OVERVIEW OF STORAGE TECHNOLOGIES AND POSSIBLE APPLICATIONS

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EDF R&D

HYDROBALANCE kick-off meeting

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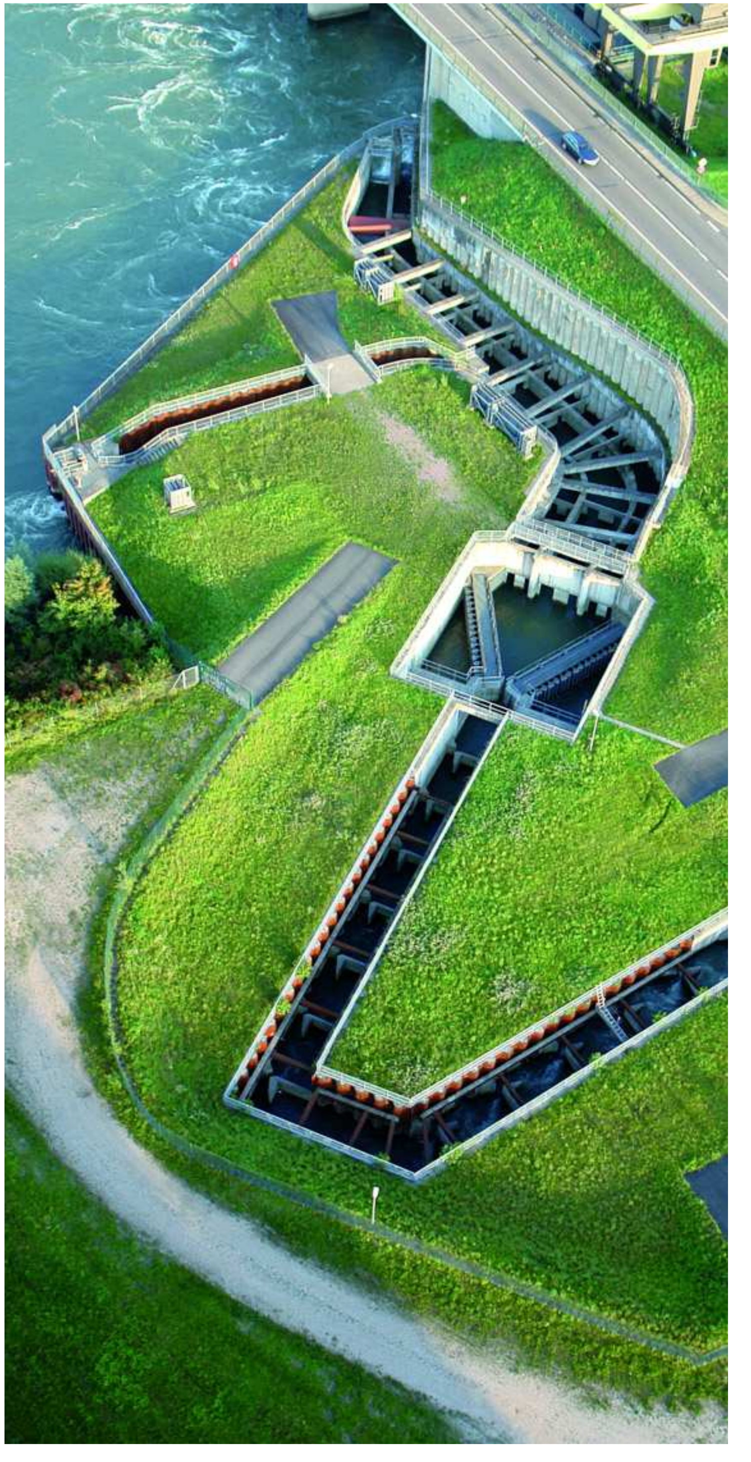
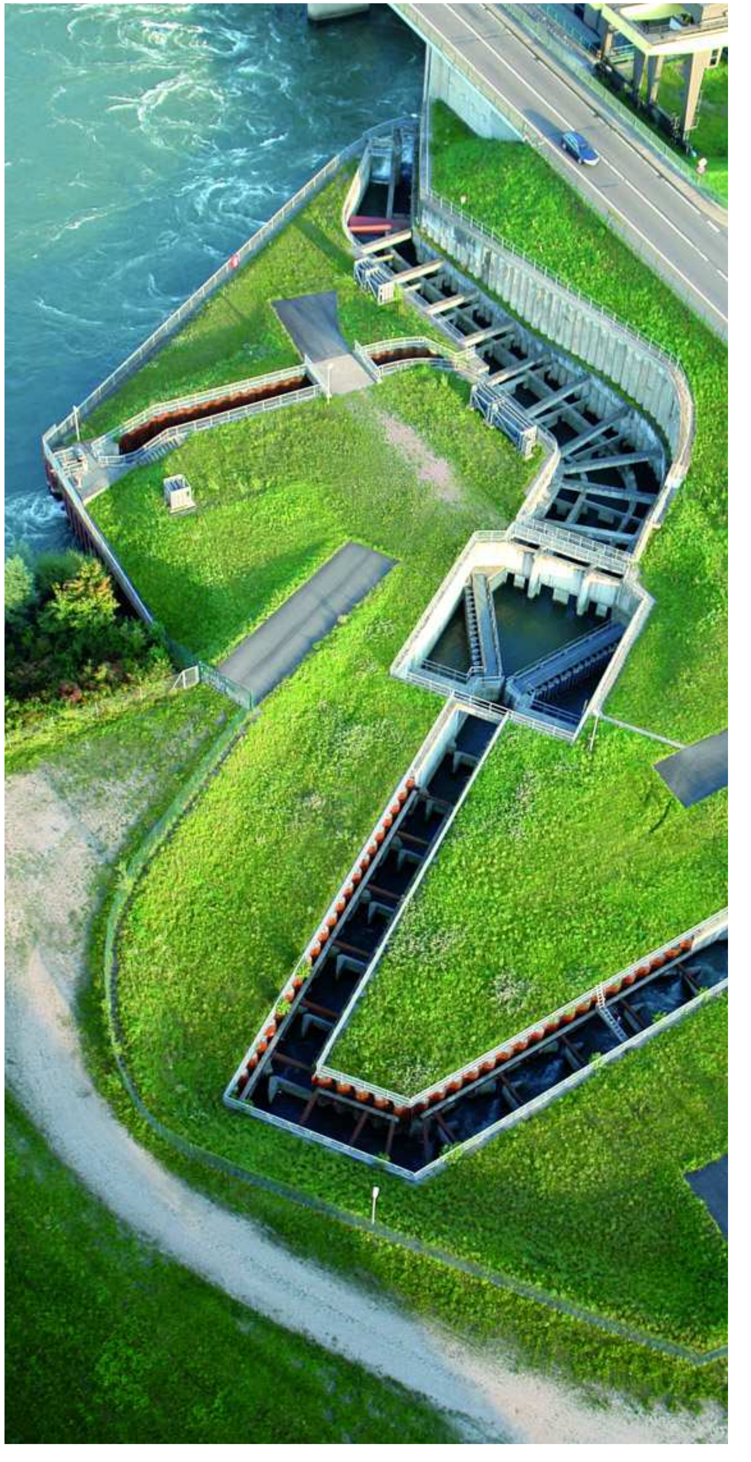
Trondheim



AGENDA

- EDF & ENERGY STORAGE
- WHICH APPLICATIONS ?
- WHICH TECHNOLOGIES ?
- CONCLUSIONS

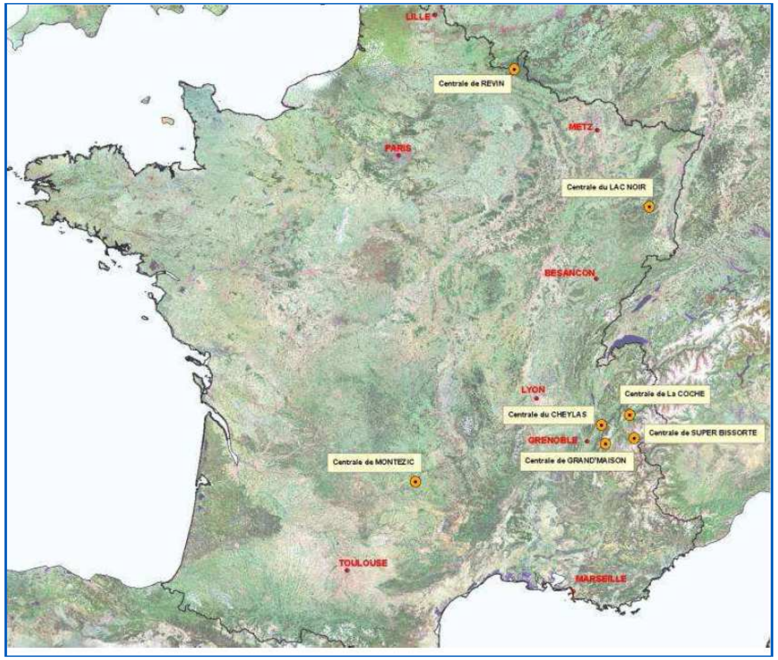


EDF, A EUROPEAN STORAGE PLAYER WITH 5 GW OF PHS IN OPERATION

- 6 pumped hydropower storage (PHS) in operation in France.
- Build in the 70s and the 80s to optimize the nuclear production
- 2 « pure » PHS otherwise inserted into valleys
- Lac Noir, 80 MW, under rehabilitation

	Montézic MSI 1982	Revin MSI 1976	G.Maison MSI 1985	S.Bissorte MSI 1987	La Coche MSI 1977	Le Cheylas MSI 1979	Total
Puissance en turbine	910 MW	720 MW	1790 MW	730 MW	330 MW	460 MW	**4940 MW**
Puissance en pompage	870 MW	720 MW	1160 MW	630 MW	310 MW	480 MW	**4170 MW**
Nb de pompes	4	4	8	4	2	2	
Constante de temps	40 h	5 h	30 h	5 h	3h	6 h	
Productible gravitaire	STEP pure	STEP pure	216 GWh	250 GWh	426 GWh	670 GWh	

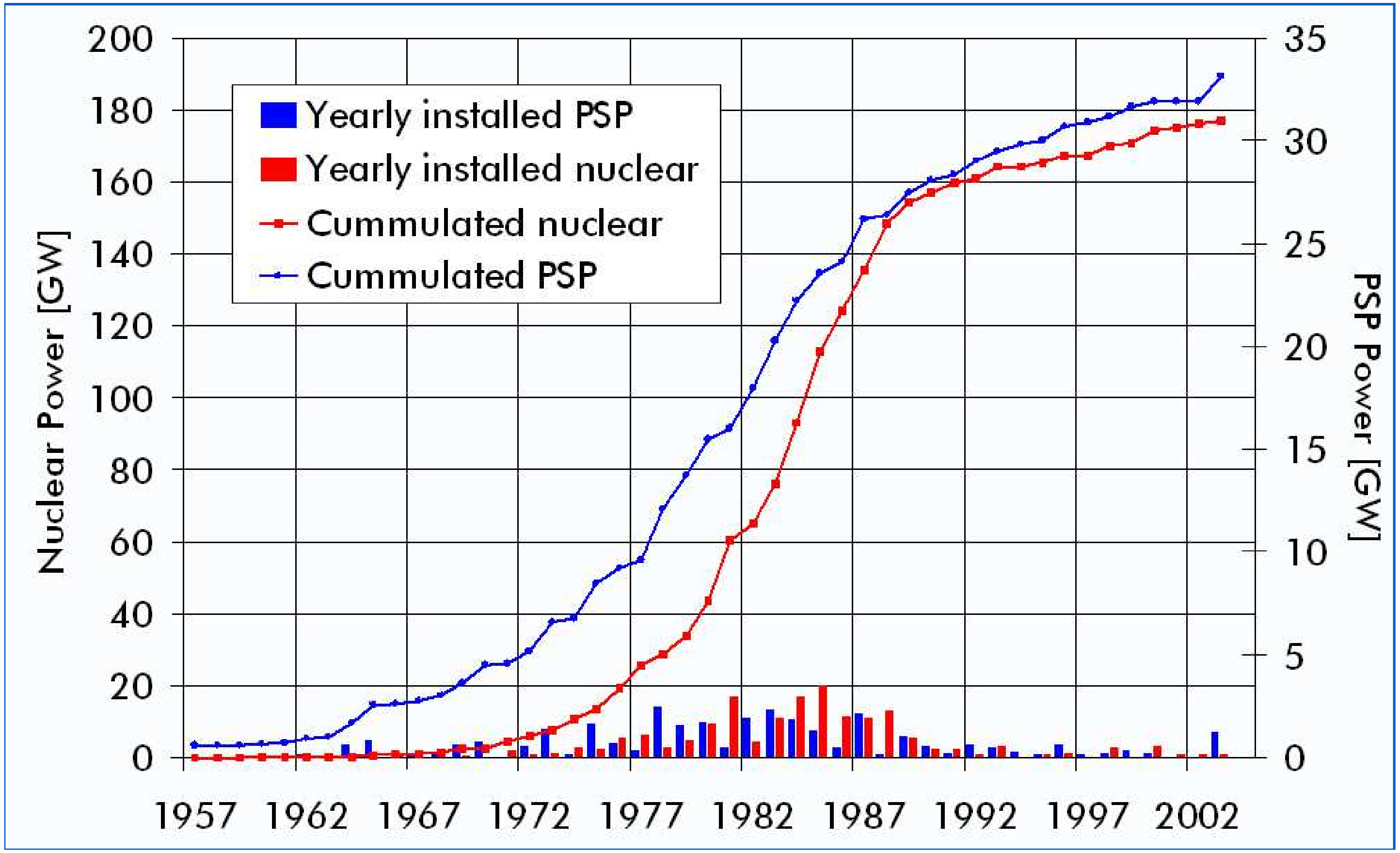
PHS operating in France



PHS locations in France

HISTORICAL DEPLOYMENT OF PUMPED HYDRO STORAGE (PHS) IN EUROPE

- PHS units have been installed in Europe massively from 1970 through the 1990 in combination with nuclear and coal build-out



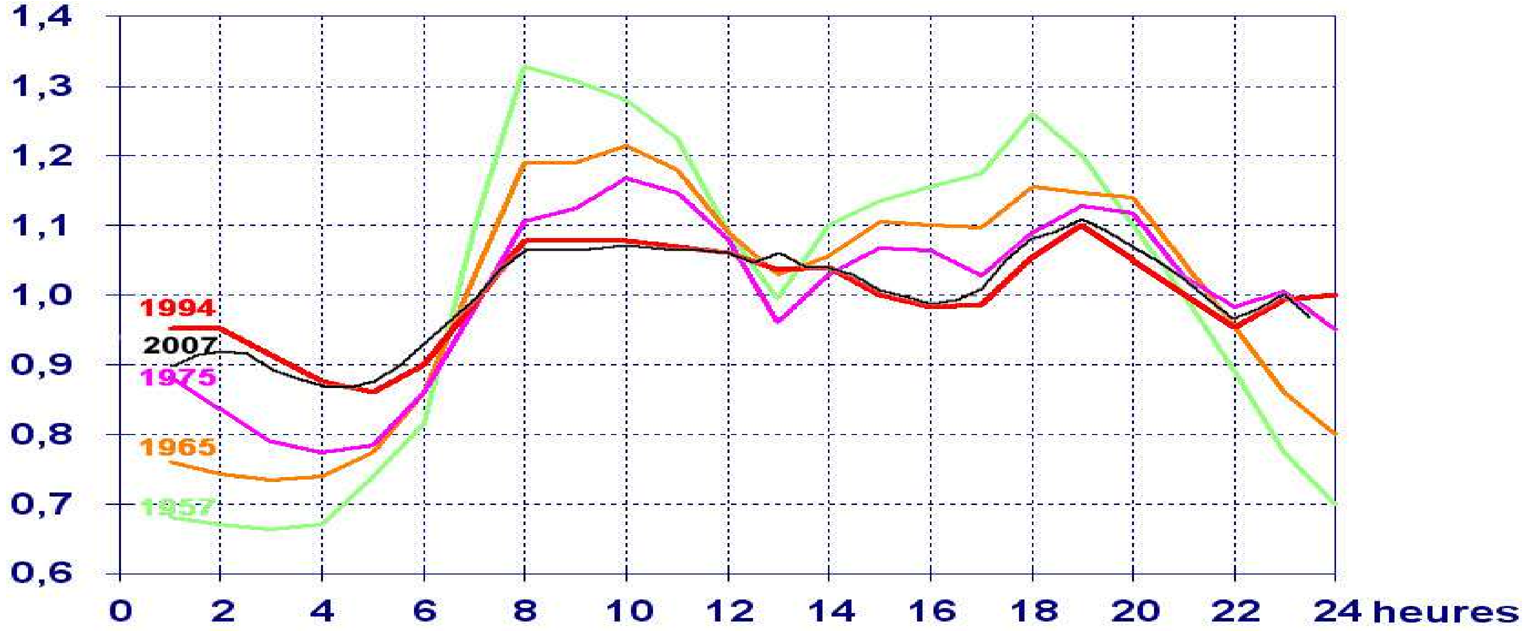
Evolution of nuclear and pump storage capacities in Europe

Source: Alstom

FRENCH WATER HEATING ALSO AN EFFICIENT WAY TO STORE ENERGY

- EDF manages, since the 60s, 12 millions of water heating in France for an annual consumption of ~20 TWh
- Used to smooth the French national and local demand
- This management has enabled the development of a French industry

Impact of the load curve of the French water heating on the demand

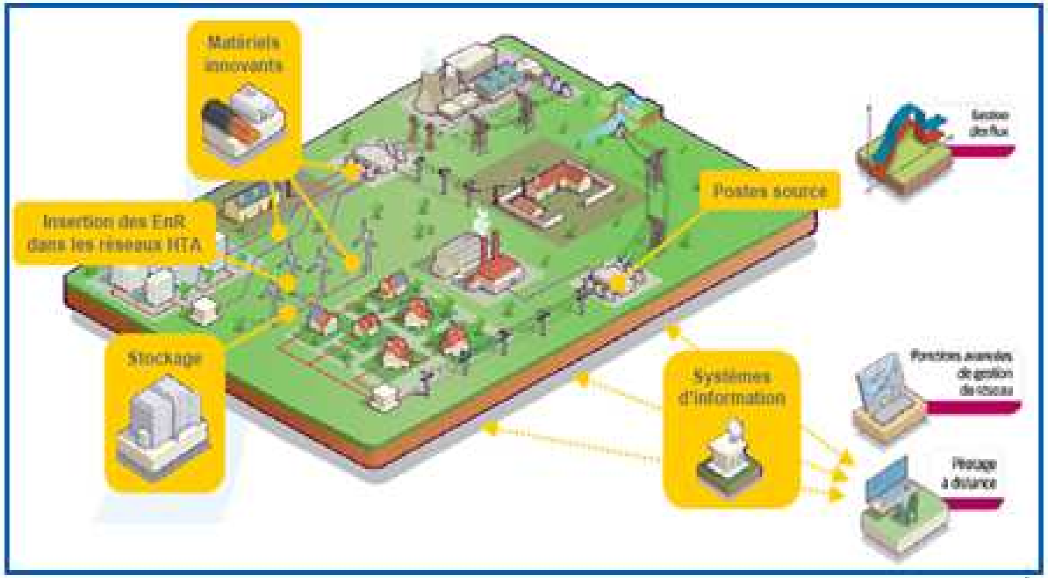


EDF R&D IS INVOLVED IN RESEARCH ACTIVITIES AROUND STORAGE

- To investigate the future needs of the system in term of applications and assess the ones that could be provided by Storage
- A need of demonstrators to validate the arrival of reliable industrial products
- European project (eStorage) with variable speed deployment at the “Cheylas”
- EDF chairs the presidency of the European Association for the Storage of Energy (EASE)

NaS Battery 1MW – 7,2 MWh on the Réunion island

VENTEEA : Lithium-ion battery to promote the integration of renewable on distribution grids



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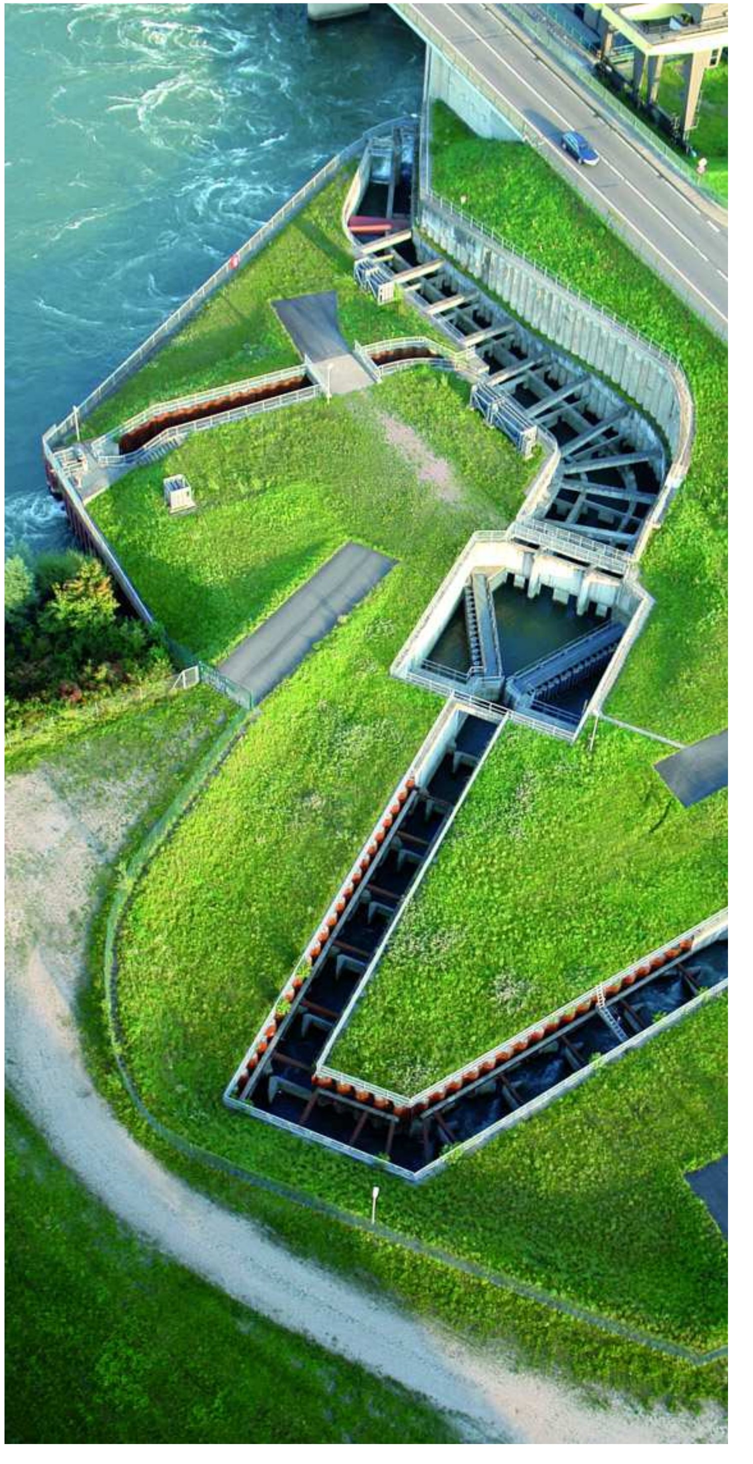
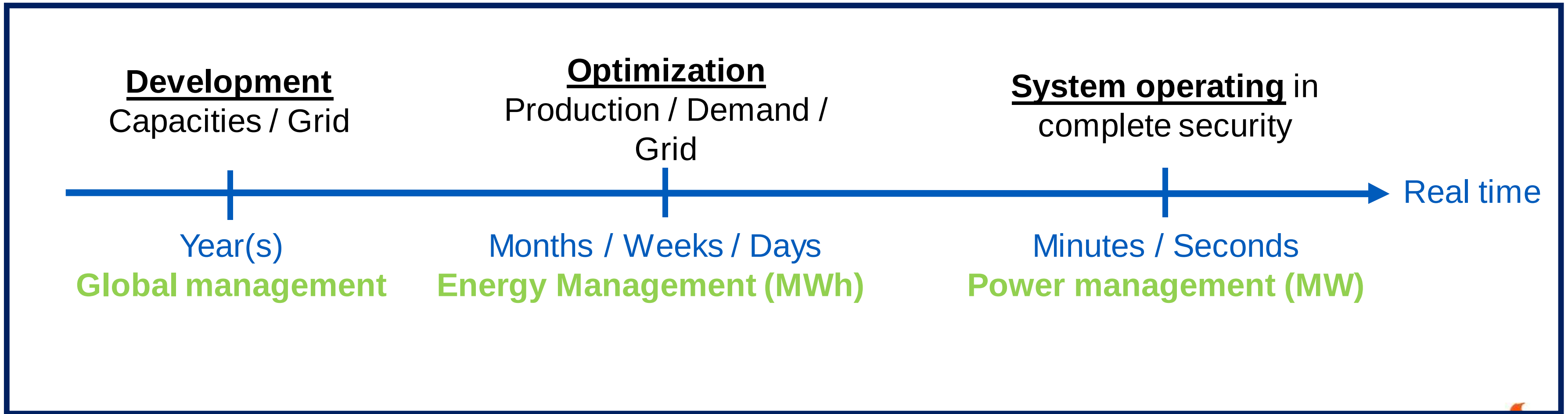


THE ELECTRICAL SYSTEM IS MANAGED ACCORDING TO DIFFERENT TIME HORIZONS

- In order to ensure the supply / demand balance at each time, the electrical system is managed according to different time horizons :
  - Annual / Pluriannual : the development of the power system is guided by the evolutions of the demand and of the generation mix
  - Seasonal : the winter (heating) and the summer (air conditioning) raise different problems that have to be dealt with in advance
  - Weekly : weekly variations may be strong (cold wave, heat waves, …) and make it necessary for the power system to adapt in a few days
  - Daily / Intra-daily : adaptations are necessary at every moment, particularly in the event of contingencies affecting demand or generation



AMBITIOUS EUROPEAN AND NATIONAL ENERGY POLICIES → OPPORTUNITY FOR STORAGE

- Energy policies promoted by the EC and Member States design a new context for European power systems. Main trends are :
  - Consolidation of a decarbonated generation mix
  - Development of renewable energy sources (RES)
  - Demand Response
  - Adaptation of the physical infrastructure (mainly in transmission and distribution)
  - Integration of electricity markets to improve use of the generation and transmission infrastructure and reduce price volatility both in time and location

Share of intermittent RES in Europe in 2012 and targets for 2020

Countries	2012		2020 Objectives
	Installed capacity (GW) *	% National mix	% National Mix
Spain	28.9 22.5 + 0 + 6.3	22 %	29 %
Germany	63.9 31+ 0,3 + 32.6	12.4 %	26 %
UK	10.6 5.9 + 3 + 1.7	5.6 %	22 %
France	11.6 7.6 + 0 + 4.0	4.0 %	12 %
Italy	24.5 8.1 + 0 + 16.4	9.7 %	8 %
USA	67.7 60 + 0 + 7.7	3.7 %	6 %
China	83.6 75.3 + 0 + 8.3	2.5 %	6 %

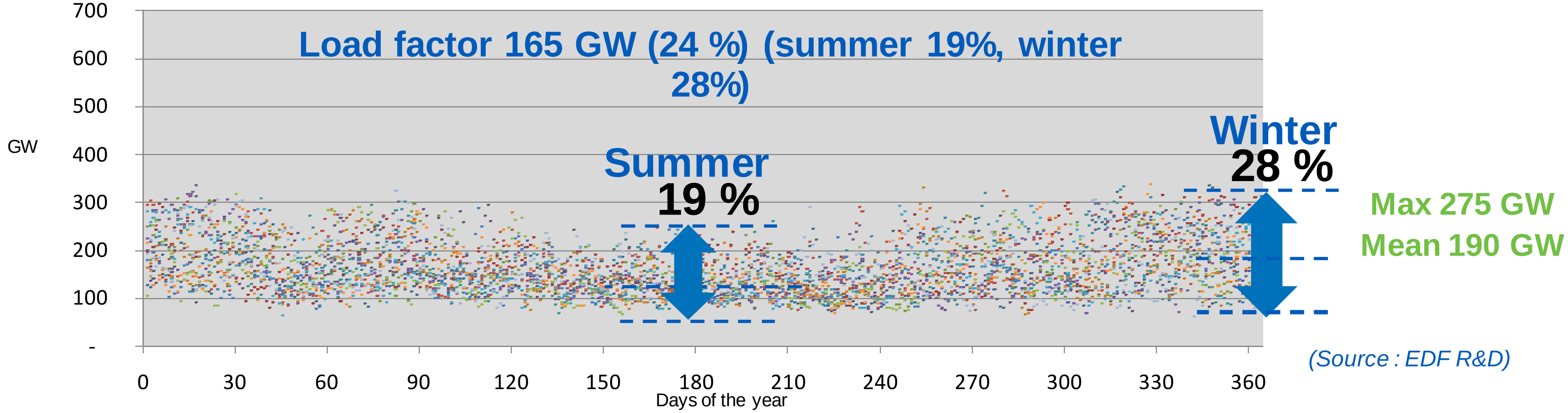
(GW)* On-shore Wind + off-shore Wind + Solar

Sources : EUROBSERV'ER, EREC, GWEC, IEA, REE, GOV.UK, AGEE, RTE, RenewableEnergyWorld, Gov.cn

TO COPE WITH VARIABILITY OF INTERMITTENT RES: NEW NEEDS FOR FLEXIBILITY

- To characterize variability, daily maximum output of intermittent generation can be compared over many scenarios :
  - *Ex: EC Roadmap towards 2050 (High RES), 60% of RES at 2030, of which 40% of wind and PV (700 GW).*
    - *The figure below uses 30 historical climate scenarios (1 day, 30 points)*

Wind & PV forecast generation in 2030 based on historical profiles



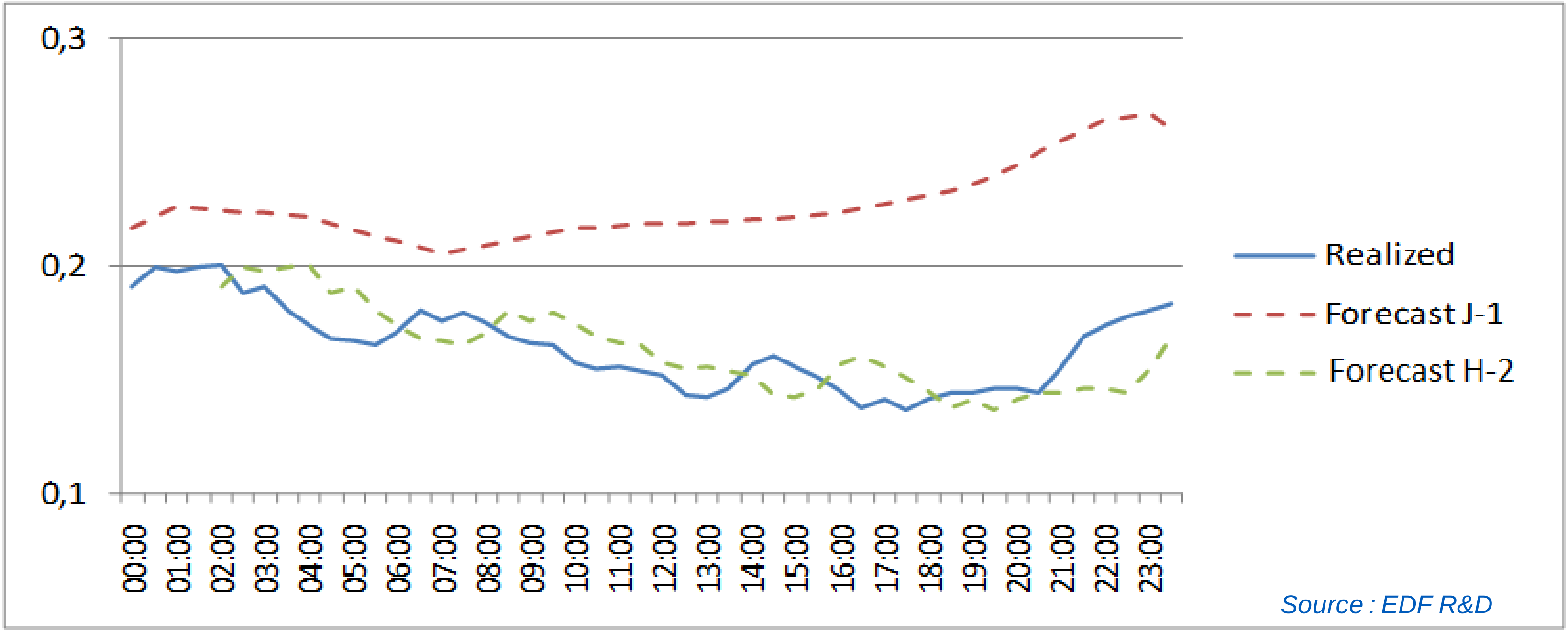
(Source : EDF R&D)

- Variability has always existed (demand) and some solutions proved to be competitive: hydro storage, PHS, flexible thermal generation, interconnections,… Storage with high duration capacity could play an increasing role

TO COPE WITH UNCERTAINTY OF INTERMITTENT RES: NEW NEEDS FOR FLEXIBILITY

- Utilities need to plan additional operating margins at different time scale to cope with uncertainty of wind and solar outputs

Load factor predicted & realized of wind generation in France 2011/01/14



- Need of additional means to provide back-up capacity, ancillary services, etc

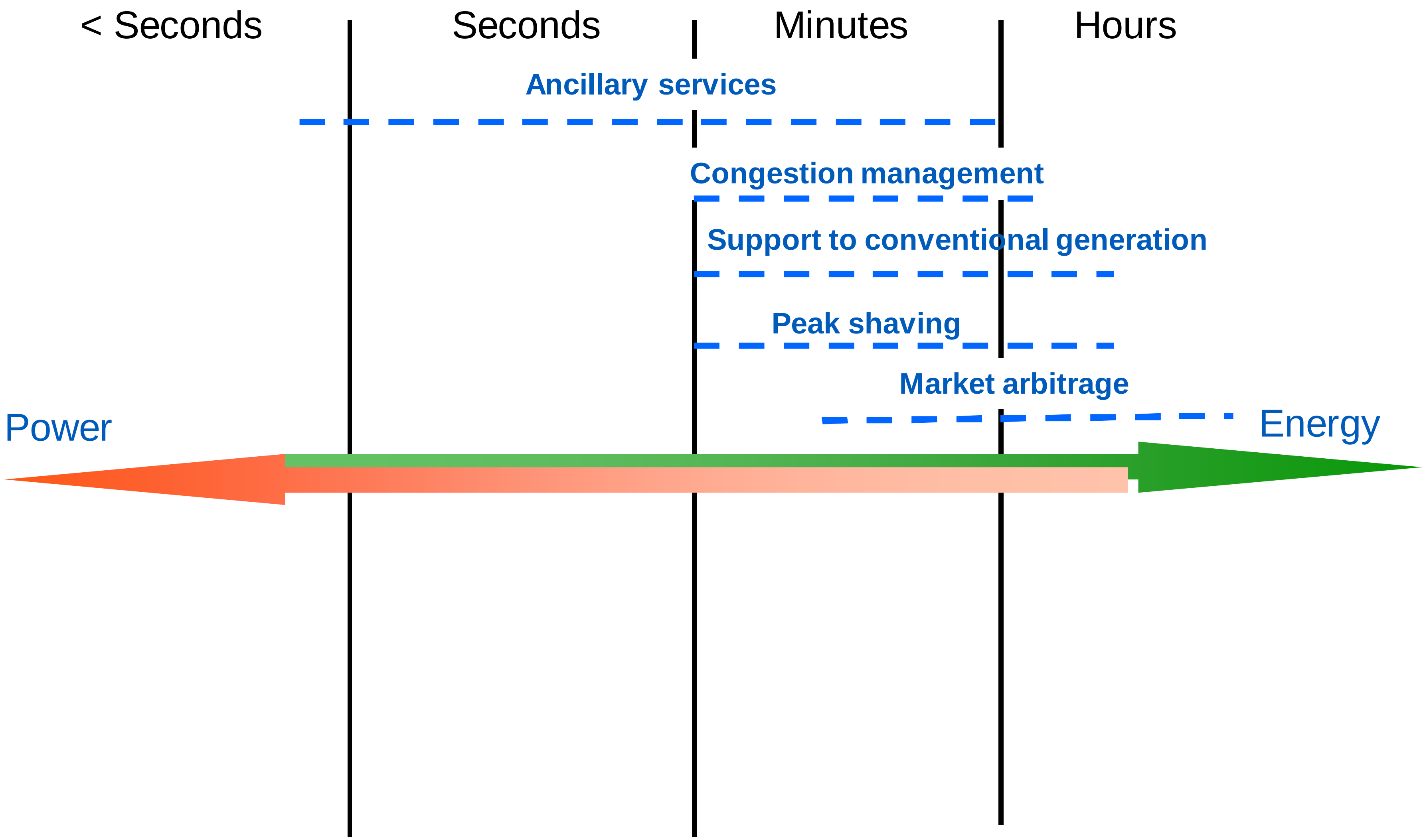
- Storage with high power capacity could play an increasing role

STORAGE COULD PLAY AN INCREASING ROLE IN A MORE FLEXIBLE POWER SYSTEM

- The technical and economical progress of some storage technologies could give it a more and more important role in the power system manegement

- Storage has two challenges to take up :
  - Economical challenge: to find a profitable *business model*
  - Technical challenge : to identify the services to the system

STORAGE APPLICATION : A DISTINCTION BETWEEN POWER AND ENERGY



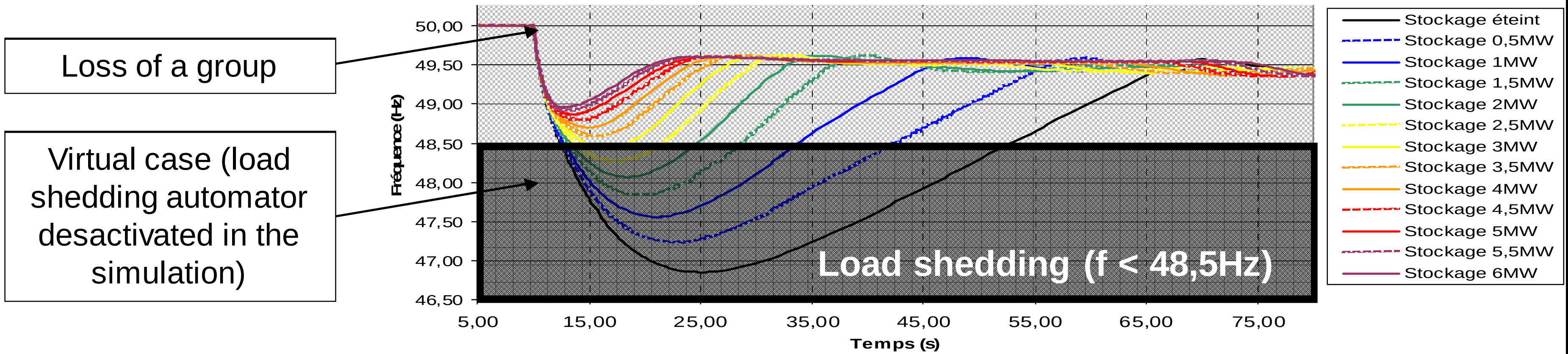
Source EDF R&D

STORAGE AND FREQUENCY REGULATION

- In island systems, the very prompt response of storage is interesting to provide “dynamic frequency control support”
  - Even with enough primary reserve, a loss of a group in isolated systems can lead to load shedding (Primary Reserve not available fast enough)
  - Requires a short response time (<1s) and a discharge duration of a few 10s

- In the simulation below, load shedding is avoided with a storage capacity of 5-10 MW, a total of primary frequency reserve of 20-25 MW and a peak demand of 250 MW

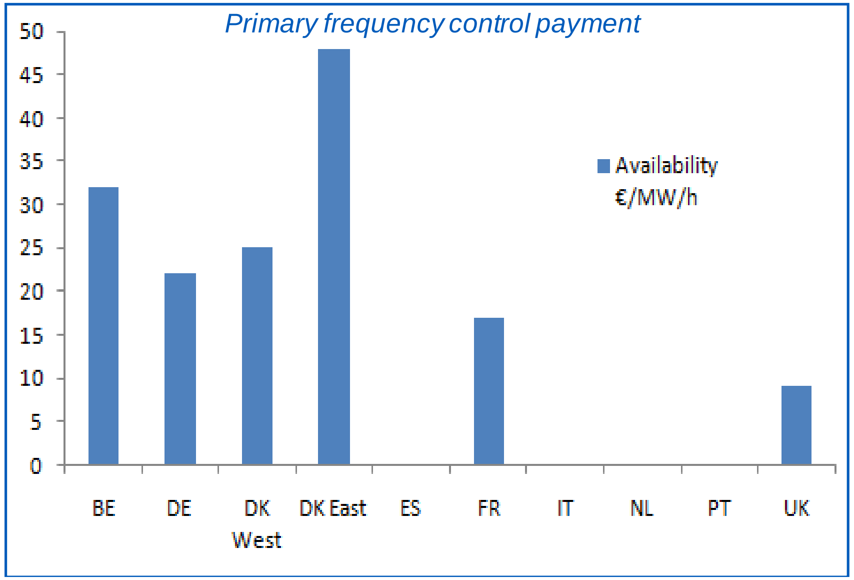
Example of frequency evolution in case of a loss of group

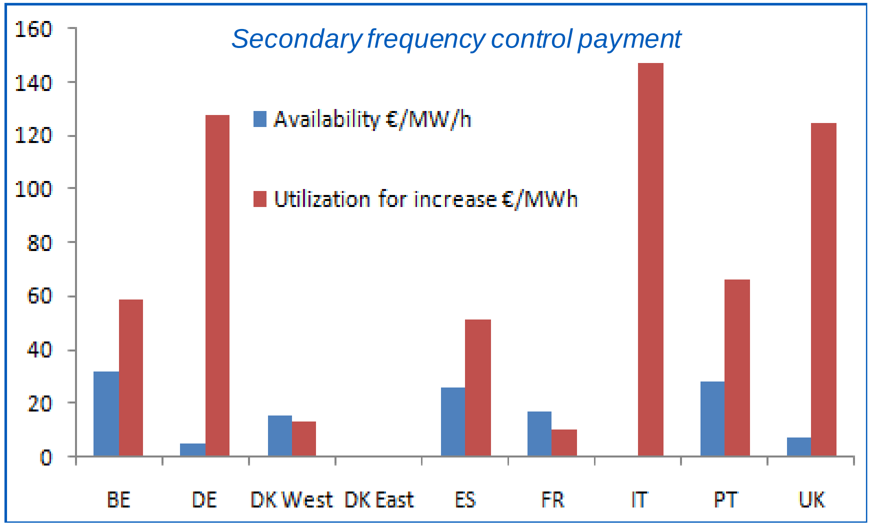


Source EDF R&D Delille G, et al., « Dynamic frequency control support », IEEE oct 2010

STORAGE AND FREQUENCY REGULATION

European benchmark on ancillary service *(source EASE)*

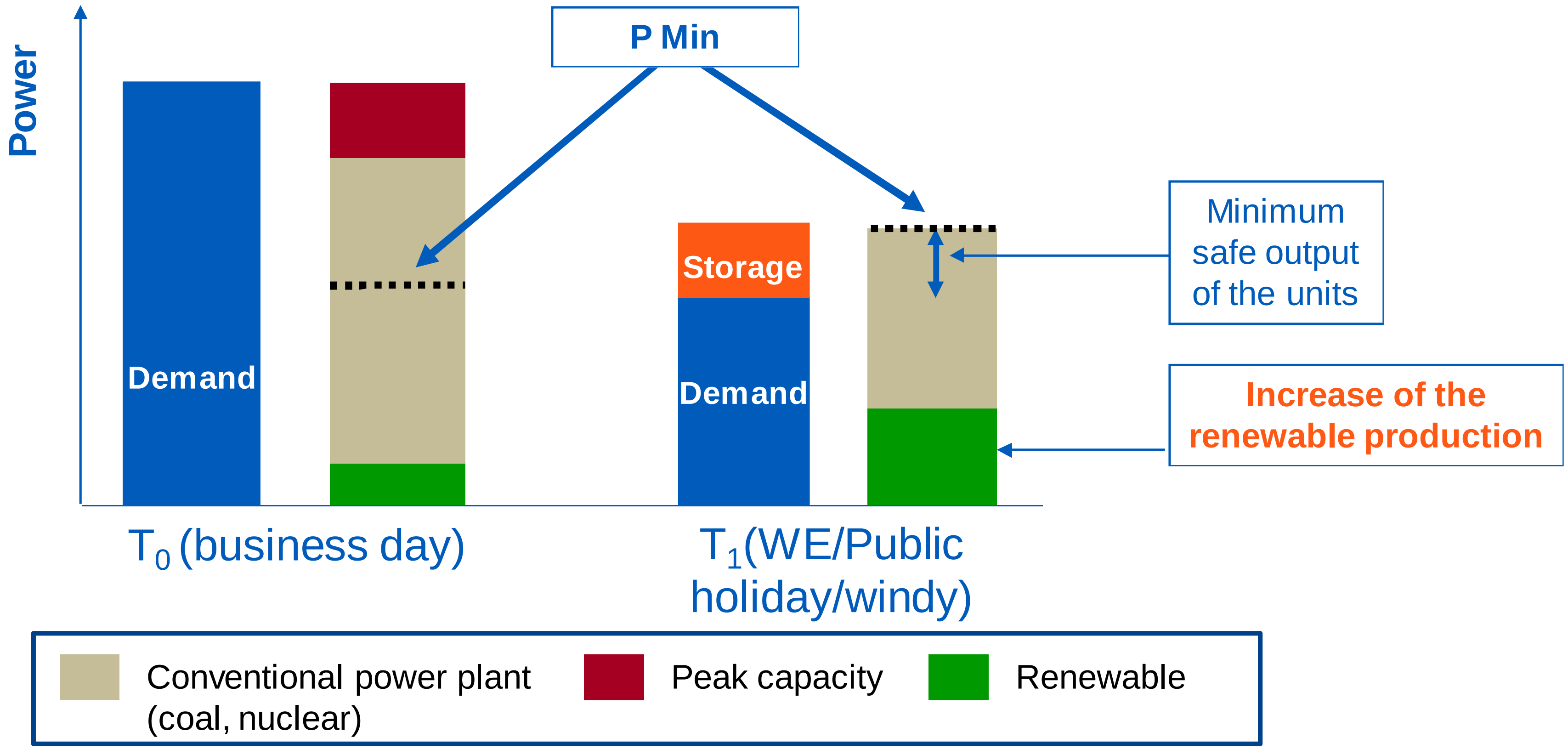




- The development of storage technologies could allow to provide services which were provided by other means in a less cost effective way
- In Europe, the size in MW for this market is limited.
  - For example, 3000 MW for Primary frequency regulation

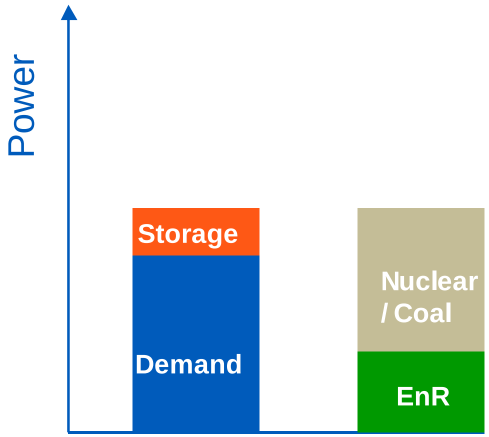
Return

STORAGE: A SUPPORT TO CONVENTIONAL GENERATION

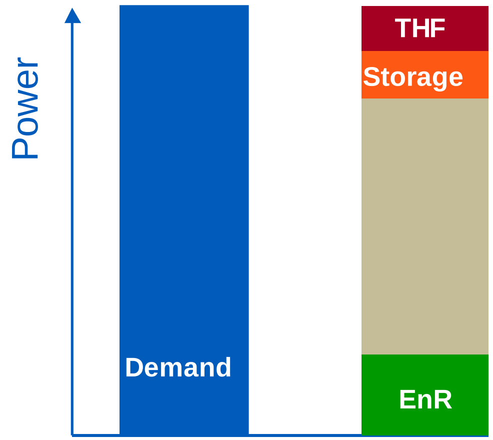


- The intermittency and the variability of renewable adds a new alea in the management of the production mix and increases the needs for maneuverability of conventional power plants (coal, nuclear)

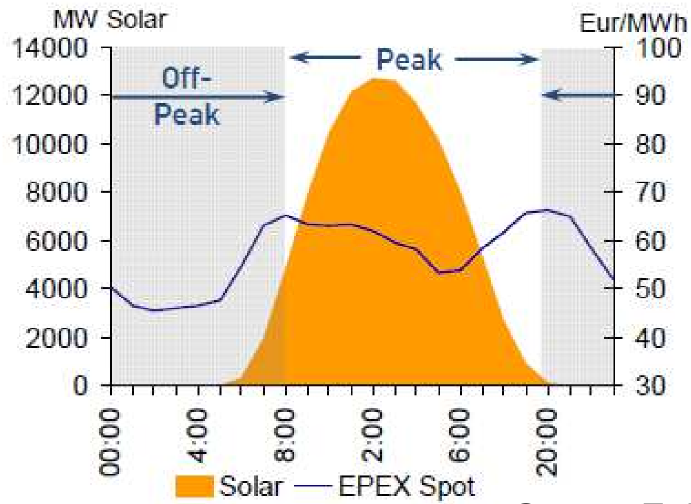
STORAGE, A TOOL FOR MARKET ARBITRAGE



Off peak hours
Ex : 25/11/2012
at 3 AM price : 11,2 €/MWh



Peak hours
Ex : 26/11/2012
at 2 PM price : 60,1 €/MWh



Source EnBW

- Historically, the arbitrage is the main application for storage
- When the Renewable production is well correlated to the demand, the spread tends to reduce (ex:Germany)
- This “energy” service is not sufficient enough to recover 100% of the cost
  - ❑What is the upper bound for this service ?

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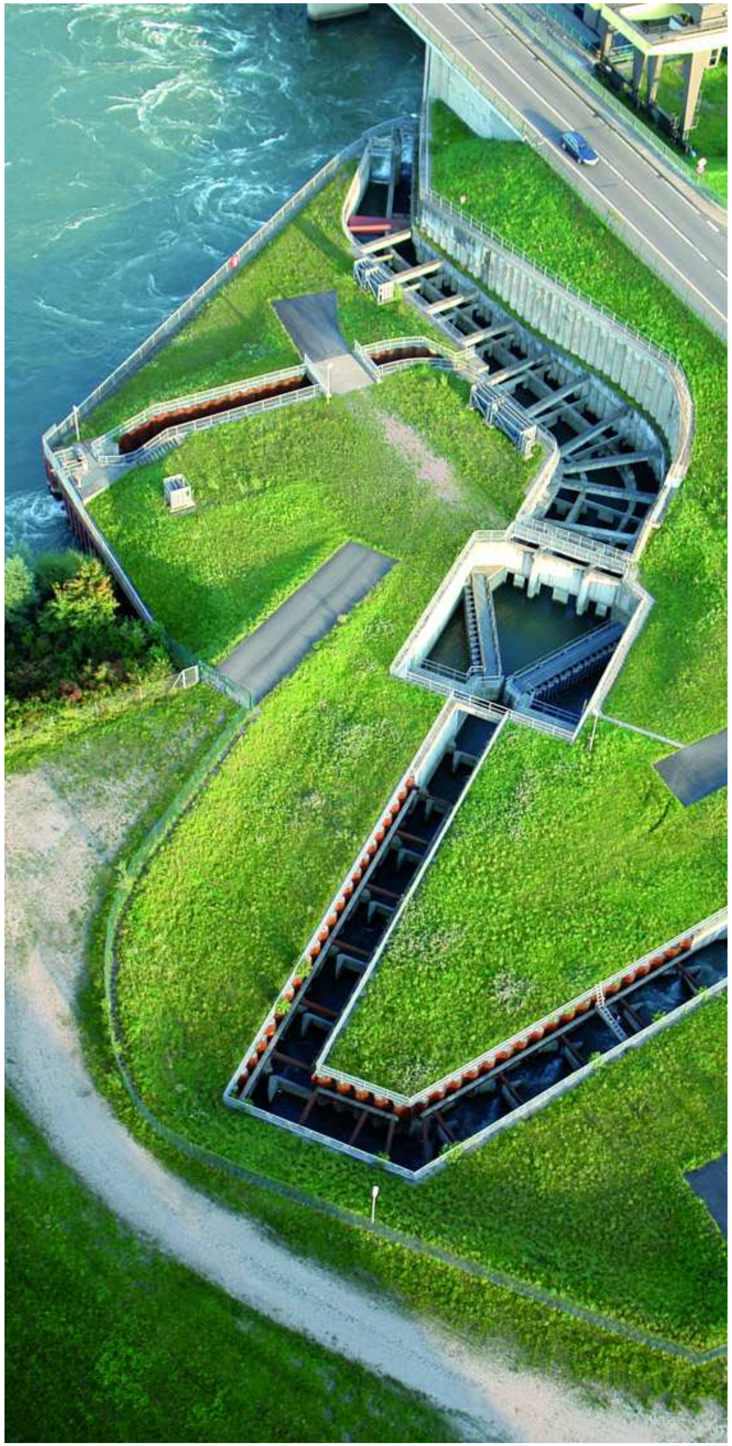
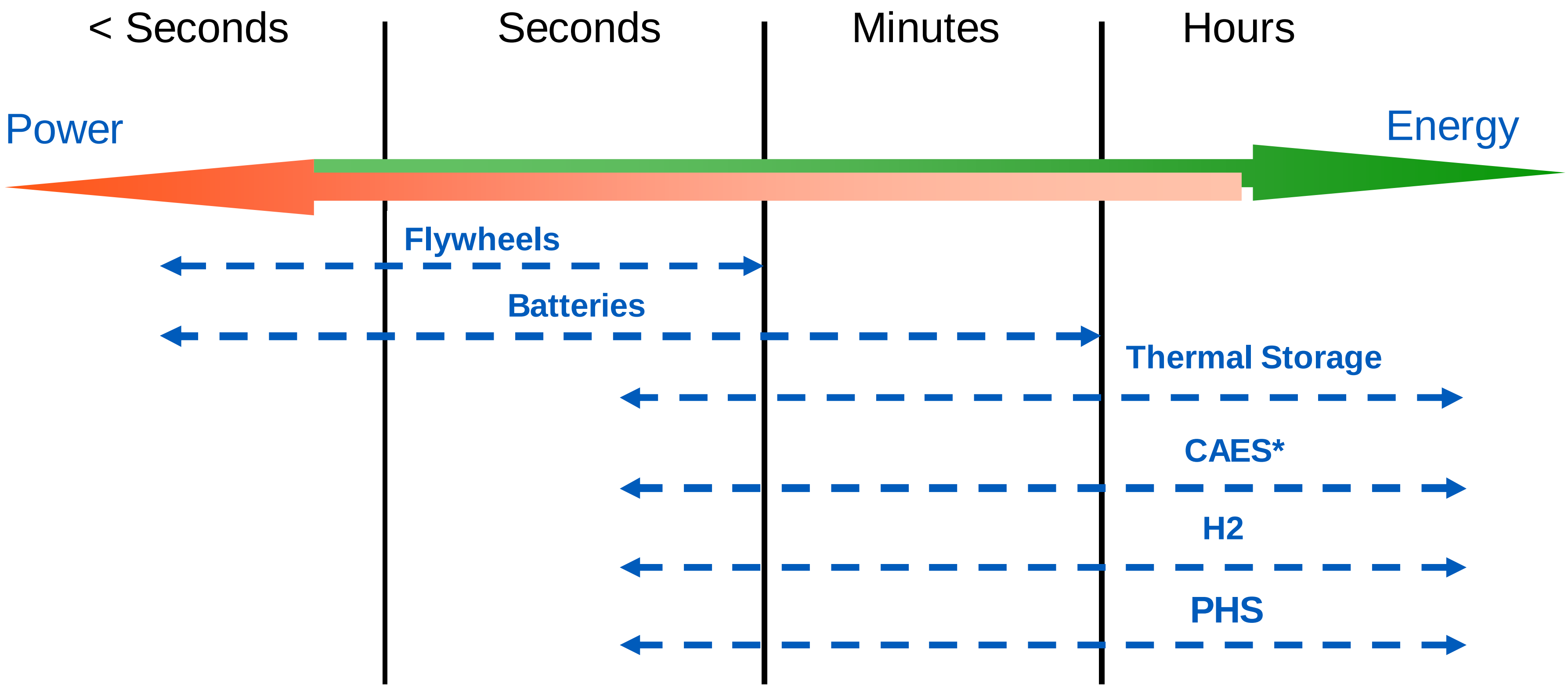


STORAGE TECHNOLOGY : A DISTINCTION BETWEEN POWER AND ENERGY



*** CAES : Compressed Air Energy Storage**

Source EDF R&D

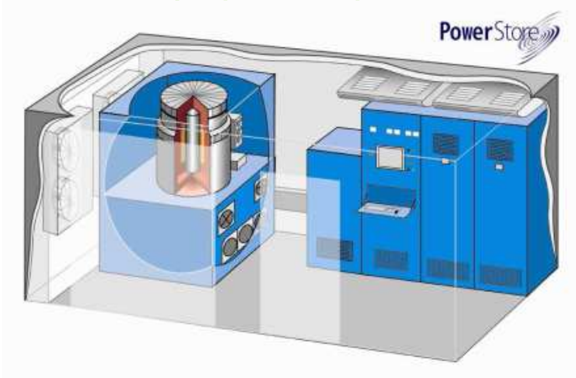
FLYWHEELS

- A flywheel is a mass to store kinetic energy
  - In charge, the speed increases / in discharge, the speed decreases
  - Limited in energy (~30 min max.)
  - Almost unlimited in terms of number of cycles
- Today, this technology is very expensive

Beacon Power (NY, U.S.A.) 20 MW / 15 min

Source : Sia partners

PowerCorp (Azores) 500 kVA/30 s



BATTERIES, A WORLDWIDE OFFER

Lead Acid
(Pb, VRLA…)

+ Cost

- Nb cycles

Sodium
(NaS, Zebra)

+ 'energy' applications

- Cost

Lithium
(Li-ion,
Li-Métal)

+ Current Cost & perspective

+ Nb cycles

- Mainly power and grid applications : Primary frequency regulation, Grid Reinforcement or Quality of supply

- One application can provide up to 70% of the revenues : arbitrage between a combination of applications to aggregate revenues vs. over sizing the device to fit the complementary services

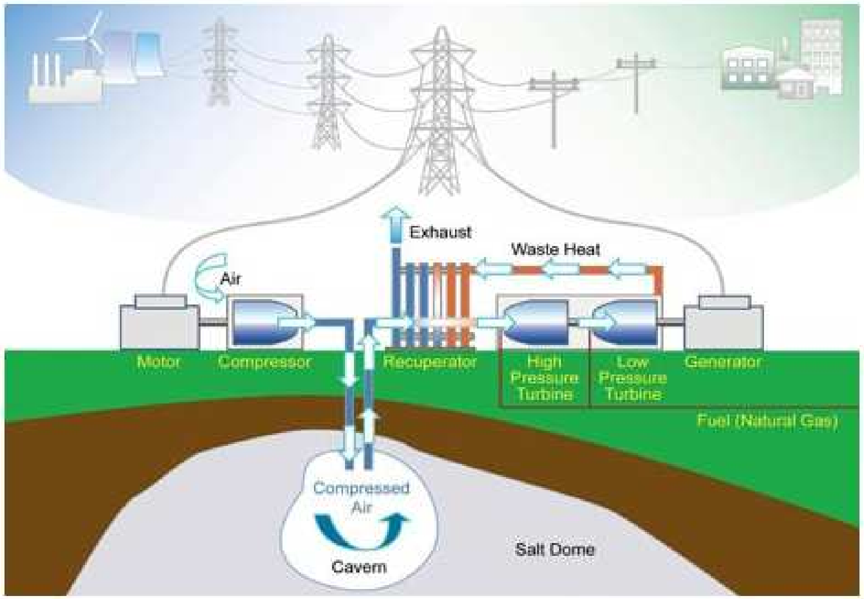
- Difficulty to assess the market: strongly depends local conditions

Key indicators

- ❑Cost and potential reduction
- ❑Number of cycles and life duration
- ❑Environmental acceptability
- ❑Industrial maturity
- ❑Reliability
- ❑Re-used battery

COMPRESSED AIR ENERGY STORAGE (CAES)

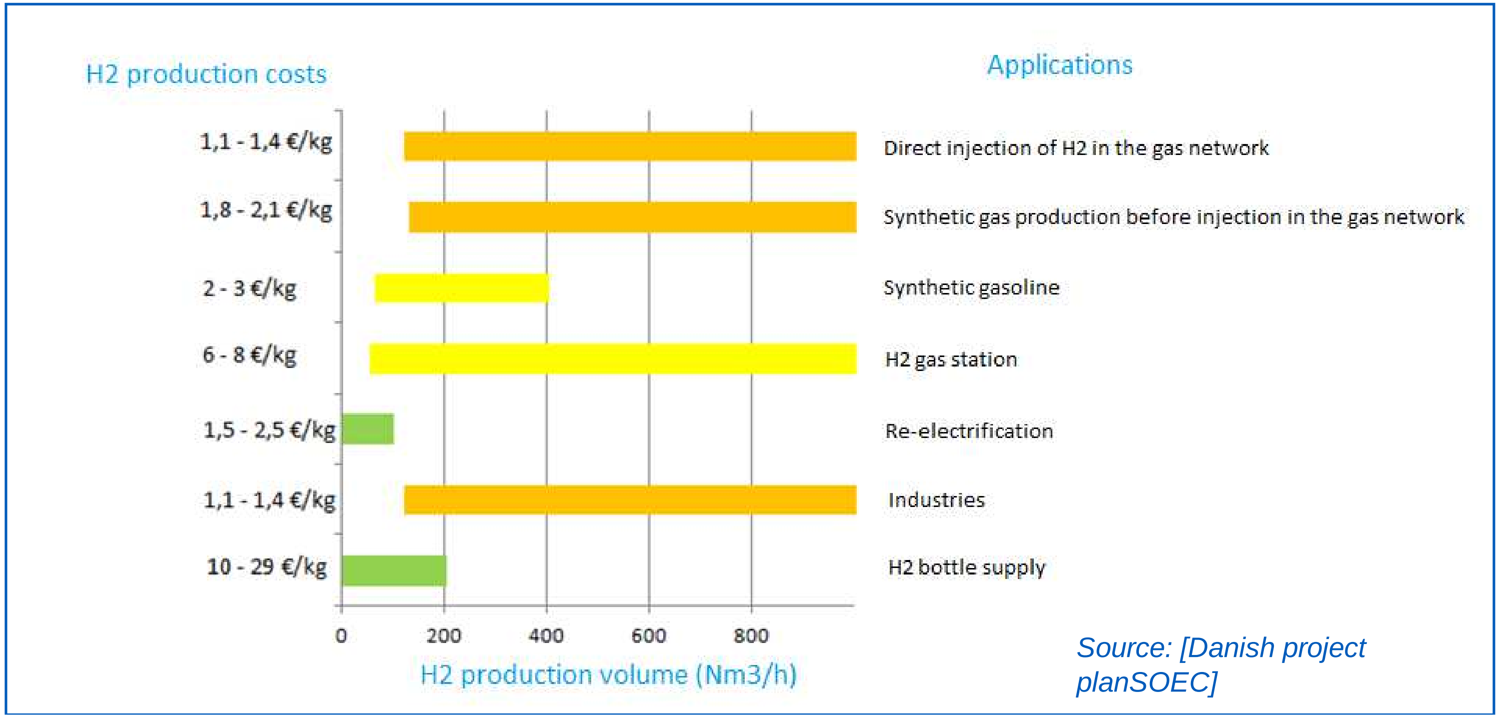
- Charge = air compression / Discharge = air decompression
- Coupled to combustion turbines or thermal storages
- 2 existing CAES plants (DE & US)
- For those which needs a cavity (salt or mined) in competition with gas storage
- Where water availability is an issue, could be an option for long duration storage
- Forecasted cost are promising



Source : GridFlex

HYDROGEN, A NEW ELECTRICITY DEMAND

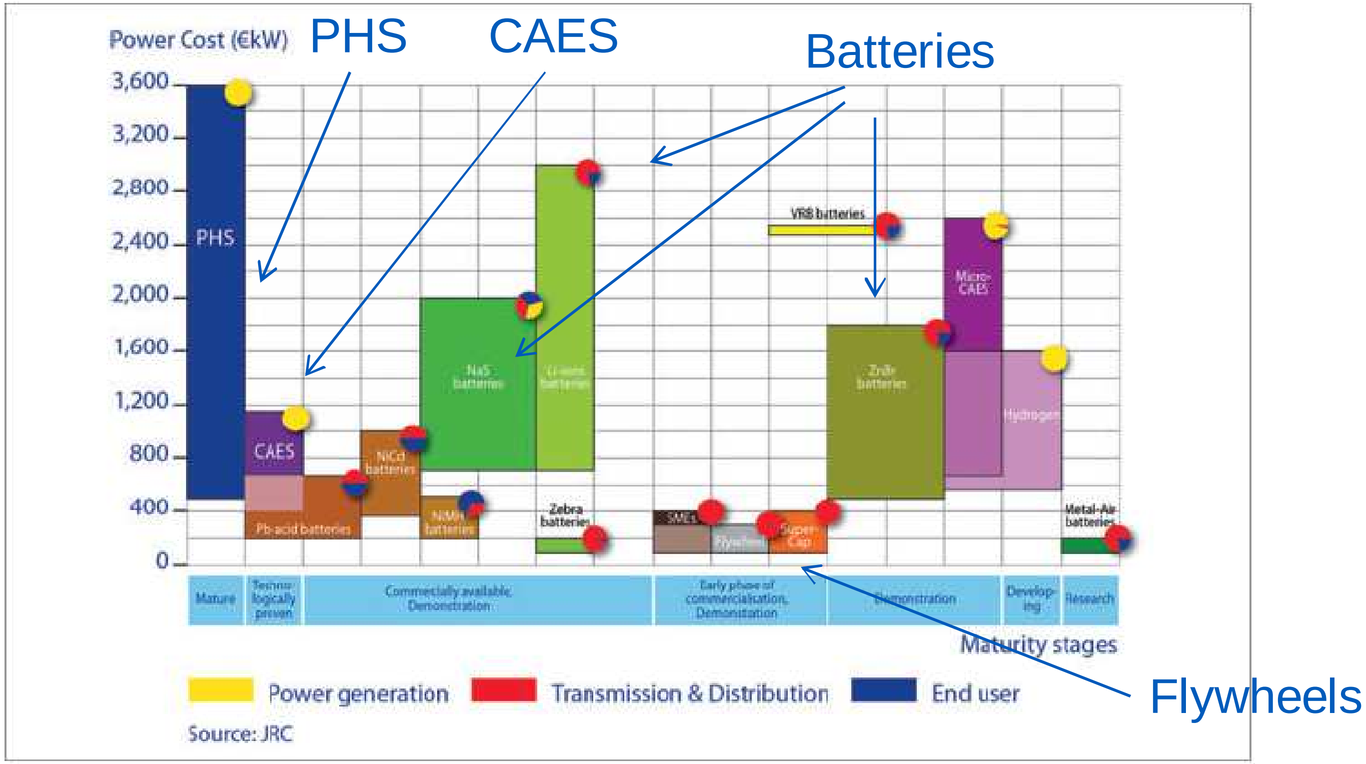
- Hydrogen can be seen as a potential energy storage solution, such as domestic thermal storage



- Excepted niche markets (isolated grids…) electricity generation is not competitive option (overall efficiency ~ 35%)
- Need a demonstrator to validate the performance in terms of flexibility for the promising PEM technology

WHICH COSTS AND WHICH MATURITY ?

- Cost hypotheses remain quite high
- Maturity varies a lot, depending on the technologies



[Source: JRC] Power storage technologies as a function of their cost and development stage

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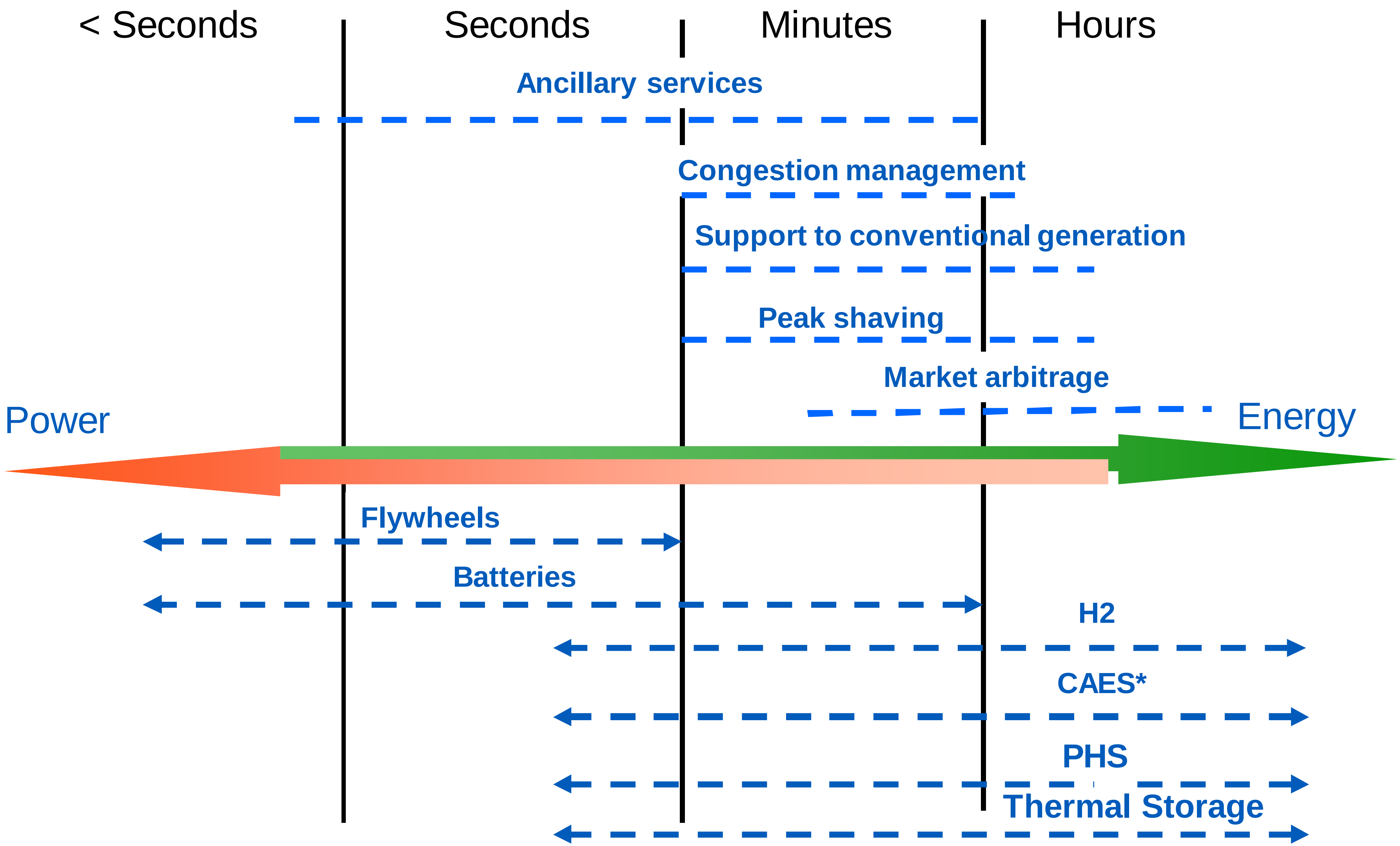

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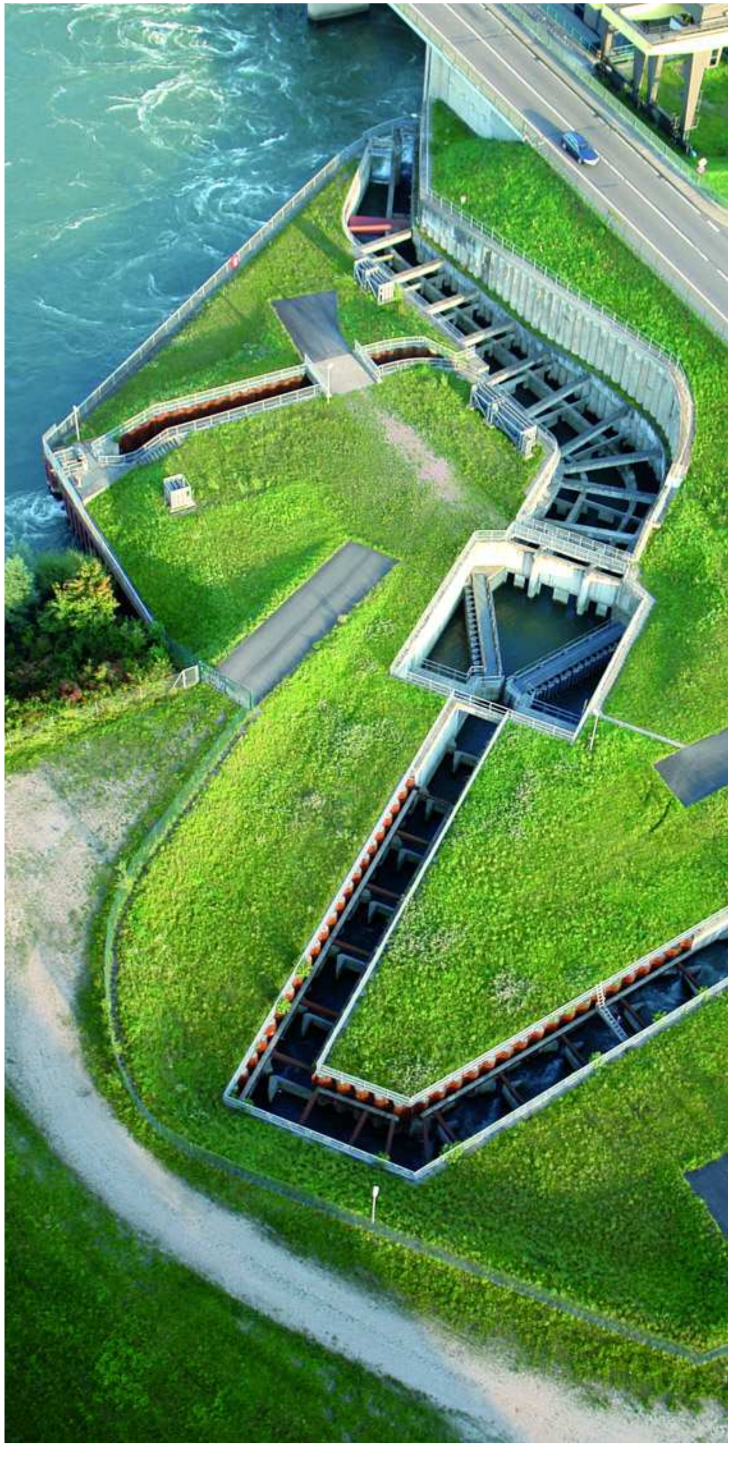

CONCLUSIONS

- To assess the storage markets we need:
  - to understand the applications, their potential and their associated revenues
  - to establish the merit orders of the technological solutions
- In term of storage device, PHS will probably remain the leading technology
- The future transport mutation towards electric mobility and the emergence of smart grids should place batteries in the heart of the future electrical system

HYDROBALANCE

- The issues addressed in “Hydrobalance” are directly linked to the management of the Power System :
  - What is the best (economically and technically) answer to the increasing part of intermittent RES in Europe ?
    - Storage development ?
    - Grid extension ?
    - More flexible production ?
    - Active Demand ?

THANKS FOR YOUR ATTENTION