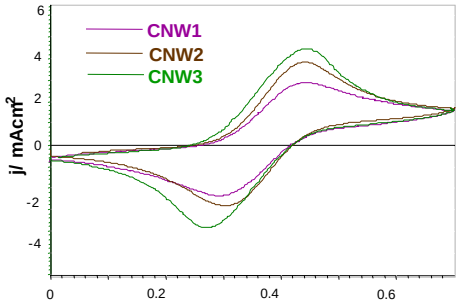
TRG700: GO reduced at 700 ºC

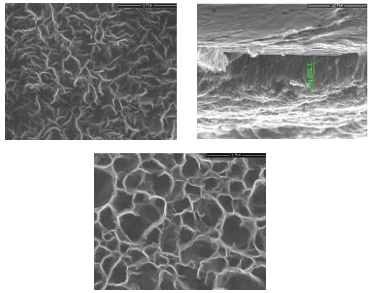
TRG1000: GO reduced at 1000 ºC

} **GRAPHENES**



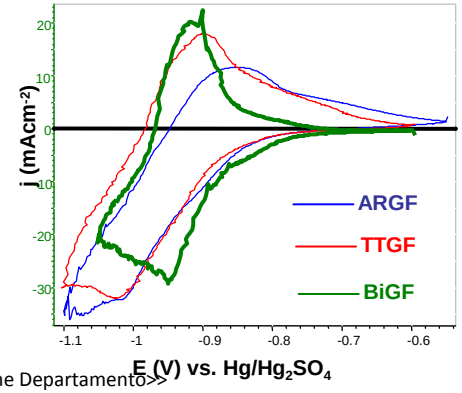


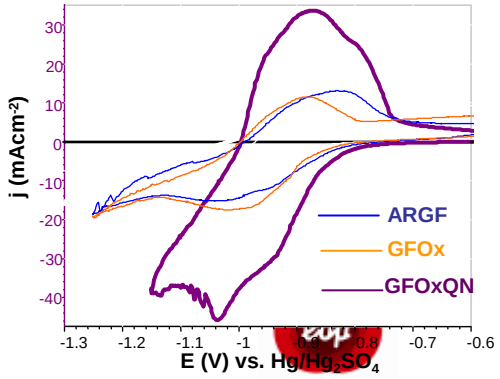




} **CARBON NANOWALLS**

POSITIVE HALF-CELD ($V^{4+/5+}$)





NEGATIVE HALF-CELD ($V^{2+/3+}$)

ARGF: Felt untreated

TTFF: Thermal felt

BiGF: Modified felt using bismuth

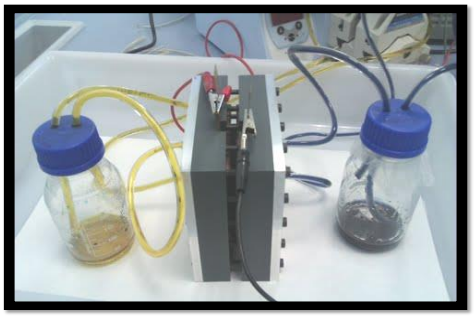
GFOx: Electrochemically oxidized felt

GFOxQN: chemically oxidized felt

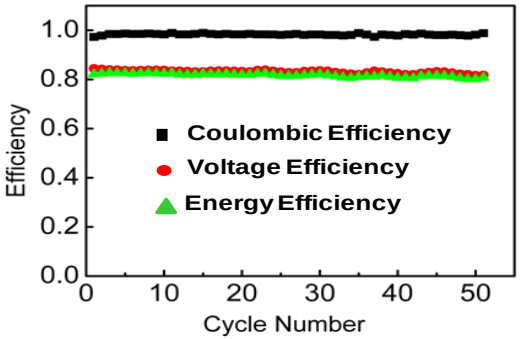
5. Redox2015 project

Findings so far

IREC
Institut de Recerca en Energia de Catalunya
Catalonia Institute for Energy Research



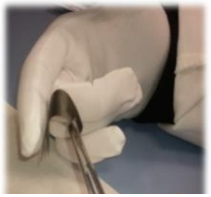
VRFB PROTOTYPE



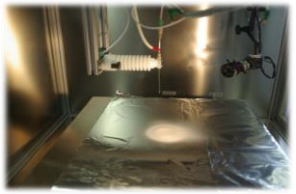
PAN commercial felt with standard electrolyte (3M H_2SO_4 and 1M $VOSO_4$)

Electrodes development

Synthesis

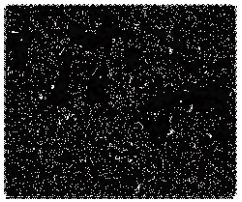


PAN based flexible nanofiber



Electrospinning

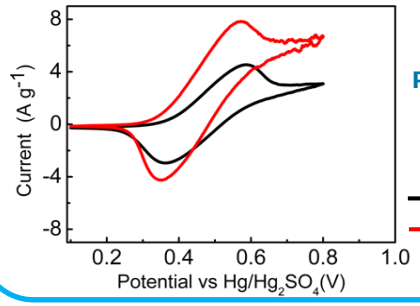
Functionalization



Graphene nanoparticles

PAN commercial felt

High energy density electrolyte

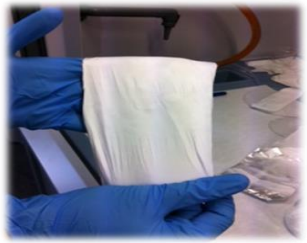


Polymeric additives in aqueous electrolytes

standard electrolyte

0.6% additive-containing electrolyte

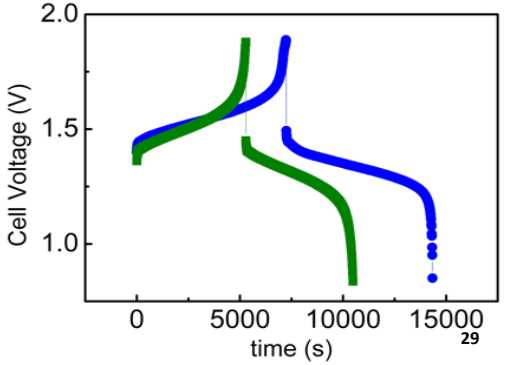
Innovative membranes



Objective: High energy and power efficiency, long life and cyclability (excellent> 30,000), 5 times the charge density of the typical solutions

Use of additives to improve the electrolyte

- standard electrolyte
- additive-containing electrolyte

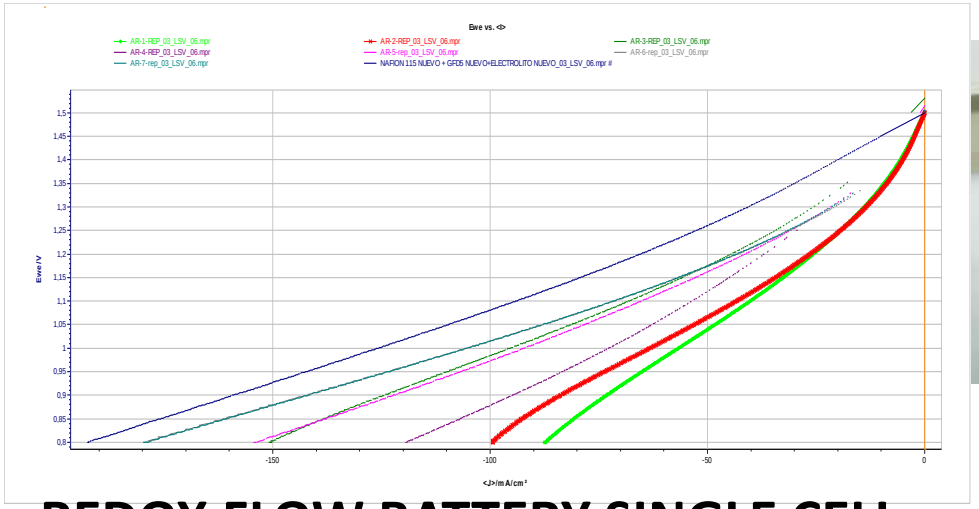


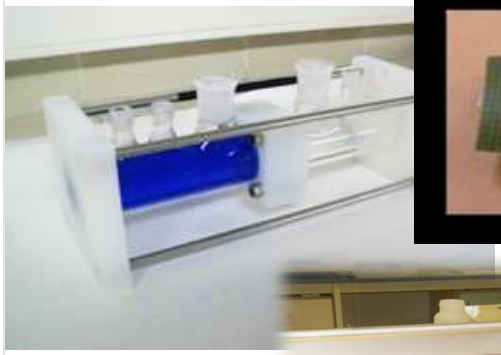
5. Redox2015 project

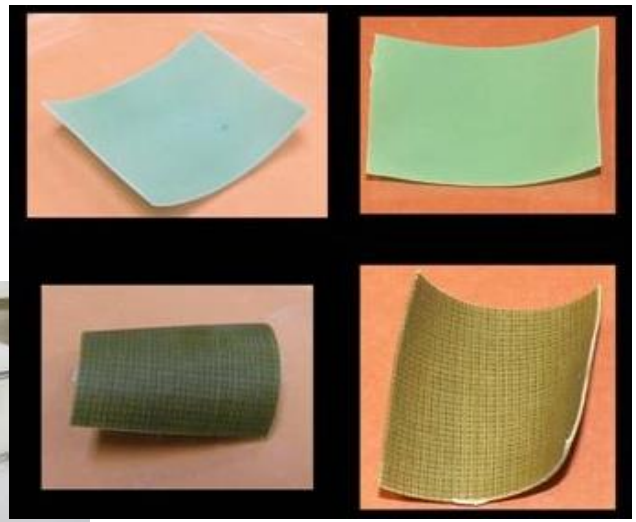
Findings so far

MEMBRANES FOR REDOX FLOW BATTERIES

- Objective: To minimize vanadium crossover through the membrane by surface plasma activation .
- These treatments cause changes in the polymer material:
  - Inversion of surface polarity
  - Surface crosslinking







REDOX FLOW BATTERY SINGLE CELL

- Single cell set-up to test new materials in flow battery operation
- Development of testing protocols for membranes and electrodes

Agenda

1.EDP in Spain

2. Conventional approach to storage: price arbitrage

3. New approach: grid services and reserves

4. Redox flow batteries are a promising option

5. Redox2015 project

6. Conclusions

6. Conclusions

- **Energy storage for price arbitrage, at the current state of art and current prices, is not competitive**
- But the increase of penetration of wind power implies different conditions to take into account
- **Reserve markets are a good opportunity for energy storage economics**
- Where pumping is not an option, other applications of distributed energy storage are necessary
- **R&D projects like REDOX2015 are needed to meet performance and cost requirements**

Thanks for your attention!

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