International Workshop on Energy Storage in the Grid: Low, Medium and Large Scale Requirements

Electrical storage for power system applications: Needs and Challenges

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RSE Ricerca Sistema Energetico

Barcelona, 9 January 2014

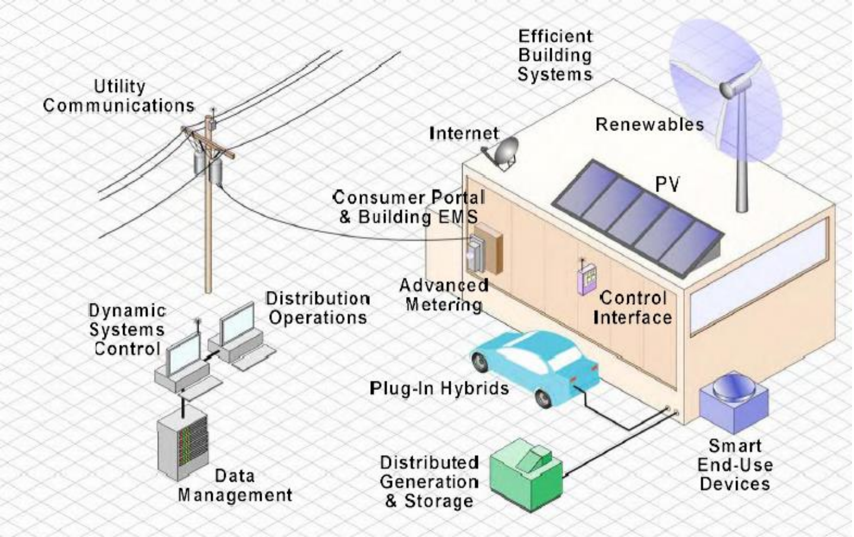
OUTLINE

- Introduction to European Energy Research Alliance and EERA JPs
- **Smart Grids and Storage**
- **Drivers and Needs**
  - ***Renewable Energy Sources (RES) Integration***
  - *Grid ancillary services, Electric Vehicles, …*
- **Grid services and Electric Storage Systems**
- **Energy Storage portfolio**
  - *Selected ES technologies (PH, CAES, Electrochemical)*
  - *Other types (e.g., Hydrogen vector)*
- **Storage technologies comparison**
- **Conclusions**

SMART GRIDS

The Networks of the future and the active role of the consumers

The evolution of the network is instrumental for the **wide diffusion and high penetration of renewable energy sources (RES)**, for the implementation of energy saving measures (hence to the reduction of CO_2 gas emissions), and to enable consumer participation.

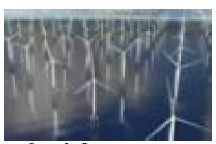


The Smart Grid vision:
Integration from supply to demand

Generation

traditional power plants

solar generation



wind farms

distributed generation

Smart Grid

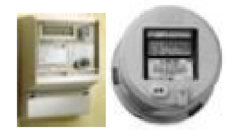
Open for all types and sizes of generation

Interaction between demand side and operation

Efficient, reliable and self-healing transmission and distribution

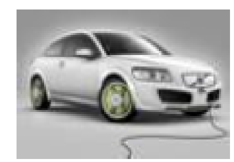
Most cost efficient solution to future requirements

Consumption

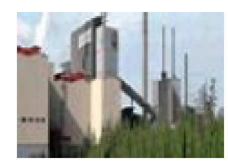


smart meters

smart house



plug-in vehicles



industry

Drivers and Needs for Energy Storage (1/2)

	**Thermal & Nuclear**	**Generation Levelling** (Energy Arbitrage/Shifting)	Improve overall generation efficiency through on/off-peak shifting of net generation/demand
	**Intermittent Renewable**	**Energy Balancing**	Compensate intermittent generation with flexible charging/discharging
	**T&D Grid**	**Congestion Management**	Relief congestion with flexible resources in effective grid locations
		Ancillary Services	Frequency regulation, Reserves, Voltage/VAr support, etc.

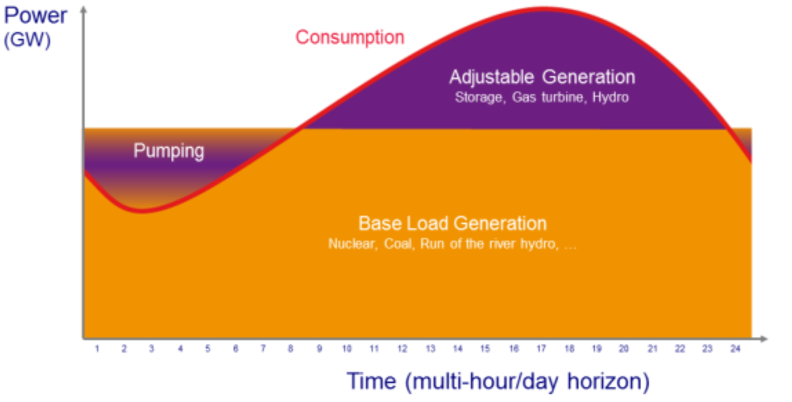
Drivers and Needs for Energy Storage (2/2)

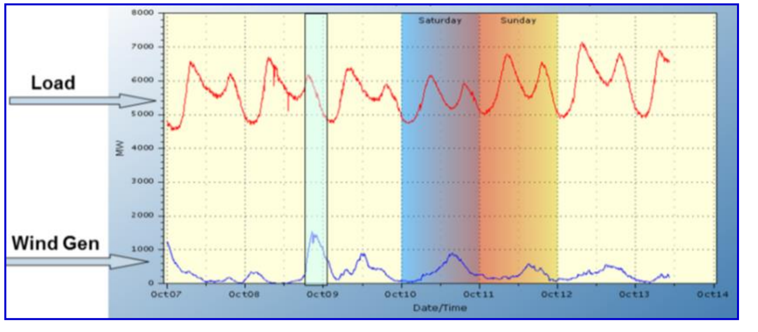
- Energy Arbitrage/Shifting

  - Renewable integration

    - Grid Frequency Regulation

      - … … …





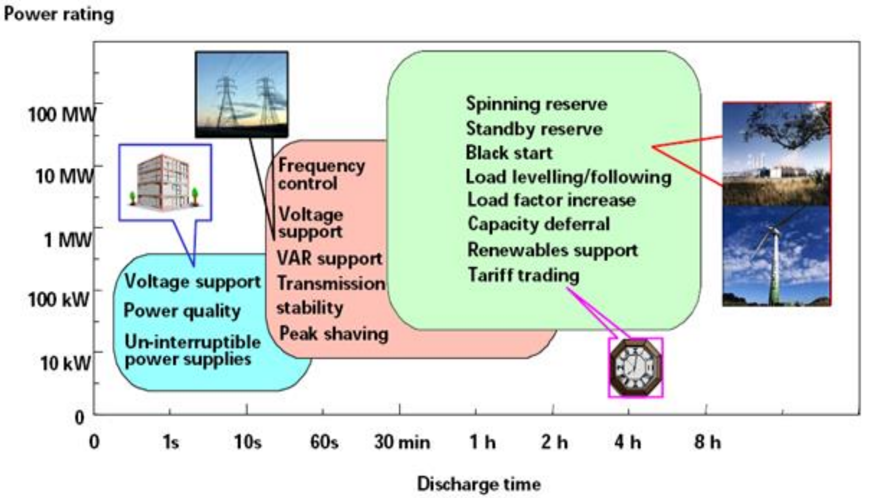
Integrating Intermittent Generation Requires Flexible Resources

MW Intermittency contributes to Price Volatility

Grid Services

Electric Supply
- Electric Energy Time-shift
- Electric Supply Capacity

Ancillary Services
- Load Following
- Area Regulation
- Electric Supply Reserve Capacity
- Voltage Support



Grid System
- Transmission Support
- Transmission Congestion Relief
- Transmission & Distribution (T&D) Upgrade Deferral
- Substation On-site Power
- Island (micro) network management

End User / Utility Customer
- Demand Side Management (to shift high peak usage to low cost time)
- Demand Charge Management (to lower high peak fixed charge)
- Electric Service Reliability
- Electric Service Power Quality

Energy Storage can provide a variety of Benefits

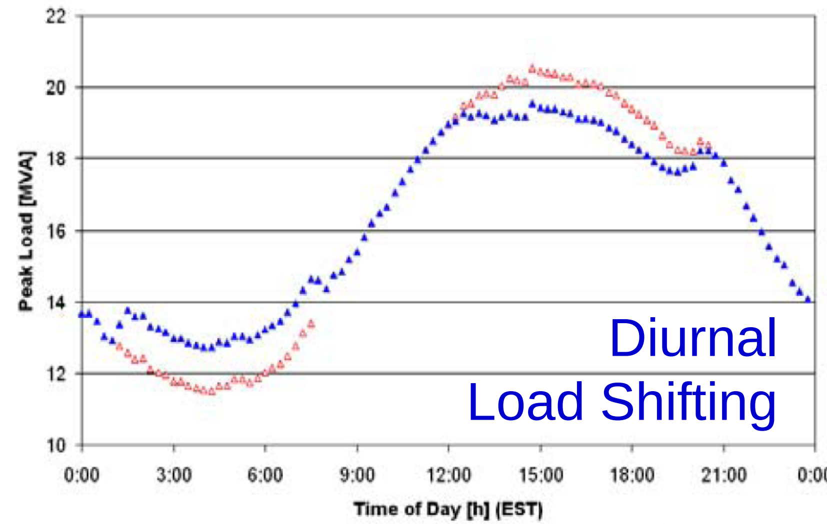
Generation – Supply Side	Delivery – Transmission & Distribution
Renewables Integration	T&D Network Investment Deferral
Rate Optimization	T&D Component Life Extension
Price Arbitrage / Peak Shaving	Transmission Access / Congestion Mngmt.
Capacity Value	T&D Asset Utilization
Cycling Cost Management	Reliability
Ancillary Services	Power Quality

RES Integration
Timing Matters

DIURNAL PEAK SHIFTING

Minutes to Hours

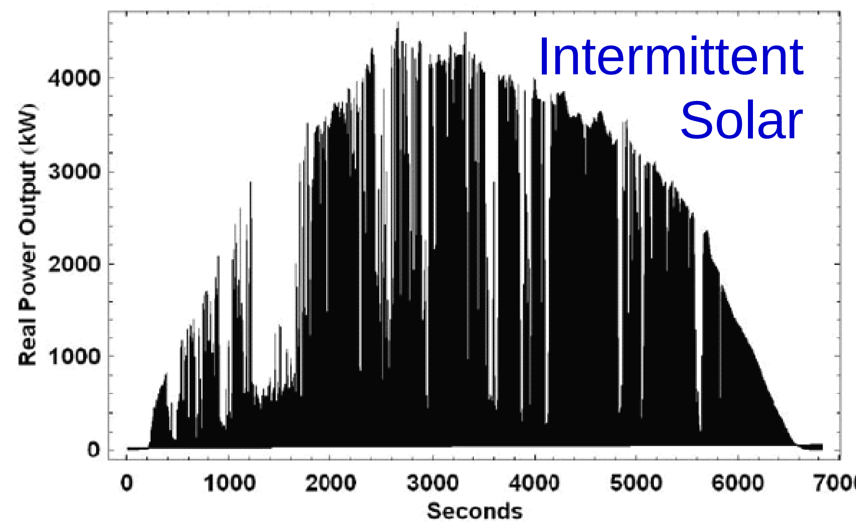
High **Energy** storage solutions



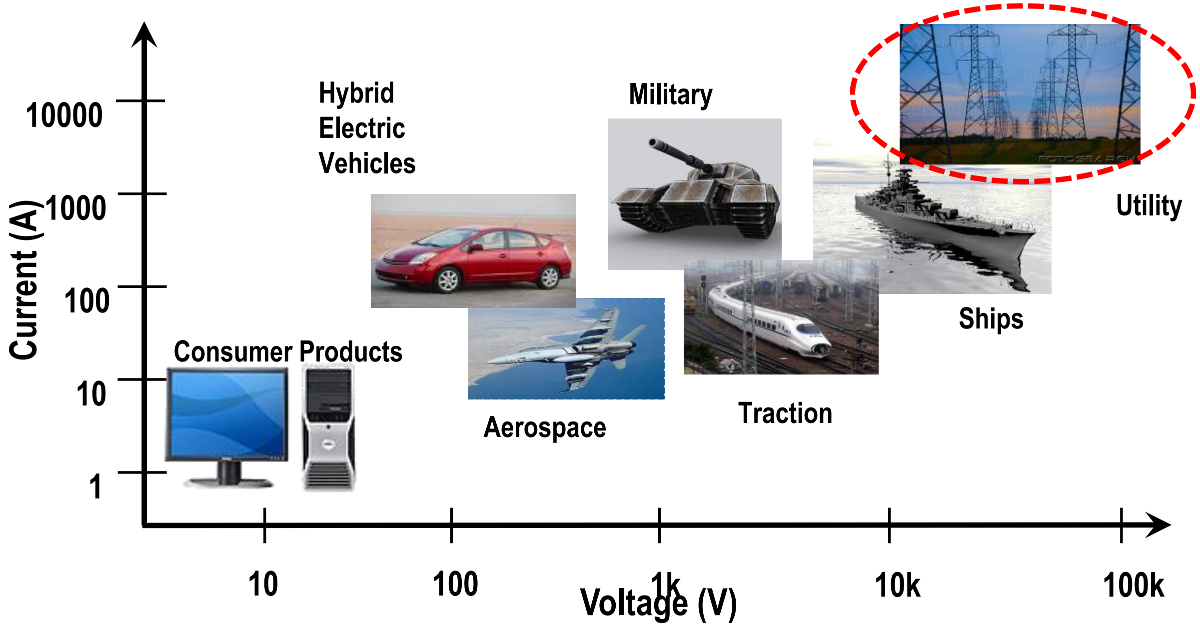
VOLTAGE AND FREQUENCY

Seconds to Minutes

High **Power** storage solutions



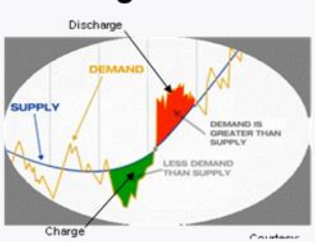
Energy Storage: Scales of Power & Time



Different power requirements and time regimes will need different storage solutions

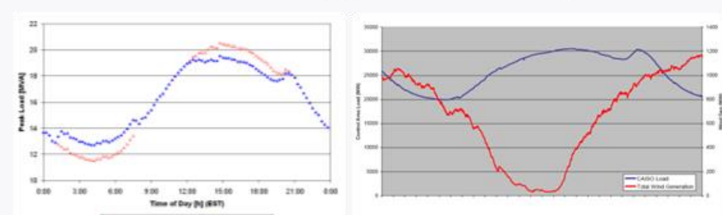
Seconds to Minutes — **Minutes - one Hour** — **Several Hours - one Day**

Regulation



Ramping

Peak shaving, load leveling



ES Cross-Cutting Challenges
Impacts on Energy Technologies

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- **Grid stability and distributed generation require innovative energy storage devices:**
  - Grid integration of intermittent energy sources such as wind and solar
  - Storage of large amounts of power
  - Delivery of significant power rapidly

- **Enabling widespread utilization of hybrid and all-electric vehicles requires:**
  - Substantially higher energy and power densities
  - Lower costs
  - Faster recharge times

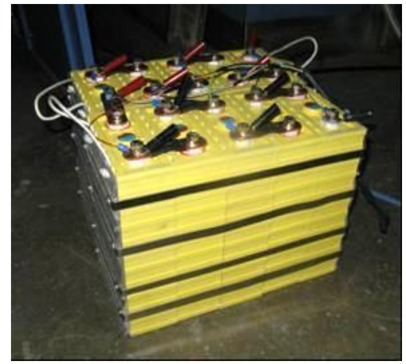
Drivers for Hybrid and Electric Vehicles

- Increasing oil price - need for fuel efficiency
- Stricter environmental requirements - low emissions
- New societal awareness and taxation policies - demand for EV's
- New infrastructure and business models emerging - interaction with smart grid, smart cities, utilities

Advances (capacity improvements, cost reductions)
in electrochemical energy storage enable new applications

Mainly Li-ion batteries, but also supercapacitors and PEMFC as range extender

Characterization elements for Storage Systems



- Capacity and power
- Lifetime
- Energy efficiency
- Specific energy and space requirement
- Cost
- Other useful characteristics

Energy and Power:
Electric Storage Technologies

Energy

- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Batteries
  - Sodium Sulfur (NaS)
  - Flow Batteries
  - Lead Acid, Lead Carbon
  - Lithium Ion
  - NiMH
  - NiCad
- Flywheels
- SMES
- Electrochemical Capacitors

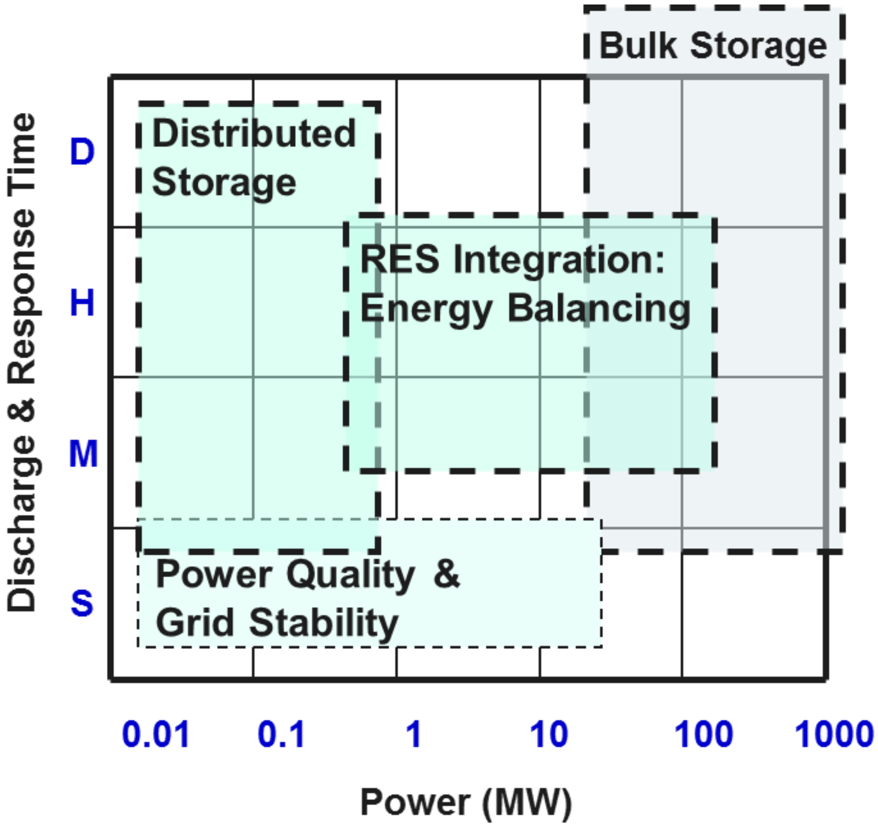
Power

Pumped Hydro 400 MW

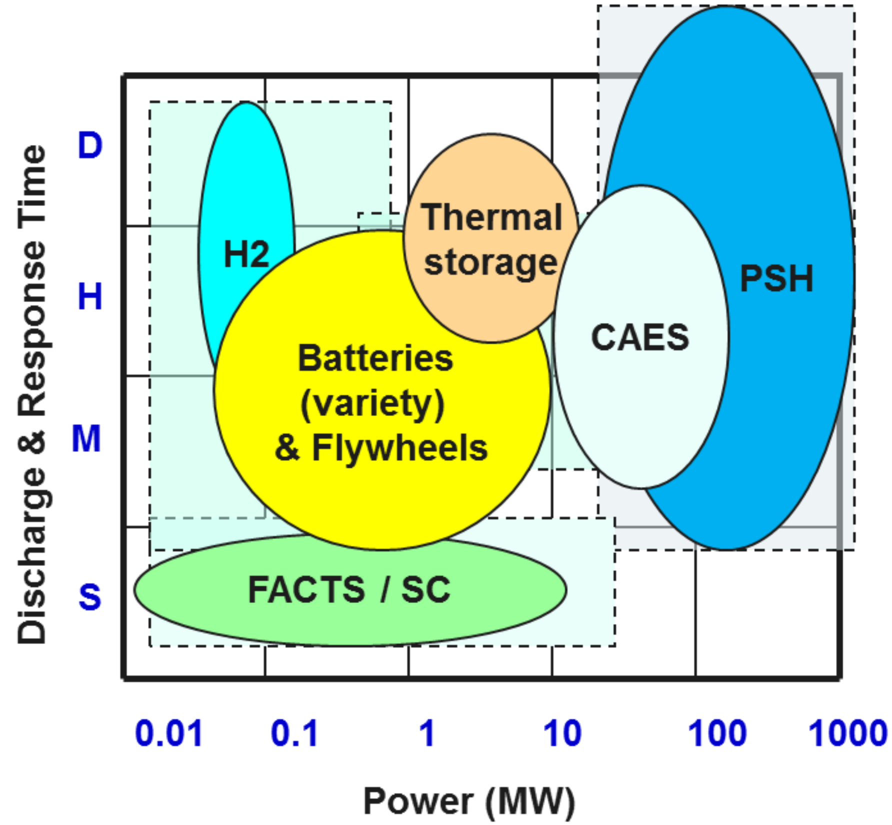
NaS Battery 2 MW

Flywheels 1 – 20 MW

Grid Applications: Energy Storage Portfolio



Service Requirements



Storage Technologies

Pumped Storage Hydro
Present Status

- **Grid-scale Bulk Storage**
  - Power: 50 - 500MW/unit
  - Storage: > 8 hours @ full load
  - Overall efficiency: up to 85%
- **Operational Flexibility**
  - Gen: 0% to 100% in ~ 2 min; .
  - Pump: 0% to 100% in ~ 5 min.
  - Reactive power capability (lead/lag VAr)
- **Competitive Cost**
  - $1500/kW ~ $2500/kW (power capacity)
  - $7 - $40/kWh (energy storage)
- **Technology Innovation: Variable Speed Machine**
  - Adjustable pumping (& generation)
  - Fast response: ~1 sec
  - Efficiency improvement
  - Projects in progress

With approximately **140GW** installed world-wide, **Pumped Hydro** (PH or PSH) accounts for over **99%** of the world's storage

Pumped Storage Hydro
Critical issues & Research needs

- Market modes at multiple time scales
- Environmental impacts
- Social acceptance
- Interconnections, grids, HVDC technology
- Benefits of large-scale use of storage hydro combined with large scale offshore and onshore wind and solar energy production in Europe
- Benefits of wind-hydro co-generation
- Design of reversible pump turbine plants
- System design to achieve dynamic flexibility
- Build a test facility

Compressed Air Energy Storage
Present Status

There are two large CAES plants in the world:

- **290MW** at Huntorf in Germany (1978)
- **110 MW** in McIntosh, Alabama, US (1991)

Both existing CAES plant use salt caverns where the salt is dissolved to store the compressed air (other geological structures may be suitable including abandoned mines, aquifers and depleted gas fields).

Over ground CAES requires a purposely built vessel.

Similar to PH, the CAES application is in energy arbitrage and ancillary services.

With approximately **400MW** installed world-wide, **compressed air energy storage (0.3%)** is the second largest electricity system connected storage capacity.

Compressed Air Energy Storage
Critical issues & Research needs

- System design
- Environmental impacts and safety
- Technical solutions for underground compressed air storage
- Development of turbines only running on compressed air
- Design and build a compressed air system in connection with a wind turbine

The ADELE research project in Germany – first turbine to be driven by compressed air only

Barriers to Energy Storage

The next largest electricity system connected storage technology is **NaS** batteries at **316 MW** (0.25%).

All other storage technologies combined account for just 85 MW or approximately 0.07% of the world's storage capacity (EPRI, 2010). These technologies include other **battery** technologies, **flywheels** and **supercapacitors**. These are generally employed in highly specialized applications such as ancillary services and power quality applications.

All storage technologies are characterized by relatively **high capital costs** compared to conventional generation technologies and combined with the **round trip energy loss**, this creates a **significant barrier** to their wide scale deployment.

Status of Storage Technologies
Electrochemical Storage

Electrochemical Storage Systems – Technical approaches

- Batteries
- Redox-flow batteries
- Fuel Cells, electrolysers and hydrogen storage
- (Supercapacitors)

Start-up phase

- Lithium Ion Batteries
- Lithium Sulfur Batteries
- Lithium Oxygen Batteries
- Supercapacitors

Active Materials to be investigated based on

- Intercalation mechanisms
- Conversion mechanisms

Electrochemical Storage
Critical issues & Research needs

- **Development of advanced battery materials and chemistries**
  - Electrochemical and thermodynamic-kinetic investigation of Li(Ni,Mn,Co)O2(NMC) cathode or other materials
  - Conversion-type cathode materials for lithium-ion batteries
  - Investigation of anode materials
  - Investigation of electrolytes
- Understanding battery performance: lifetime (including calendar life), cycle life, operation conditions, 2nd life of batteries (life cycle analysis)
- Investigation of novel battery concepts
- Supercapacitors (SC)
- Investigation of alternative electrochemical storage systems
- Safety, reliability, battery abuse, standards
- Application-oriented research
- Electrolysers – carrier storage – fuel cells

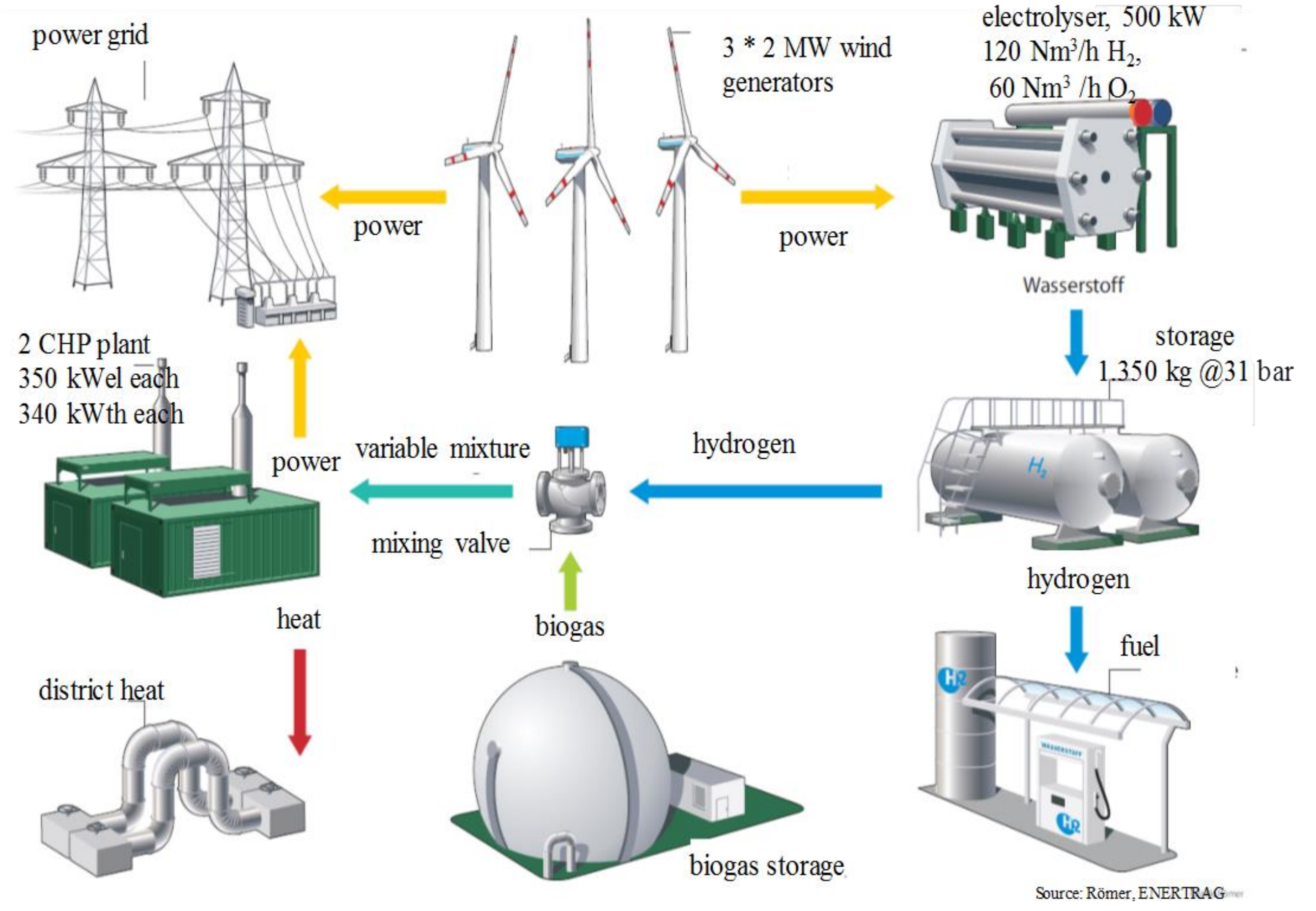
Qualitative Responses

Technology	Major Hurdles
CAES	Materials cost-effectiveness, eliminated fuels use, ubiquitous storage, geological risk, heat exchange of compressed air, compressor efficiency, heat recovery
Batteries	Energy density, controls for smart grid capability, manufacturability, electrode mechanical stability
Flywheels	Scalability of manufacturing
Electrochemical capacitors	Scalability of manufacturing. Control systems for capacitors
Flow batteries	Application control algorithms, low cost ZnBr

- Demonstration of long-term reliability and safety, lifetime, maintenance, operation, stability, reliability, cost reduction
- Grid modeling and simulation to show value
- Need for standards, guidelines

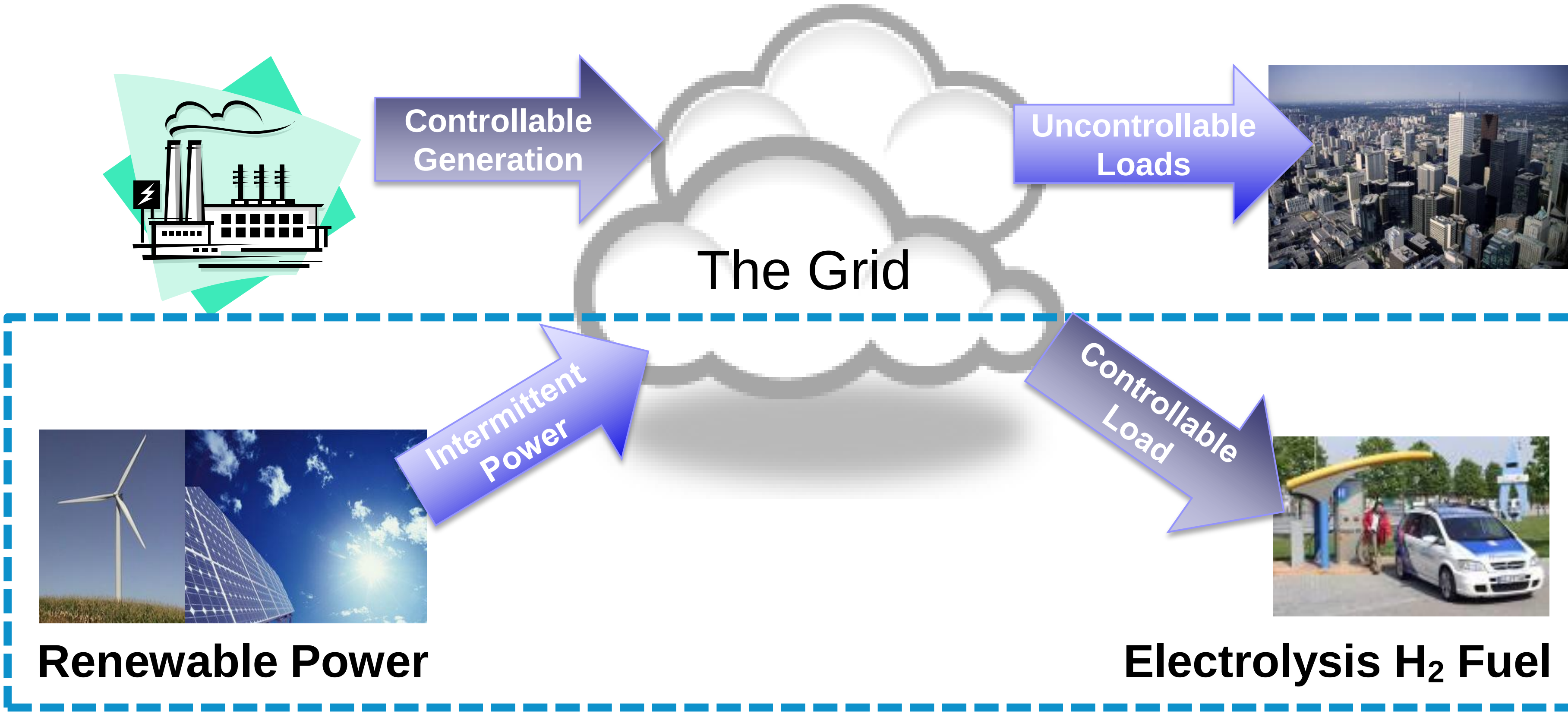
Storages for RES integration
Hydrogen (1/2)

Hybrid renewable power plant with storage (Germany 2011)



Storages for RES integration Hydrogen (2/2)

- Electrolysis hydrogen generation pathway to fueling
- Controllable load matches with intermittent renewable energy



Storage Technologies
Comparison (1/2)

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APPLICATION	Hydro	CAES	Na/S	Na/NiCl	Li-ion	Ni/Cd	Ni/MH	Lead/Acid	Redox	Flywheel	SC
Time shift	✓	✓	✓	✓	✓	(✓)	(✓)	✓	✓	✗	✗
Renewable integration	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	(✓)	✗
Network investment deferral	✓	(✓)	✓	✓	✓	(✓)	(✓)	(✓)	✓	✗	✗
Primary Regulation	✓	(✓)	✓	✓	✓	✓	✓	✓	✓	(✓)	✗
Secondary Regulation	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)	(✓)	✓	✗	✗
Tertiary Regulation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗
Power System Start-up	✓	✓	✓	✓	✓	✓	✓	✓	(✓)	✗	✗
Voltage support	✓	✗	✓	✓	✓	✓	✓	✓	(✓)	✓	✓
Power quality	✗	✗	(✓)	✗	(✓)	(✓)	✗	(✓)	(✓)	✓	✓

Storage Technologies
Comparison (1/2)

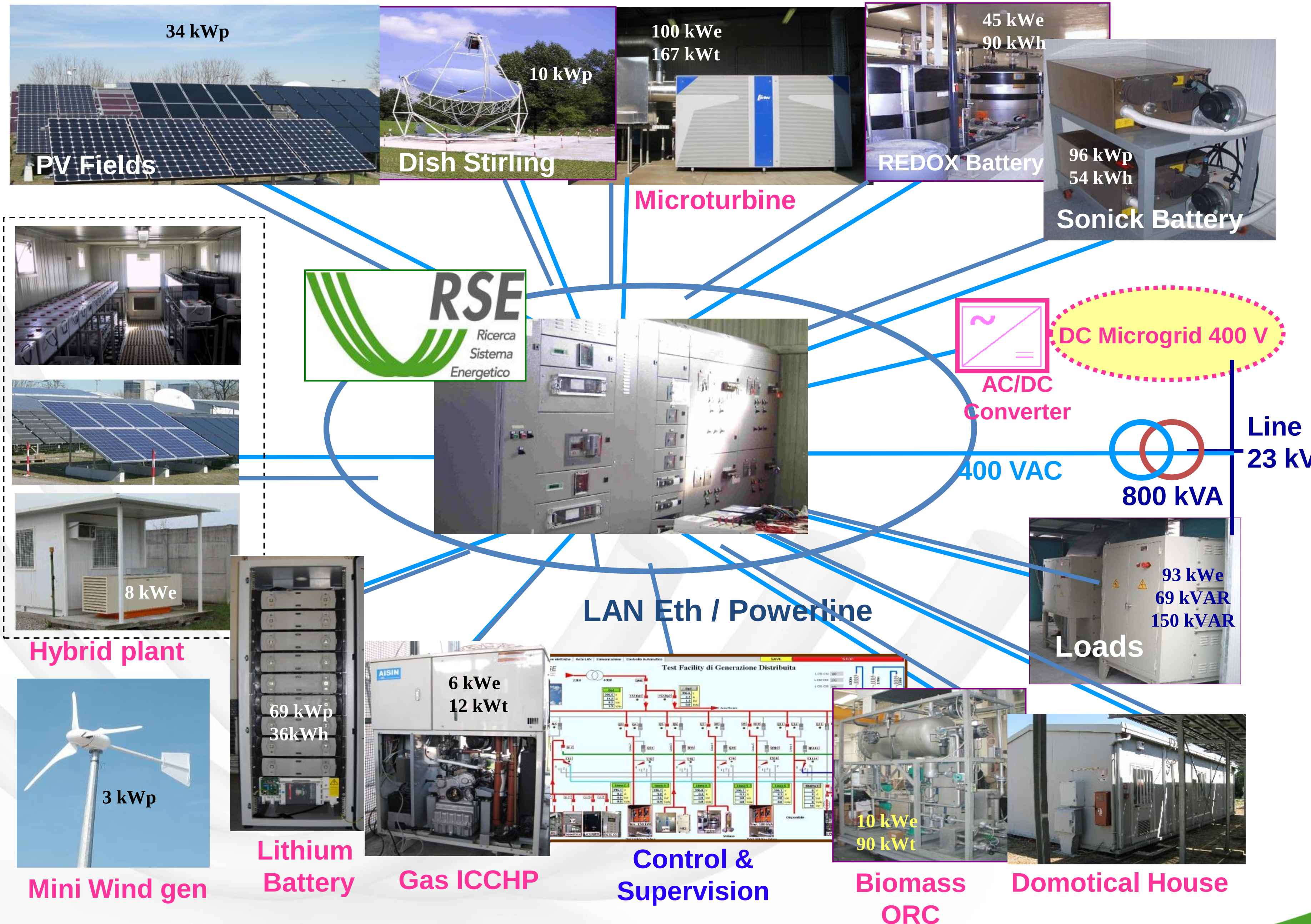
D4.1 “Electrical Energy Storage Technology Review” p. 103
https://sites.google.com/site/eerasmartgrids/documents-download

Technology		Power rating [kW]	Energy rating [kWh]	Investment costs C_E [€/kWh]	Investment costs C_P [€/kW]	Round trip efficiency [%]	Lifetime [cycles]
High-Power Storage	Supercap	$10^{-2} - 500$	$10^{-3} - 10$	10,000	300	90	1,000000
	SMES	$10 - 10^{4}$	$10^{-1} - 10^{2}$	8000	400	95	1,000000
	Flywheel	$100 - 2{\cdot}10^{4}$	$10 - 5{\cdot}10^{3}$	8,000	2,000	85	1,000000
Conventional batteries	Lead acid	$10 - 10^{4}$	$100 - 10^{5}$	200	400	80	300
	NiCd	$10^{-3} - 2.7{\cdot}10^{4}$	$10^{-2} - 1.5{\cdot}10^{4}$	700	600	65	1500
	NiMH	$10^{-3} - 200$	$10^{-2} - 500$	600	500	70	500
Advanced batteries	Lithium-ion	$10^{-3} - 2{\cdot}10^{4}$	$10^{-2} - 10^{5}$	1000	2000	90	4,000
	NaS	$10^{3} - 10^{5}$	$6\ 10^{3} - 6{\cdot}10^{5}$	400	3,000	80	4,500
	NaNiCl	$60 - 2{\cdot}10^{3}$	$120 - 5{\cdot}10^{3}$	650	1,500	80	2,500
Flow batteries	ZnBr	$5 - 10^{3}$	$50 - 4{\cdot}10^{3}$	500	1,500	75	3,000
	VRB	$5 - 2{\cdot}10^{3}$	$10 - 10^{4}$	500	2,500	75	10,000
Bulk storage	CAES	$10^{5} - 5{\cdot}10^{5}$	$2{\cdot}10^{5} - 10^{6}$	20	520	65	25,000
	Pumped hydro	$10^{5} - 10^{6}$	$2{\cdot}10^{5} - 5\ 10^{6}$	100	1,000 ÷ 5,000	70	25,000

Technical and economic comparison among different storage technologies

Summary

- **Portfolio of grid Energy Storage (ES) solutions in varying stages of readiness:**
  - **PSH** has top performance and competitive price for grid storage, serving 3 key areas of energy shifting, power balancing, and frequency regulation
  - Community ES technologies hold significant opportunities – coordinating across the fleet of resources is essential for successful deployment
- **Facilitating effective Energy Storage R&D**
  - Public policy: **coordinated strategy**, regulatory certainty, stream-lined process
  - Business environment: market-based valuation of revenue/cost with equitable treatment for all energy storage resources: capacity, energy, …
- **Leveraging global experiences & resources**
  - **International collaboration** and information sharing (as in the EERA JPs)
  - **Inter-disciplinary approach** for comprehensive coverage of critical areas: from individual devices to full system operation, from technical performance to business modelling, from Lab testing to large demo and then grid applications


34 kWp
PV Fields
10 kWp
Dish Stirling
100 kWe
167 kWt
Microturbine
45 kWe
90 kWh
REDOX Battery
96 kWp
54 kWh
Sonick Battery
RSE
Ricerca
Sistema
Energetico
DC Microgrid 400 V
AC/DC
Converter
Line
23 kV
400 VAC
800 kVA
8 kWe
Hybrid plant
93 kWe
69 kVAR
150 kVAR
Loads
LAN Eth / Powerline
3 kWp
Mini Wind gen
69 kWp
36kWh
Lithium
Battery
6 kWe
12 kWt
Gas ICCHP
Test Facility di Generazione Distribuita
Control &
Supervision
10 kWe
90 kWt
Biomass
ORC
Domotical House

CONCLUSIONS

Increased deployments of distributed generation (including high penetration of variable renewables, self generation and back-up power), storage technology and electric vehicles on the network of the future …

Will storage technologies, either large scale or distributed, decrease enough in price in order to be competitive and widely used?

The Goal is to make Energy Storage

widely spread and Ubiquitous

on the Electric Grid !!

Thank you for your attention

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EERA European Energy Research Alliance
Smart Grids Joint Programme

eerasg.eu

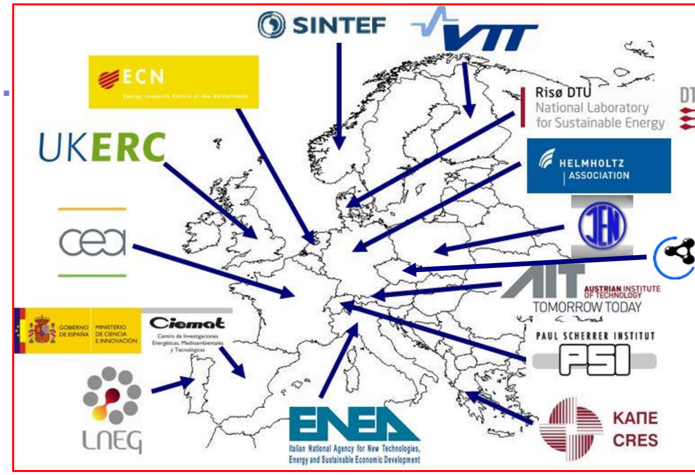
About EERA

- Alliance that aims to accelerate development of new energy technologies
  - Strengthen, expand and optimise research capabilities
  - Improve coordination and cooperation
  - Reduce fragmentation and duplication
  - Promote harmonisation of National and EC programmes
- Called for in the Strategic Energy Technology (SET) Plan
- Participation in EERA is in principle open to all research organisations
  - Not just a membership; need to bring in significant R&D capacity
- Based on own resources

EERA
European Energy Research Alliance

EERA Structure

Executive Committee
15 members, 3 observers



Secretariat
5 members

Joint Programme A | Joint Programme B | Joint Programme C | Joint Programme …

Joint Programme [coordinator]

Launched in June 2010:
- **Photovoltaics** [ECN]
- **Smart Grids** [RSE]
- **Wind** [DTU]
- **Geothermal** [CEGL]

Launched in November 2010:
- **Bioenergy** [VTT]
- **CCS** [IFP]
- **Materials for Nuclear** [KIT]

Launched in November 2011:
- **CSP** [CIEMAT]
- **Marine Energy** [UK ERC]
- **Fuel Cells** [ENEA]
- **AMPEA** [CEA]
- **Energy Storage** [KIT]
- **Smart Cities** [AIT]

SP4: Electrical Storage Technologies

Task 4.1: Electric Energy Storage technologies (VTT)

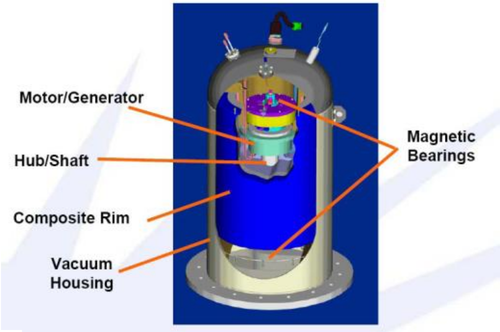
Task 4.2: Performance testing of storage technologies (Tubitak)

Task 4.3: Integration of storage resources to smart grids: Services (IWES)

Task 4.4: Control algorithms for storage applications in smart grids (AIT)

Task 4.5: Economic, technical and environmental benefits of incorporating an electrical storage system into the network (SINTEF)

	TASK	SUB-TASK	TASK Leader	AIT	ECN	ENEA	ERSE	LABEIN	LABORELEC	RISOE	IWES	JRC	SINTEF	TUBITAK	VITO	VTT
4.1	Electric Energy Storage (EES) Technologies	Two-way technologies: e.g., batteries, supercapacitors, flywheels, etc.	VTT													
		One-way technology: e.g., solar power, heat pumps, etc.														
4.2	Performance Testing of Storage Technologies	Performance test	TUBITAK													
		Test cycle issues														
		Standardization needs														
4.3	Integration of Storage Resources to Smart Grids: Possible Services	Concept for grid connection	IWES													
		Services for electricity market (for TSOs, DSOs, end-users, etc.)														
		Impact for long-term network development														
		Technical and economical issues for DER penetration														
4.4	Control Algorithms for Storage Applications in Smart Grids	Control strategy for multiple storage systems	AIT													
		New charging and de-charging algorithms														
		Control strategy offering of storage services to market														
4.5	Economic and Technical Benefits of Incorporating an ESS onto Network	Algorithm impacts on storage lifetime expectancy	SINTEF													
		Economic feasibility study of choosen concepts														
		Environmental influences														



First JP Deliverables

Deliverable D4.1

Smart Grids Joint Programme

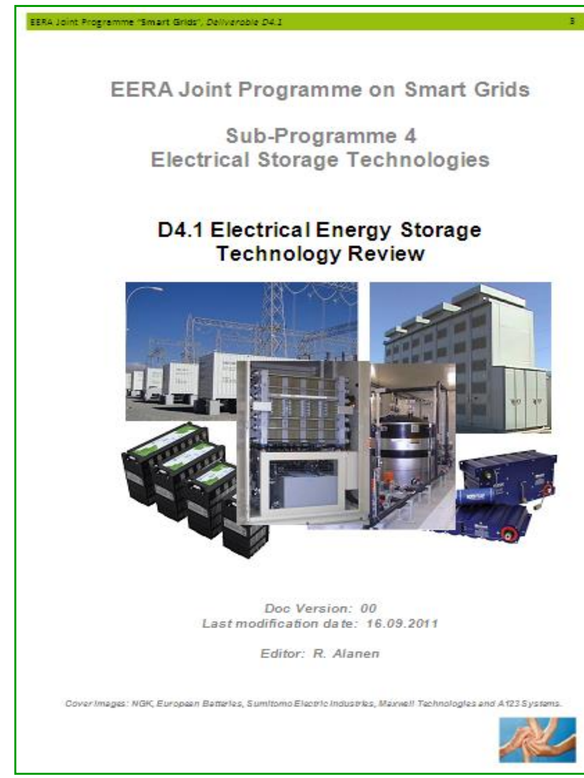
"Electrical Energy Storage Technology Review"

Report: 109 pages, 16 Authors (8 Partners)

http://sites.google.com/site/eerasmartgrids/documents-download

Content:

- No.12 technologies analyzed
- Technical Properties
- Economical Aspects
- Control system and Interface
- Life Cycle Aspects
- Manufacturers, Commercial Products and Solutions
- Development Trends and Future Expectations
- Potential **Application Areas in Smart Grids**



Deliverable D4.1:
Considered EES technologies

Chapt.

3 SUPERCAPACITORS (SC)

4 SUPERCONDUCTIVE MAGNETIC ENERGY STORAGE (SMES)

5 FLYWHEELS

6 CONVENTIONAL BATTERIES

7 ADVANCED & DEVELOPING BATTERIES

- 7.1 LITHIUM ION BATTERIES
- 7.2 NaS BATTERIES
- 7.3 NaNiCl (ZEBRA) BATTERIES

8 FLOW BATTERIES

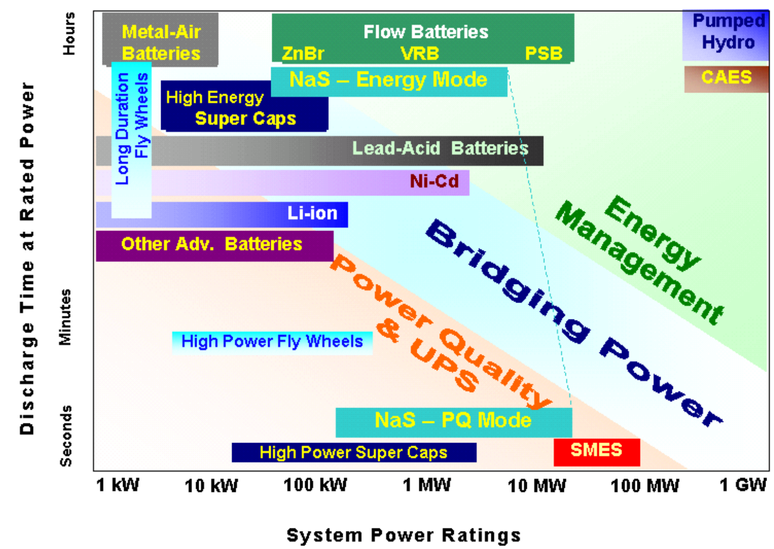
- 8.1 ZnBr BATTERIES
- 8.2 VANADIUM REDOX BATTERIES

9 COMPRESSED AIR ENERGY STORAGE SYSTEMS (CAES)

10 PUMPED HYDROELECTRIC STORAGE SYSTEMS (PSH)

11 OTHER STORAGE SYSTEMS

- 11.1 THERMAL ENERGY STORAGE (TES)



Hybrid and Electric Vehicles
Applications and needs

Several application areas within electric vehicles

- **Person cars** (EV, PHEV, EREV, HEV), **commercial vehicles** (trucks, buses, forklifts, mining, forestry), **Rail traffic** (trains, trams, trolleys), **recreation** (boats, scooters)
- Battery design and materials optimised according to user profile (e.g. fast or slow charging, power or energy optimised battery concept, end-user analysis)

Electric commercial vehicles can bridge the gap from battery materials to grid-connected storage

- **Advanced Li-ion batteries** in commercial battery packs of up to about 150 kWh/300 kW
- **Interaction with the grid (V2G)** depends on the usage pattern and the ownership of the Energy Storage System (ESS)