ENERGY STORAGE
INTER-PLATFORM GROUP

STATE OF THE ART OF ENERGY STORAGE REGULATIONS AND TECHNOLOGY

GIA
Energy storage
inter-platform group

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I. INTRODUCTION

Energy storage is rising to become a key factor in today's society, particularly with regard to intelligent electric grids, which are faced with the challenge of catering for new social demands. This issue was already raised in the FutuRed Vision 2030 document.

The European Commission has acknowledged the upcoming relevance of storage in its Horizon 2020 research and development programme, and is planning to invest significant efforts towards developing storage technology in the field of smart grids. The 2007 SET Plan already foresaw the need to make progress in terms of storage profitability, and considered it a challenge to be solved by the EU in the decade of 2007 to 2017. Subsequently, in 2011, the European Energy Research Alliance launched a Joint Energy Storage Programme to back the development of projects in this field.

In spite of this, Spain does not house any initiatives that include all of the key players on the energy storage scene and, as the sector gains ground, it has become necessary to coordinate the work of the various institutions involved in it, though without creating yet another platform.

It was in this scenario that the Storage Inter-Platform Group was born, known as GIA for its Spanish initials. The GIA is comprised of a number of institutions that are linked to energy storage one way or another. This includes public and private bodies that are engaged in business and/or research. This way, it looks out for the interests of all of the sectors involved.

The purpose of this document is to sum up the main conclusions drawn from the work carried out by the Storage Inter-Platform Group, which is broken down into 7 sub-groups according to the various objectives pursued:

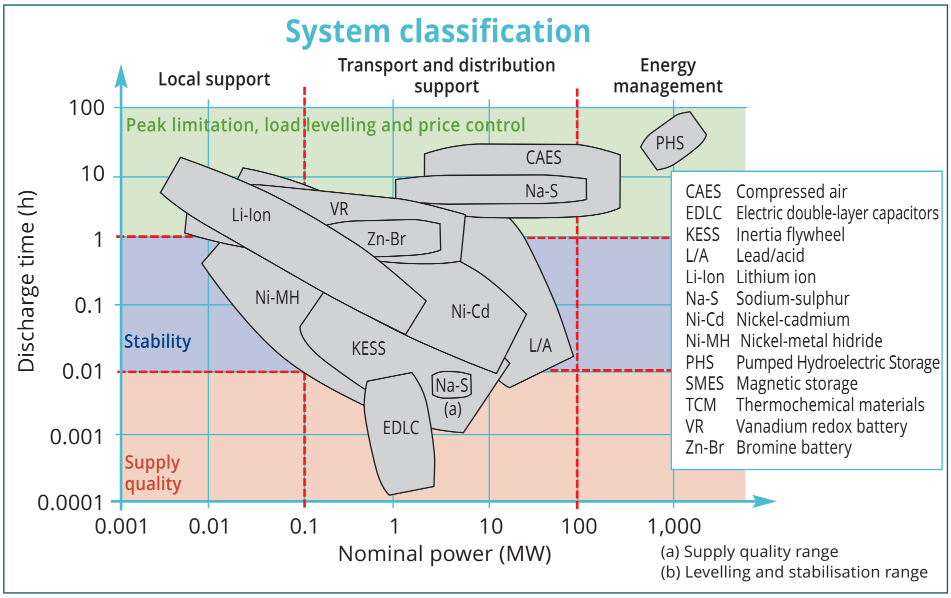
- **Regulation Sub-Group:** This group takes care of the regulatory aspects concerning energy storage in Spain, Europe and the whole world.
- **Grid Integration and Applications Sub-Group:** This department looks into the factors involved in integrating storage in the grid.
- **Existing Technology Sub-Groups:** These groups have been studying the different types of existing technology from a critical standpoint, defining their operational costs and the main challenges they face in order to become competitive technological options in the future. These groups are:
  - Electrochemical Storage
  - Chemical Storage
  - Thermal Storage
  - Mechanical Storage
  - Magnetical Storage

This document will provide a brief description of the main conclusions reached in each chapter.

II. POWER-ENERGY CHART

Generally speaking, the power-energy chart is a reasonably accurate compilation of the data available, which are shown in Figure 1. Nevertheless, changes may be suggested for certain types of technology in order to update the discharge times and nominal power values.

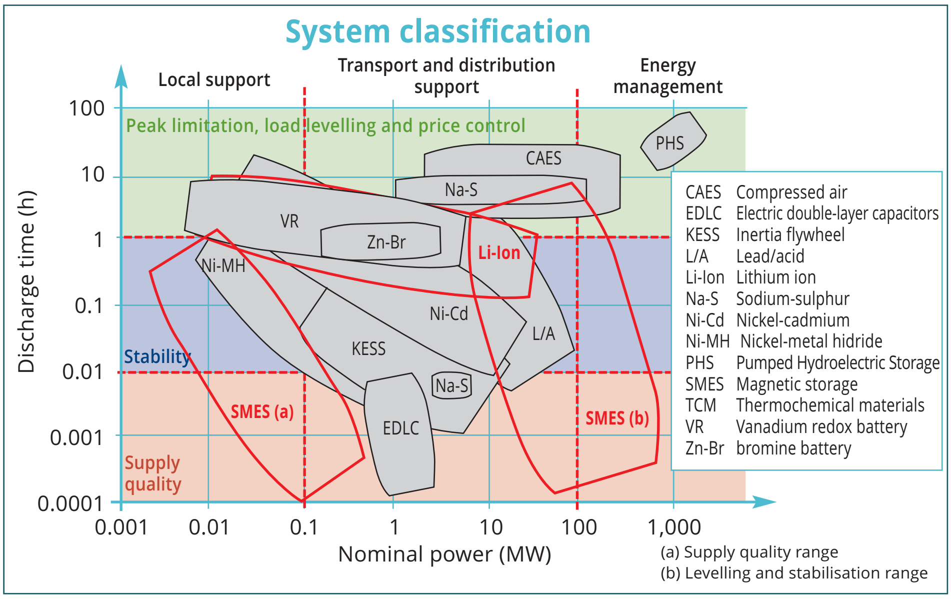
Figure 1. Cost of investment per conventional unit of power and energy



Source: Produced by the GIA based on data by the Electricity Storage Association. www.electricitystorage.org.

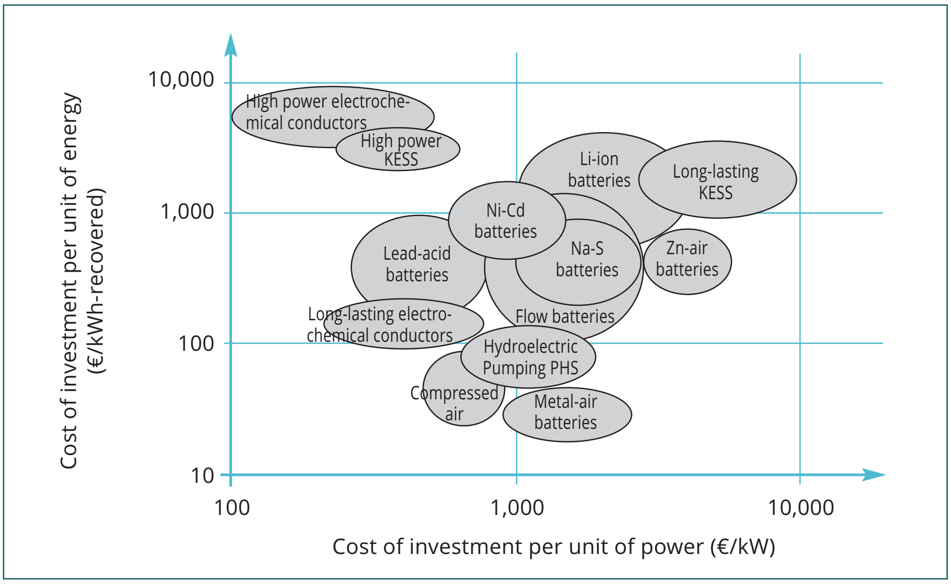
It must be borne in mind that these data are not precise; they are merely for guideline purposes and depend largely on the technology used and on the setup. From our point of view, the chart shown in Figure 2 is a closer to current reality.

Figure 2. Proposed cost of investment per unit of power and energy according to the Storage Inter-Platform Group's conclusions



Source: Produced by the GIA based on data gathered during its work

III. STORAGE TECHNOLOGY COSTS CHART

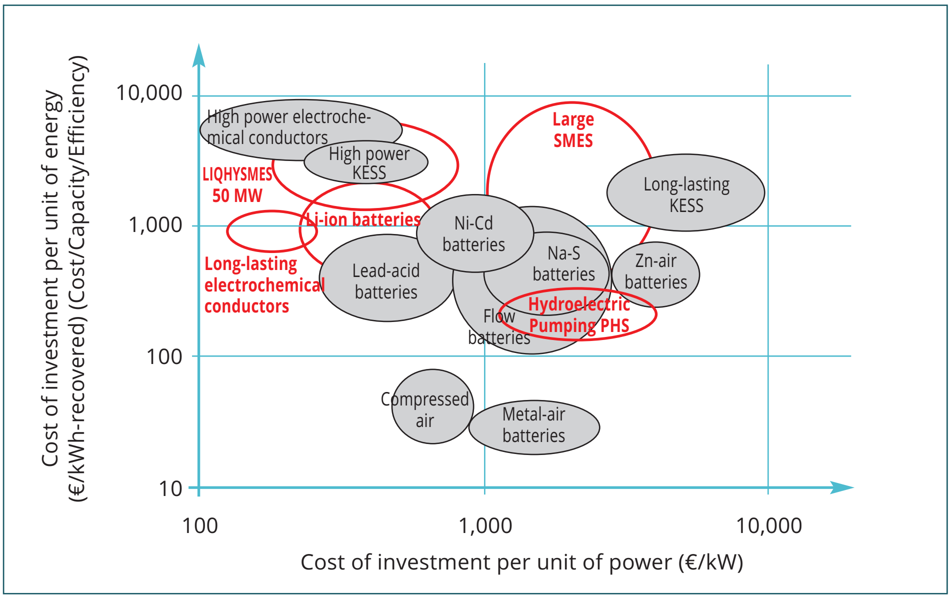


Source: Produced by the GIA based on data by the Electricity Storage Association. www.electricitystorage.org.

As part of the GIA's work, the cost charts relating to the various types of storage technology were also reviewed.

Although the costs of such types of technology tend to match other costs that are already known and are reflected in other documents, such as Figure 3.

Figure 3. Cost of investment per conventional unit of power and energy.



Source: Produced by the GIA based on data gathered during its work.

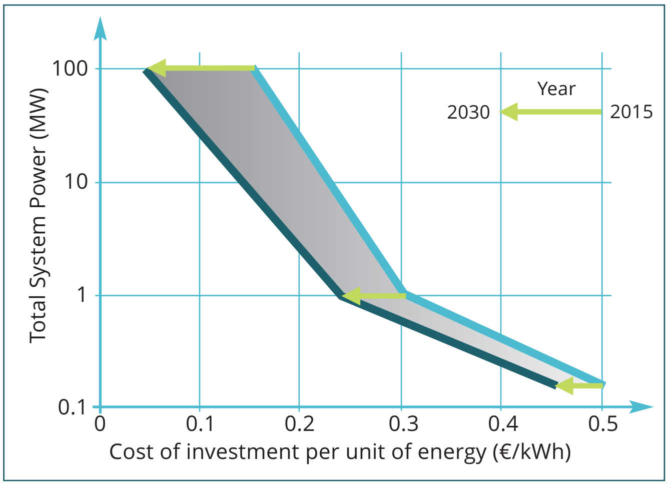
our study has shown that some types of technology should be moved within the chart, which would give rise to Figure 4.

Figure 4. Proposed cost of investment per unit of power and energy according to the Storage Inter-Platform Group's conclusions

There are two special types that can not be included in the charts shown in figures 3 and 4: chemical storage and thermal storage.

With regard to chemical storage, much of its technology is currently below TRL level 8, making it difficult to define its cost of investment. The data available are far from representative, even for the purpose of making an estimate. Therefore, Figure 5 shows the expected evolution in the cost of stored energy (KWh) according to the overall estimated power for different chemical storage systems.

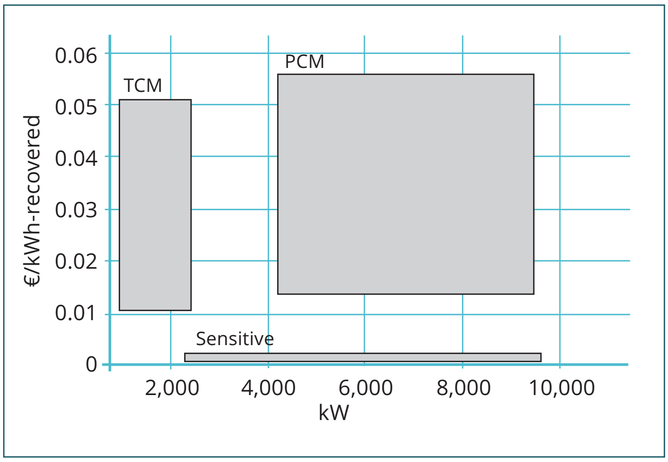
Figure 5. Foreseeable evolution of the cost of stored energy based on total power



Source: Produced by the GIA based on data gathered during its work.

Figure 6 refers to thermal storage, where the end product is not electricity and only thermal energy demands can be supplied. Its integration is particularly favourable in fluctuating sources of thermal energy that are unable to meet their thermal energy demands. In thermal storage, charge/discharge times and thermal power are not dependent on the type of system used, but on the setup of the specific equipment, which is made to transfer heat quickly or slowly depending on demand.

Figure 6. Cost of investment per unit of recovered power and energy



Source: Produced by the GIA based on *Energy Storage Technologies – Characteristics, Comparison, and Synergies, in Transition to Renewable Energy Systems.*

For thermochemical systems, where mass transfer also comes into play and operating conditions and charge/discharge times may vary significantly, most pilot systems show lower power levels and longer charge/discharge times than those seen in latent heat storage.

1. REGULATION GROUP CONCLUSIONS

1.1. Introduction

In the current state of affairs, regulatory developments in electrical storage systems are still at an early stage and few countries have taken any action in the matter. This leaves energy storage without the structure of a framework to encourage its development and deployment. Much of the progress made in the matter has arisen from grid implementation plans, with the example of California's plan proving particularly ambitious, or from funding allocated to develop this type of systems, either coupled with a different type of technology or alone. Examples of the latter are seen in Germany and Japan.

The USA is the country with the most advanced regulations, and certain Asian countries are also taking significant steps forward in this regard, be it in response to their electric systems' limitations or to their ambitious goals for the electrical storage market of the future. Closer to home, Germany stands out over all European countries in terms of regulatory developments owing largely to the high levels of renewable energy it needs to include in the system.

1.2. Regulatory situation in Spain

Spain's regulatory framework says nothing in relation to energy storage systems, with the exception of hydraulic pumping, which is considered a conventional generation system, and thermal storage associated with thermal solar power plants. Nevertheless, all energy production and consumption plants must be registered with a code in order to operate. The Canary Islands boast a stronger storage initiative backed by Act 17/2013, whereby system operators will be the owners of the new pumping facilities when their aim is to secure the supply of energy, to ensure the system's safety or to integrate non-manageable renewable energy sources.

In 2010 (by virtue of Decree-Act 6/2010) a new figure emerged: "System load managers as providers of charging services", thus giving rise to a new agent who, as a consumer, is empowered to re-sell electrical energy for electric vehicle charging. Although Royal Decree 647/2011 conceives that load managers might encourage the integration of production under a special regulatory system, Royal Decree 1699/2011 established that no accumulation elements can be placed between the system owner's generation circuit and the measurement device, though such elements may be authorised by Spain's regional authorities provided they do not enter the grid according to the REBT (Low Voltage Electrotechnical Regulations), guide ITC BT 40.The modification of the Royal Decree excludes from the ban of placing consumption elements between the generation facilities and their measurement equipment, to the auxiliare generation services and to the accumulation facilities.

This amendment was a result of the recently approved RD 900/2015, by which self-consumption is regulated. This Royal Decree enables the installation of storing elements in the self-consumption facilities, as long as they include the protections established in the industrial safety and quality standards, and are installed so as to share measurement equipment to record net generation, or measurement equipment to record energy consumed per hour. It is important to underline that until the mentioned standard on industrial safety and quality has not been approved, the storing elements will be installed in a way that measurement equipment and protections are shared with the generation facility.

Currently, there are mainly two modes of self-consumption. On the one hand, the mode of energy supply with self-consumption, which maximum contracted power will be 100kW. Under this mode, selling surpluses of electricity to the grid is not allowed, thus the storing system could be used exclusively to regulate the energy generated and/or demanded to the grid, in order to minimize the cost of electricity. On the other hand, the mode of production with self-consumption (applicable in electricity production facilities registered in the administrative record), in case it is regulated under specific retribution, could receive the respective economic compensation for supplying electricity to the grid, allowing the establishment of business models for storage, taking into consideration the sale of energy. However the specific compensation is established to compensate both the investment on the renewable generation facility and its operation, but does not include the investment and operation in storage.

Being storage associated to self-consumption, owners should confront a transitory charge for the self-consumed energy (until the specific charges are approved). Only the consumers benefiting from the mode of supply with self-consumption, connected in low voltage and with contracted power equal or lower to 10 kW shall be exempt from that payment (in addition to the electric systems of the Canary Islands, the cities of Melilla and Ceuta, and cogeneration facilities producers of electricity). Finally, this Royal Decree prevents self-consumption shared among several users. Therefore the electricity storing elements will have to be used by a single final consumer.

1.3. Regulatory situation in Europe

There is currently no common regulatory framework on storage, though there are a series of established technical priorities for its short- and long-term development. Current standards apply to the battery tests conducted to develop electric vehicles. Some Member States have, however, made progress in regulatory terms, the most significant being:

United Kingdom

Transitional arrangements have enabled storage to enter the capacity market.

Germany

Storage is exempt from electrical consumption fees and grid connection fees, and can benefit from subsidies (for residential users) and favourable rates for renewable energy. It can only operate in the adjustment market.

Sweden

Aside from some uncertainties and restrictions, participants in the electrical market are allowed to operate storage systems in order to offset loss, prevent overloads, sell energy and so on.

Italy

DSOs and TSOs can build and operate batteries provided they are the most efficient solution to a given problem.

1.4. Regulatory situation in the rest of the world

Here is a summary of the main regulatory aspects in the countries that contribute most towards storage development. However, there are other countries that have also taken steps in this direction to a lesser degree in the form of subsidies, incentives or specific regulations for certain devices.

USA

Market rules and rates have been altered enabling a more competitive storage scenario. Plus, some states have adopted laws to encourage its development.

Puerto Rico

It is obligatory to include storage in new renewable energy projects.

China

Technical guidelines were issued for connecting these systems, as a complement to the funding offered for storage technology.

Japan

Storage is promoted largely by means of incentives and a series of technical requirements have been laid down as a prerequisite for approval.

South Korea

An ambitious storage plan has been launched, including aid, incentives, system certification, price system reviews, etc.

1.5. Regulatory aspects of undeveloped technology

We are lacking a specific regulatory framework for undeveloped technology, which is why pilot facilities are governed by general rules and standards. The most important points for storage are:

- Lack of regulations for operating certain types of accumulation technology.
- Difficulties/constraints for obtaining permits, licences and authorisations.
- Obstacles hampering the use of distribution and transmission grids.
- Lack of policies and rules imposing uniform standards to avoid extra costs for inter-connection with distribution grids.

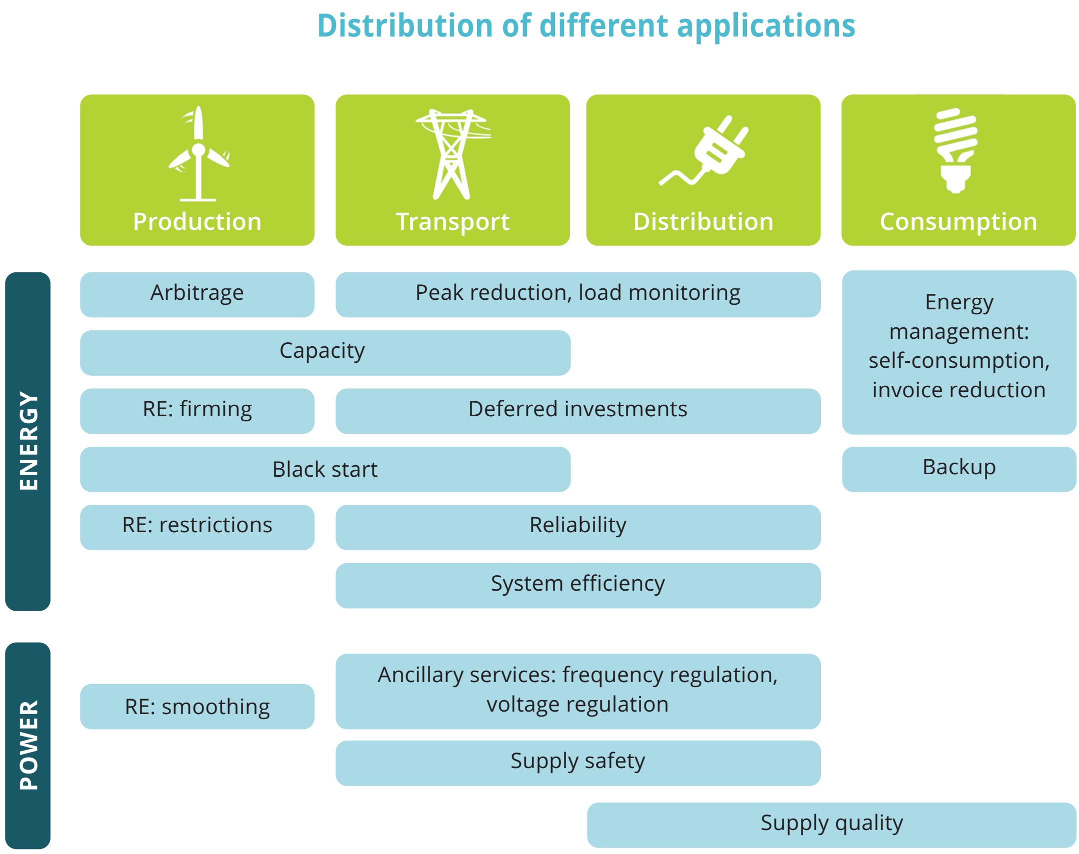
2. GRID INTEGRATION AND APPLICATIONS GROUP CONCLUSIONS

Connecting unpredictable renewable energy sources to electric grids has increased the level of stress they have to bear. Intermittent renewable energy production comes in addition to an already volatile consumption, making its management and operation even more difficult. Therefore, as the degree of integration of renewable sources rises, so too will the need for new systems that are capable of ensuring the grid's stability. Faced with this challenge, storage rises as a powerful tool for operating the system, and not only while integrating renewables. Intermittent production entails the need to keep back-up power which often lacks the speedy response that storage would be able to provide.

2.1. Applications of energy storage

Figure 7 shows how the different applications of energy storage are distributed according to the end user and capacity (Energy and Power).

This visual layout gives us an idea of the most suitable types of technology for each situation. It can also be used to analyse the possibility of combining several services in a single storage device.



NB: Applications relating to renewable energy feature the initials "RE". For instance, RE firming refers to obtaining a constant power output by providing energy when production drops below a certain level.

Figure 7. Visual distribution of different applications.

2.2. Operational strategies and power electronics

Operational strategies and power electronics both influence storage integration and use. Nevertheless, there are other complementary aspects to be taken into consideration in our analyses:

POWER HARDWARE

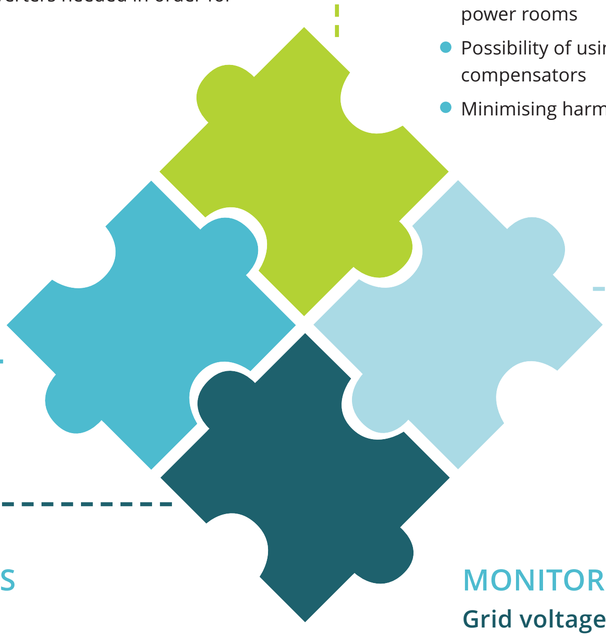
Types of power electronics systems

- Performance, cost, maintenance and availability of power electronics systems
- New develppments and types of converters needed in order for storage to progress

EFFECT ON GRID QUALITY

The effect of electronics on the grid

- Systems for synchronisation with the grid so that deviations do not affect the grid's reference signal
- Possibility of controlling storage equipment remotely using power rooms
- Possibility of using power converters as reactive energy compensators
- Minimising harmonics



SYSTEM FUNCTIONALITIES

Storage system versatility

- A monitoring strategy can be followed to integrate storage in the energy market while at the same time using it to support the grid
- Storing systems can fulfil different energy functions

MONITORING SOFTWARE

Grid voltage and frequency

- Using storage systems with power electronics to monitor the grid's voltage and frequency stability, especially in distribution grids and micro-grids
- On/off grid operation

Figure 8. Main specific problems of integrating storage systems in the grid.

2.3. Impact of energy storage systems on the grid

The presence of a storage system in the grid may at times pose a challenge for integration. Sometimes, however, it can pose significant advantages. Below, its impact is broken down into four groups:

Behaviour in the event of a short-circuit

Different operation protocol depending on the location of the shortage (internal, in the storage system; or external, in the grid).

Improvements in insular or weak grids

The presence of a storage system entails the following advantages:

- Less fluctuations in grid frequency
- Reduced load shedding and consumption peaks
- Support in the event of voltage gaps

Wave quality

Power electronics associated with a storage system can lead to an increase in grid harmonics.

The presence of a storage system could help prevent flickering, given that this is a low voltage phenomenon.

Grid short-circuit power

- Lower grid short-circuit power levels
- Minimised requirements for installed equipment

A reduction in short-circuit power levels would make the grid weaker and more sensitive to disturbances.

Figure 9. Impact of storage systems on the grid.

2.4. Challenges for grid integration

The main challenges that need to be overcome in order to integrate storage technology in the grid are:

1. Financial and regulatory factors.

2. They must be seen as a combined solution (complemented by other solutions such as flexible production) so as to guarantee the system's flexibility.

3. Storage systems show greater interoperability as regards the grid thanks to their two-way operation, making for huge potential to stabilise the grid, but also making it more complex. This calls for new energy management strategies that will depend on the type of storage technology selected and on installed capacity.

4. It is important to know a series of critical parameters before installing these systems in the grid, such as maximum power, footprint (weight and size), safety systems, etc.

3. ELECTROCHEMICAL STORAGE GROUP CONCLUSIONS

All types of electrochemical energy storage technology share certain characteristics, such as high efficiency and significant self-discharge, compared with other technologies such as hydraulic or chemical. This makes them extremely useful in short-term storage systems that require frequent charging and discharging. Additionally, their cost is more dependent on capacity than on power, as they are more strongly limited by the amount of energy they store than by the speed at which they provide it. This category includes the following types of technology: lead batteries, nickel batteries, high or low temperature sodium batteries, lithium-ion batteries, lithium-sulphur batteries, metal-air batteries, flow batteries and electrochemical capacitors.

(*) http://www.navigantresearch.com/newsroom/energy-capacity-of-advanced-batteries-for-utility-scale-energy-storage-applications-will-grow-71-percent-per-year-through-2023.

3.1. Technology Readiness Level (TRL)

Not all of these types of technology have reached the same readiness level, known as TRL. Some, such as lead batteries, are well-developed commercial technologies, while others, such as sodium-ion batteries, are still in the lab. Table 1 shows the TRL expected for each type of technology.

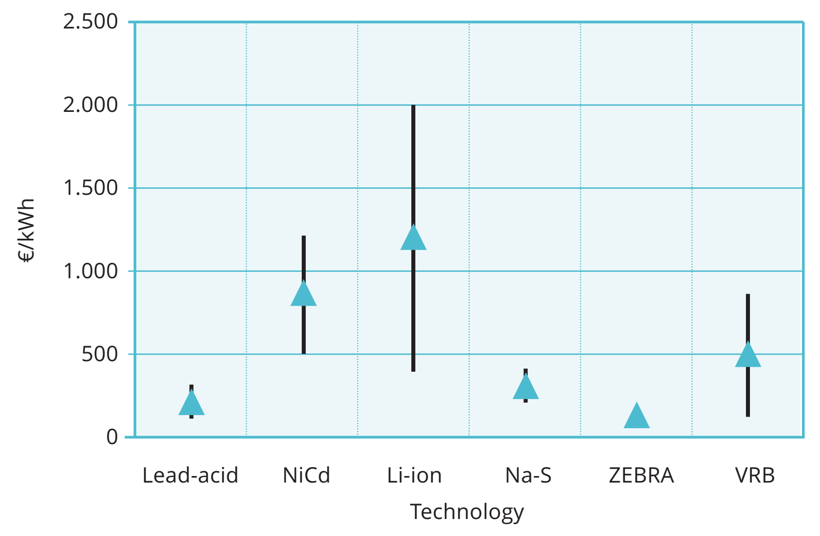
Table 1. Electrochemical storage technology readiness level.

Technology	Current situation	TRL
Lead batteries	Mature commercial technology	9
Nickel batteries	Mature commercial technology	9
Sodium batteries	NaS – Large-scale demonstration ZEBRA – Small-scale demonstration Na-ion - Lab	8 6 - 7 2 - 3
Lithium-ion batteries	Used in portable electronics – Commercial technology Large-scale use – Demonstration Advanced materials – Lab and small prototypes	9 7 - 8 2 - 3
Lithium-sulphur batteries	Demonstration	5 - 6
Metal-air batteries	Li-air rechargeable and Al-air rechargeable – Lab Zn-air rechargeable – Prototype	2 - 3 4 - 5
Flow batteries	Vanadium – Demonstration Zn-Br – Demonstration Other	7 5 - 6 3 - 4
Electrochemical capacitors	EDLC – Early commercial technology Hybrids – Prototype	8 - 9 4 – 5
Top patent registering country	Japan, with leading companies in almost every type (Table 15)	

3.2. Cost of the different types of electrochemical storage technology

According to K. Bradbury,[1] Figure 10 shows the cost of the main types of electrochemical storage technology that have reached a sufficient TRL to be assessed. The types of technology shown include ZEBRA batteries (sodium nickel chloride) and VRB (vanadium redox batteries).

Figure 10.
Operational costs by type of technology.



3.3. Challenges for developing this technology

The roadmap developed by the EASE and the EERA[2] includes the technological challenges and objectives of batteries and supercapacitors. A summary of those challenges and objectives is shown in Table 2. Although Na-S batteries are not included in the table, their main technological challenge would be lowering operating temperatures.

Table 2. Challenges for electrochemical storage technology.

Technology	Current situation	2020-2030 objectives	2050 objectives
Li-ion (energy)	Max. (Co based) 241 kWh/kg - 535 Wh/L; 500 cycles Safe (LFP based) 130 Wh/kg - 300 Wh/L 500 cycles; –20 +60 °C 500-1000 €/kWh; €0.25/kWh/cycle	180-350 Wh/kg; 350-800 Wh/L Safe; >10,000 cycles –20 +70 °C €200/kWh; €0.10/kWh/cycle	>350 Wh/kg >800 Wh/L; Safe >10,000 cycles –20 +70 °C <€200/kWh
Li-ion (power)	50-90 Wh/kg; 105-190 Wh/L 3 kW/kg; 10,000 cycles –10 +60 °C; >€1000/kWh	80-95 Wh/kg; 170-200 Wh/L >5kW/kg; Safe >15 years; –20 +70 °C; €20/kW	>100 Wh/kg; 220 Wh/L 10 kW/kg; Safe; >15 years; –20 +70 °C; <€20/kW
Redox flow batteries	(Vanadium) 10-20Wh/kg - 15-20Wh/L 10-20 years; >10,000 cycles +10 +40 °C (Zn-Br) 50-60 Wh/kg; >2000 cycles Service cost €0.10€/kWh €400/kWh; €600/kW	VBr 2nd generation 20-40 Wh/kg >100 °C Temp. range Service cost €0.07/kWh €120/kWh; €300/kW	Service cost €0.03/kWh €70/kWh €200/kWh
Metal-air systems	700 Wh/kg (Polyplus) Poor life cycle	>500 Wh/kg 3000 cycles; €300-500/kWh	500-1000 Wh/kg; 10,000 cycles; €100/kWh
Na-ion		40% expected decrease in battery cost	
Li-S	350 Wh/kg – 35 Wh/L (Sion Power) 4-6%/ monthly self-discharge 60-100 cycles; –40 +25 °C	500 Wh/kg 3000 cycles <€350/kWh	600 Wh/kg 10,000 cycles €200/kWh

3.4. Environmental impact

The main environmental effects are listed in Table 3.

Table 3. Main environmental impact of electrochemical storage technology

Type	Source of environmental risk
Lead batteries	Lead toxicity, but high recycling rate (>90%)
Nickel batteries	Cadmium toxicity, but high recycling rate
Sodium batteries	Insignificant. High temperatures in some cases
Lithium-ion batteries	Violent Li reactions. Low recycling rate (40%)
Flow batteries	Corrosive liquids flowing outside the battery
Metal-air batteries	Presence of highly reactive metals: Li, Na...
Electrochemical capacitors	Acetonitrile toxicity as a solvent

3.5. Hybridisation with other technology

Opportunities for hybridisation could be geared towards using one device for supplying power demands and another for energy demands, simultaneously combining slow and quick response systems. Such possibilities are summed up in Table 4.

Table 4. Possibilities for hybridisation with other technology.

Technology geared preferentially towards energy storage	High-power technology, rapid response and a high number of cycles
Sodium-sulphur batteries	Electrochemical capacitors
Flow batteries	High-power lithium-ion batteries (for example, titanite anode and spinel cathode)
High energy density lithium-ion batteries	Inertia flywheel
Lithium-sulphur batteries	Advanced lead-carbon batteries

4. CHEMICAL STORAGE GROUP CONCLUSIONS

Energy, in its many forms, can be transformed and stored as chemical energy by means of processes that produce chemical molecules which store the energy they receive in their chemical bonds. One of the main advantages of this type of energy is that it is easily transported by transporting the molecules that contain it, in addition to the fact that its energy density – gravimetric or volumetric – can be very high, standing at roughly 10,000 Wh/kg in petrol, which is well above the energy density of other energy storage systems. These chemical compounds open up a world of options for recovering the energy stored inside them. One is to transform them back into electrical energy. Another would be to turn them into thermal energy.

The most commonly used compounds are hydrogen (H_2) and methane (CH_4), with carbon dioxide (CO_2) and water (H_2O) also playing a part in the reactions that take place.

4.1. Technology Readiness Level (TRL)

Among the various types of chemical storage some are significantly developed, such as alkaline electrolysers, while others are at an earlier stage, such as artificial photosynthesis systems. There are also different degreesof development within each type of technology. Table 5 shows the readiness levels of the main technological options.

Table 5. Chemical storage technology readiness levels.

Chemical storage technology	Current situation	TRL
Alkaline electrolysers	Mature commercial technology	9
PEM electrolysers	Demonstration	7-9
SOEC electrolysers	Prototype – Small-scale demonstration	4-7
Co-electrolysers	Prototype – Small-scale demonstration	4-7
Synthetic methane methanation	Prototype – Large-scale demonstration	4-8
Biomethane	Prototype – Large-scale demonstration	4-8
Artificial photosynthesis PEC (photoelectric catalyst systems) for H_2	Prototype – Small-scale demonstration	4-6
Artificial photosynthesis PEC (photoelectric catalyst systems) for solar fuels. Solar refinery	Prototype-Small-scale demonstration	4-6
Artificial photosynthesis Solar thermal systems for solar fuels	Lab – Small-scale demonstration	3-6
Power to Liquid	Prototype – Small-scale demonstration	4-6
Power to Gas	Demonstration	6-8
Top patent registering country	Japan with 14 patents, closely followed by France with 13 (Table 16)	

4.2. Cost of the different types of chemical storage technology

Table 6 shows the cost of each type of technology per Kg of H_2 and per m^3 of CH_4 produced.

Table 6. Current and estimated costs of chemical storage technology.

Technology	Price €/ kWh H_2 (2015)	Price €/kWh CH_4 (2015)	Price €/ kWh H_2 (2030)	Price €/ kWh CH_4 (2030)
Alkaline electrolysers	9-12		<0.8	
PEM electrolysers	10-13		<0.9	
SOEC electrolysers	11-15		<0.9	
Co-electrolysers	n.a.			<15
Synthetic methane methanation		25-32		<15
Biomethane		25-32		<15
Artificial photosynthesis: PEC (photoelectric catalyst systems) for H2	12-18		<0.8	
Artificial photosynthesis: PEC (photoelectric catalyst systems) for solar fuels. Solar refinery	n.a.			<2.2 (MeOH)
Artificial photosynthesis: Artificial solar thermal systems for solar fuels	n.a.			<3.4(MeOH)
Power to Gas		35-45		<0.22
Power to Liquid	n.a.			<2.2 (MeOH)

4.3. Challenges for technological development

The major challenge for this type of technology lies in increasing the average life span of the equipment involved. Other challenges are summed up in Table 7.

Table 7. Challenges for chemical storage technology.

Technology	CHALLENGES		
Alkaline electrolysers	Increasing efficiency by 70%	Increasing average life span by >15 years	Reducing maintenance costs
PEM electrolysers	Increasing efficiency by 70%	Increasing average life span by >15 years	Reducing maintenance costs
SOEC electrolysers	Efficiency >85%	Increasing average life span	
Co-electrolysers	CO/H_2 control		
Synthetic methane methanation	Increasing average catalyst life span	Increasing resistance to CO_2 purity	
Biomethane	Increasing average catalyst life span		
Artificial photosynthesis: PEC (photoelectric catalyst systems) for H_2	Rising to industrial scale production systems	Increasing average life span	
Artificial photosynthesis: PEC (photoelectric catalyst systems) for solar fuels. Solar refinery	Rising to industrial scale production systems	Increasing average life span	
Artificial photosynthesis: Artificial solar thermal systems for solar fuels	Rising to industrial scale production systems		
Power to Gas	Improving features in catalysts	Increasing average life span	
Power to Liquid	Improving features in catalysts	Increasing average life span	

4.4. Environmental impact

Table 8 contains a summary of the main environmental impacts caused by chemical storage technology.

Table 8. Main environmental impact of chemical storage technology.

Type	Source of environmental risk
Alkaline electrolysers	Work in a basic environment
PEM electrolysers	
SOEC electrolysers	Component recycling
Co-electrolysers	
Synthetic methane methanation	Catalyst recovery
Biomethane	Use of biogenic resources and waste
Artificial photosynthesis: PEC (photoelectric catalyst systems) for H_2	Work in extreme pH environments. Recovery and recycling of electrocatalytic elements
Artificial photosynthesis: PEC (photoelectric catalyst systems) for solar fuels. Solar refinery	Use of land
Artificial photosynthesis: Artificial solar thermal systems for solar fuels	Use and occupation of land
Power to Gas	Catalyst recovery
Power to Liquid	

4.5. Hybridisation with other technology

Chemical storage technology can be combined with, complemented by or alternative to:

- Synthetic fuels: as they are used in basic goods to obtain other more complex products. Reusing CO_2.
- Electric grid management: natural gas networks, for instance, are essential for storing/distributing hydrogen or synthetic methane gas.
- Fossil fuel storage by means of injection in gas pipelines.
- Reformed hydrogen stations, where CO_2 emissions are avoided.

5. THERMAL STORAGE GROUP CONCLUSIONS

Thermal storage systems are an efficient form of storing energy and enable the use of more favourable renewable energy sources or thermal hot spots that are not constantly available, such as residual heat, solar power or ambient cooling. The different types of thermal storage technology are shown in Figure 11.

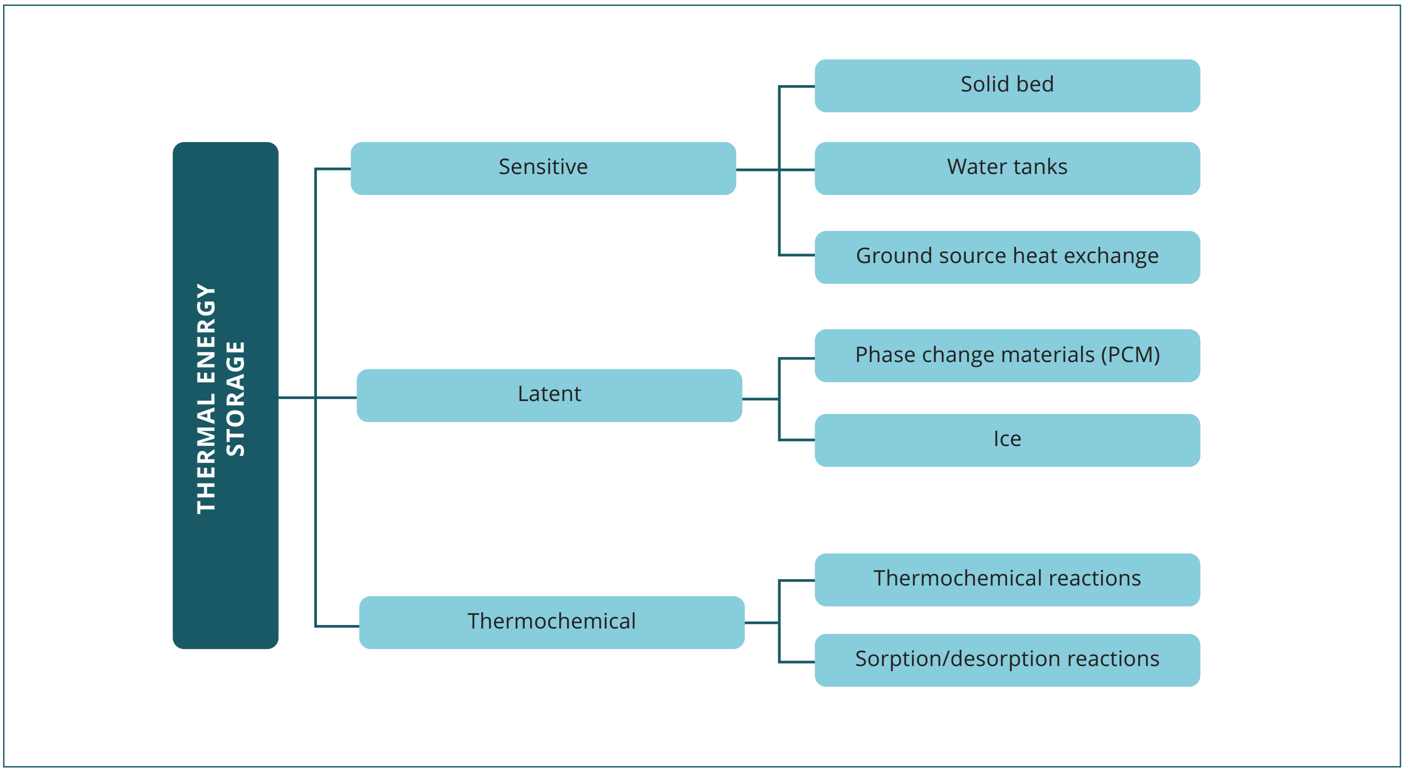


Figure 11. Types of thermal storage technology.

5.1. Technology Readiness Level (TRL)

The readiness level of a given type of technology does not only depend on the type of thermal storage in question; its application is also strongly influential. Table 9 shows the readiness level of each of the types of thermal storage technology.

Table 9. Thermal storage technology readiness level, examples according to application.

TRL	Technology	Examples of applications
9	Sensitive	Water tanks to make use of thermal solar energy by means of thermal storage on a daily and seasonal basis
		Ground-source heat exchange systems at low temperatures (<40 °C)
		Refracting solids for the glass and metal industry or for home heating
		Molten salt for thermal solar plants
	Latent	Ice for cooling commercial buildings by taking advantage of off-peak rates, by means of tri-generation or by reducing the power installed in the cooling machine, or for thermal safety in computer server rooms
		PCM for thermal protection of sensitive products, such as transporting blood, organs or art
	Thermochemical	TCM for regulating temperatures in sensitive products
6-8	Sensitive	Ground-source heat exchange systems at low temperatures (40-90 °C)
	Latent	Water tanks enhanced by adding PCM to make the most of solar energy
		PCM for solar thermal plants, including PCM in construction elements and for cooling purposes in large buildings
3-4	Latent	PCM for heating and cooling, for producing industrial cooling or solar cooling and as temperature regulating systems in photovoltaic panels
	Thermochemical	TCM for solar thermal plants and seasonal solar power storage for heating
0-2	Sensitive	Sensitive at high temperatures (>1000 °C)
	Thermochemical	TCM for heating and cooling and for transporting thermal energy

Top patent registering country: Japan takes the lead in latent and sensitive heat storage technology, while France heads up the thermochemical materials market (Table 17)

5.2. Cost of the different types of thermal storage technology

The costs of the main types of thermal storage technology are shown in Figure 12.

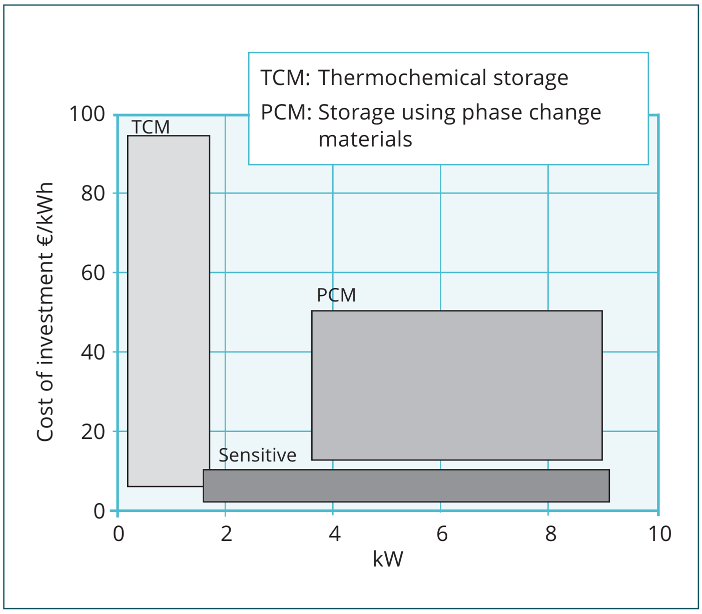


Figure 12. Costs of the main types of thermal storage technology.

5.3. Challenges for technological development

The major challenges to be overcome by this type of technology in order to be implemented in the short- to mid-term are summed up in Figure 13.[3]

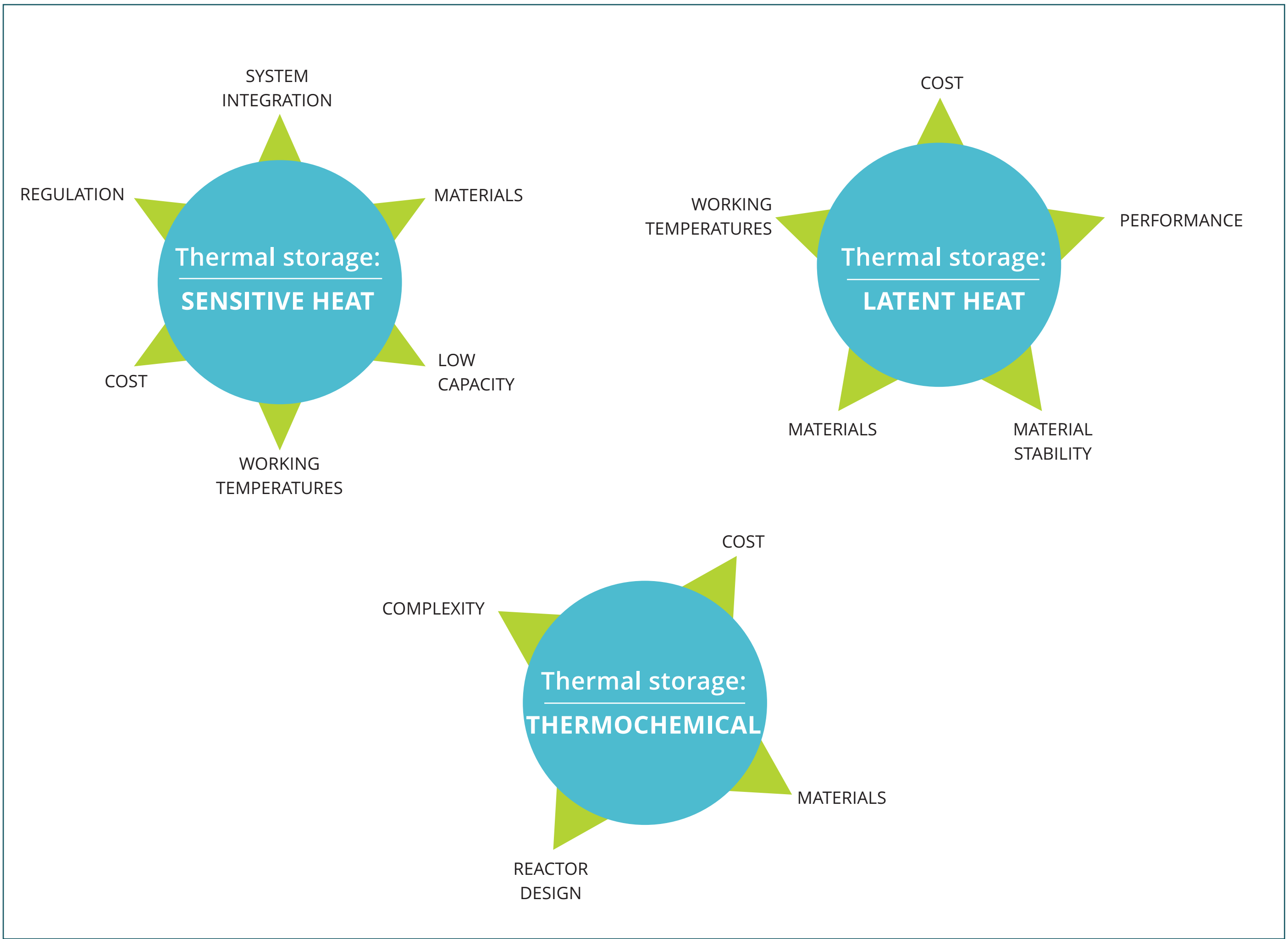


Figure 13. Challenges of thermal storage technology.

5.4. Environmental impact

Although all energy storage systems entail a certain environmental cost, installing a thermal energy storage system can often involve a significant reduction in the size of other heating or cooling machines as well as an increase in the system's efficiency. For instance, with ground-source heat exchange or solid bed exchange systems, the environmental cost can be considered minimal. In the latter case, options are being considered for recycling waste such as dross in this type of systems. As regards phase change materials, there are a number of studies that quantify their environmental impact using the life cycle analysis method, comparing between a ventilated façade (VDSF) with or without PCMs (REF).[4] The outcome is shown in Figure 14.

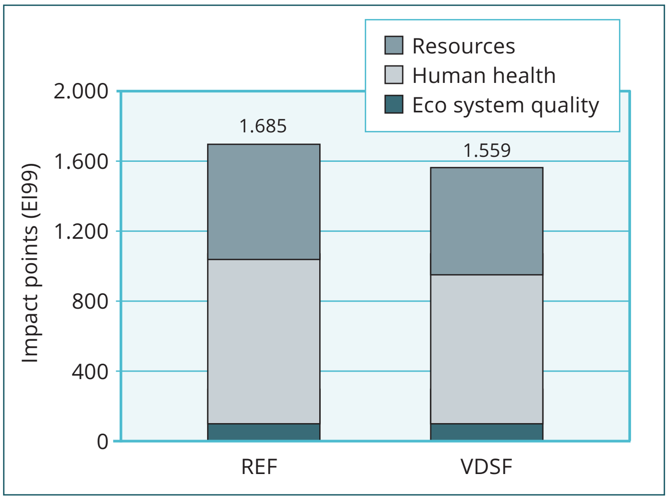


Figure 14. Outcome of the assessment of a ventilated façade with and without PCMs using the Eco-Indicator 99 (de Gracia *et al.* 2014).

5.5. Hybridisation with other technology

Thermal storage technology shows great potential for hybridisation with other types of technology, especially those that are available intermittently or seasonally (such as solar energy), where performance is strongly dependent on external factors. The most significant advantage of thermal storage is that transformations are not required, which means there is no loss of efficiency in processes that demand energy in the form of heat and that allow for the use of thermal sources. Figure 15 illustrates this advantage.

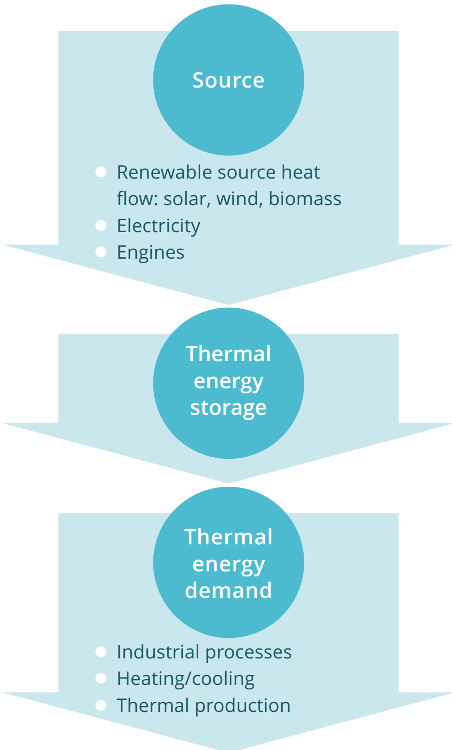


Figure 15. Hybridisation of thermal heat storage technology.

6. MECHANICAL STORAGE GROUP CONCLUSIONS

Two types of technology will be considered in this chapter: storage in the form of rotational kinetic mechanical energy, commonly known as inertia flywheel storage (hereinafter, KESS for Kinetic Energy Storage System), and storage in the form of potential mechanical energy of large water masses, which is known as Pumped Hydroelectric Storage (hereinafter, PHS). KESSs store kinetic energy in an inertia flywheel driven by an electrical machine which in turn is actioned by a power converter. PHS consists in pumping water from an upper tank to a lower tank and storing energy in the form of potential energy inside water.

6.1. Technology Readiness Level (TRL)

The TRL of KESSs depends on the technology they are based on, as shown in Table 10. As regards PHS, there are different degrees of maturity, but overall it can be considered to stand at TRL 9.

Table 10. TRL of kinetic and power storage.

Tipo	Elemento	Tipo	TRL
KESS	Flywheel (including bearings)	Metallic + Ceramic bearings (slow flywheels)	9
		Compound + Magnetic bearings (fast flywheels)	< 7
	Electric machine	Homopolar Reluctance Permanent magnet synchronisation	<7
	Power converter	Machine → Depends on the type of machine Grid → Two-way grid connection converter	9
PHS		Electrical operation based on synchronous machines; induction machines with variable speed operators; without variable speed operators	9
Top patent registering country: Japan with just under 40 patents (Table 18)			

6.2. Cost of the different types of mechanical storage technology

It is expected that KESSs will prove most competitive in applications with a discharge time of less than one hour. Table 11 shows the current costs of this type of technology in two applications. In terms of energy, these costs are well above what should be its target values. In terms of power, however, they are more reasonable. With regard to PHS, this technology is the most financially viable option at this time in terms of power. In terms of energy, the costs are strongly dependent on the location.

Table 11. Mechanical storage technology production costs.*

Current KESS costs per application	€/kWh	€/kW
Frequency regulation	7,358-8,302	1,840-2,075
Uninterruptible power supply (UPS)	9,434-66,038	236-755

PHS costs	€/kWh	€/kW
Reversible pump turbines	50.94-547 (fresh water) 243-524 (salt water)	1,415-5,660

(*) Dollar/euro exchange rate $1.06/€. On 19 March 2015.

6.3. Challenges for technological development

Below is a description of the major challenges this technology must overcome. Those challenges are listed according to components in Table 12.

Table 12. Challenges for mechanical storage technology. [7, 8 and 9]

KESS Element	Challenges	
Flywheel (including rotation)	LENTOS	Cost of manufacturing high-resistance flywheels; developing weight relief systems
	RAPIDOS	Manufactured using compound materials; integration of bearings in the machine; power systems with magnetic bearings
Electric machine	Rotor cooling; vacuum operation; mechanical strain on mobile parts; increased particle density; position detection or sensorless systems	
Power converter	High commutation frequencies; high voltage operation; control system speed	
Other	Developing casing or affordable contention systems	

PHS Element	Challenges
Turbine	Problems with pressure oscillation at low charge levels; broadening the stable operation range; reducing lubricant leaks; lowering fish mortality due to passing through the turbine
Electric machine	Reducing rotor inertia; improving start procedures; improving electrical insulations and protection; developing protection mechanisms against voltage gaps (in variable-speed systems)
Full plant	Developing active power control systems (in variable-speed systems); implementation in conventional hydro-electric plants; evaluating the solution of underground hydro-pumping and sea water; supporting renewable energy production

6.4. Environmental impact

The main impact caused by this type of technology can be seen in Figure 16.[5, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19]

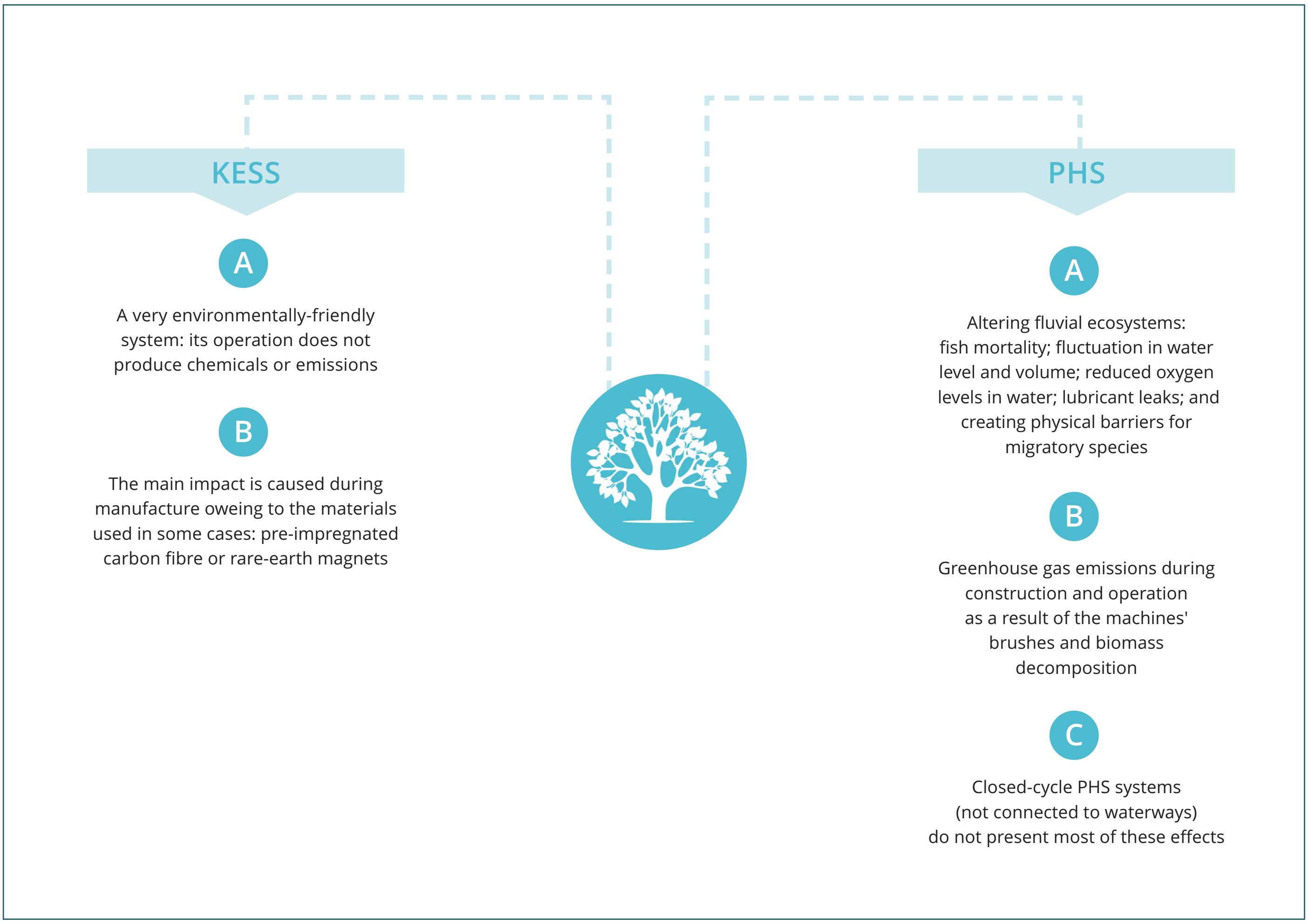


Figure 16. Main environmental impact caused by mechanical storage technology.

6.5. Hybridisation with other technology

Possibilities for hybridisation with other types of technology are summarised in Figure 17.

KESS

Suitable for hybridisation with batteries due to:

- Rapid response
- Limit discharge time
- Lack of degradation after a number of charge/discharge cycles

PHS

- Suitable for hybridisation with non-manageable production systems such as wind power or photovoltaic energy.
- Can help mitigate non-manageable production variability when used in the system's adjustment services.
- Can contribute to control voltage levels, tertiary regulation and load shedding.
- In turbine mode, they can provide primary or secondary regulation. In operation at variable speed or in a hydraulic short-circuit, they can also provide primary or secondary regulation in consumption mode.

Figure 17. Possibilities for hybridisation using mechanical storage technology.

7. MAGNETIC STORAGE GROUP CONCLUSIONS

The magnetic storage is based on establishing a magnetic field in a superconductor coil.The feasibility of a magnetic energy storage system that is capable of keeping up the excitation current without supplying energy continually in a coil is conditional upon the existence of conductors with no electric resistance. The emergence of superconducting materials has enabled coils to be built with high current density, capable of producing magnetic fields with high flow density and very low energy consumption. This is known as an SMES (Superconducting Magnetic Energy Storage) system. The basic components of an SMES system are: a superconducting coil, a cryogenic system to keep up the superconducting state, an electronic system to control and protect the coil, and the power electronics to enable coupling to the grid, both for storing energy and returning it.

7.1. Technology Readiness Level (TRL)

Within SMES technology, superconductors may have a low or high critical temperature with different TRL levels, as shown in Table 13.

Table 13. SMES technology readiness level.

Technology	Current state	TRL
Low critical temperature superconductors	More systems built and tested on the grid. Up to 20 MJ of energy accumulated. Commercial and portable systems. Helium-based cryogenic technology. Used for grid quality and mid-scale levelling.	9
High critical temperature superconductors	Systems built and tested up to 2.5MJ. Used for grid quality and military purposes. Technology based on cooling through conduction, without cryogenic gases or liquids. Self-contained systems.	5
Top patent registering country: Japan with 14 patents (Table 19)		

7.2. Cost of the different types of magnetic storage technology

The cost of investing in SMES essentially depends on the technology used and its function. Most experience has been acquired in systems dedicated to Supply Quality capable of operating up to 20s and based on low temperature superconductors, although financial studies have also been carried out on systems at the design stage. For low temperature systems operated and designed on the basis of powers that range from roughly ten to one hundred MW, the cost is estimated at €1,890/MW,[* and 6] or less in certain units constructed using a stored energy of roughly 15 kWh. In hybrid systems with liquid hydrogen[20] (LIQHYSMES), in addition to using high critical temperature superconductors and staying at –253 °C, the cryogenic elements are shared, thus creating a symbiosis that has its effect on the price. Based on public findings and on hypothetical power levels of 200 MW and 50 MW, and taking into account only the investment cost corresponding to the SMES, the cost per unit would be roughly €307/kW and €196/kW, respectively, with a storage capacity of 10 GJ. The cost per kWh of energy stored in a cycle, at a discharge power of 50 MW, stands at roughly €3,491/kWh. The ratio of recoverable energy cost to unit of power is shown in Table 14, which also reflects the cost of LIQHYSMES.

Table 14. Ratio of invested capital to unit of energy in relation to installed power.

Current costs per type of technology	€/kWh[* and 21]	€/kW
LIQHYSMES (50 MW)	850-7,550	189-849
Large SMES	377-9,434	377-4,150

(*) Dollar/euro exchange rate $1.06/€. On 19 March 2015.

7.3. Challenges for the development of this technology

The challenges affecting this type of technology are divided into the following groups: materials, cryogenics, coils, grid integration and electronics. Figure 18 shows a summary of the main improvements to be made in each group.

Materials

Lowering cost
Improving mechanical behaviour
Producing cylindrical conductors
Manufacturing transposer chords
Improving soldered joints between sections

Coils

Lessening environmental impact
Lowering costs
Improving materials and costs
Increasing flow density to reduce size
Increasing storage capacity
Improving winding

Cryogenics

Improving performance in cryogenic systems
Improving system reliability and lowering costs
Hybridisation with other cryogenic systems

Grid integration

Mitigating the effect of SMES or hybrid systems on the grid
Defining financial impact
Studying combined possibilities: GNL-HL-Electricity

Electronics

Lowering costs
Improving efficiency
Integrating low temperature electronics
Using reverislbe and ultra-fast superconductor switches
Enhancing the charge/discharge cycle

Figure 18. Main challenges for magnetic storage technology.

7.4. Environmental impact

The environmental impact of SMES systems can be broken down into two groups: toxicity and magnetic emissions, as shown in Figure 19.

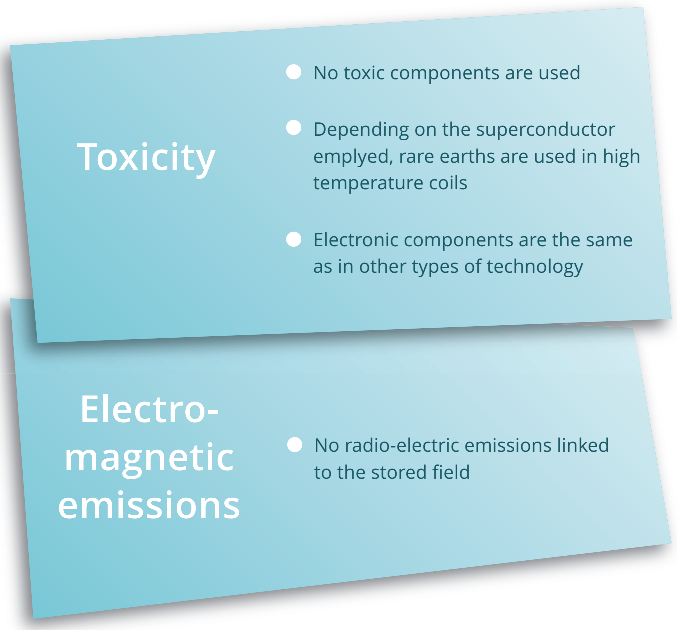


Figure 19. Environmental impact of magnetic storage technology.

7.5. Hybridisation with other technology

High discharge power and short response times make SMES systems an element that can be integrated in the electronic coupling of any storage system. Its main qualities include:

- Direct electromagnetism, allowing it to be integrated straight into the electronic grid coupling system.
- Regulating the charge/discharge process in more fragile (electrochemical) systems.
- Increasing the functionality of other systems, including the capability of grid regulation.
- Increasing the response speed of high capacity systems.
- Increasing the useful life of electrochemical systems.
- Optimising capacity and discharge power.

ANNEXES

AI. TRL SCALE

Conceived by NASA and subsequently adopted by the new Research Framework Programme (2014-2020), also known as H2020, the TRL scale is a standard method for measuring the degree of maturity of a given type of technology. The scale includes nine levels that range from the most basic technological state to successful tests in real life scenarios. Said levels are:

TRL 1: Basic idea.

TRL 2: Concept or technology formulated.

TRL 3: Concept test.

TRL 4: Component-level validation in the lab.

TRL 5: Component-level validation in a relevant environment.

TRL 6: System or sub-system validation in a relevant environment.

TRL 7: System validation in a real environment.

TRL 8: Full validation and certification in a real environment.

TRL 9: Successful tests in a real environment.

Table 15 shows a visual summary of what each level represents in the areas encompassed in this project.

Table 15. Link between TRL and the environment, type and stage of the project.

	Environment in which the project takes place	Type of project	Project stage
TRL 9			Deployment
TRL 8	Real environment	Innovation	Marketable product or service Specific test certifications
TRL 7			
TRL 6	Simulated environment	Development	Prototype/Demonstrator Technological development
TRL 5			
TRL 4			
TRL 3	Lab environment	Research	
TRL 2			Concept test Industry research
TRL 1			

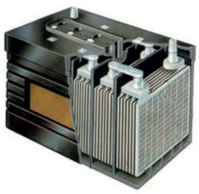
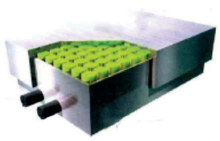
Source: Drawn up by the GIA based on an article published in a journal on Industrial Economy by MINETUR.

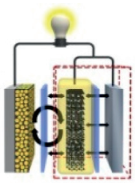
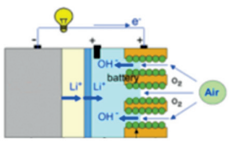
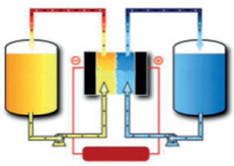
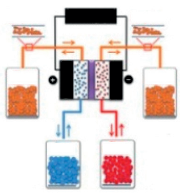
AII. PATENT SITUATION ANALYSIS

II.1. Electrochemical storage

Mention has been made to the most significant research companies in each type of technology considered in this document. Table 1 shows the institutions with the most patents for each type of technology:

Table 16. Top patent registering countries by type of electrochemical storage technology.

Storing technology		Company owner of the patent	Scale range	Country
	Lead-acid batteries	Shin Kobe Electric Mach Co. Ltd.	720	Japan
		Matsushita Electric Ind. Co. Ltd.	546	Japan
		Japan Storage Battery Co. Ltd.	463	Japan
		Yuasa Corp.	232	Japan
		Furukawa Battery Company Ltd.	174	Japan
		PANASONIC Corp.	81	Japan
		Nippon Sheet Glass Co. Ltd.	47	Japan
		Globe – Union Inc.	37	USA
	Nickel batteries	Matsushita Electric Ind. Co. Ltd	237	Japan
		Toshiba Corp.	188	Japan
		Sanyo Electric Co. Ltd.	165	Japan
		Yuasa Corp.	81	Japan
		Toyota Motor Corp.	45	Japan
		Japan Storage Battery Co. Ltd.	44	Japan
		Furukawa Battery Company Ltd.	39	Japan
		Sony Corp.	33	Japan
	Sodium batteries	NGK Insulators, Ltd.	246	Japan
		Hitachi Ltd.	144	Japan
		Sumitomo Chemical Co. Ltd.	62	Japan
		Tokyo Electric Power Co. Inc.	59	Japan
		Mitshubishi Heavy Ind. Ltd.	45	Japan
		Yuasa Corp.	43	Japan
		Science Univ. Of Tokyo	11	Japan
		General Electric Co.	11	USA
	Lithium-ion batteries	Toyota Motor Corp.	329	Japan
		Sony Corp.	248	Japan
		Matsushita Electric Ind. Co. Ltd	233	Japan
		Nissan Motor Co. Ltd.	191	Japan
		Samsung SDI Co. Ltd.	190	Korea
		Hitachi Ltd.	188	Japan
		TDK Corp.	169	Japan
		Panasonic Corp.	156	Japan

Storing technology		Company owner of the patent	Scale range	Country
	Lithium-sulphur batteries	Samsung SDI Co. Ltd.	69	Korea
		Hyundai Motor Corp.	13	Korea
		Robert Bosch GmbH	9	Germany
		PolyPLus Battery Co.	8	USA
		Oxis Energy Ltd.	6	UK
		Sion Power Corp.	5	USA
		GM Global Technology Operations LLC	4	USA
		Nagase Chemtex Corp.	4	Japan
	Metal-air batteries	Tesla Motors Inc.	28	USA
		Reveo Inc.	25	USA
		Toyota Motor Corp.	25	Japan
		AER Energy Resources Inc.	24	USA
		Electric Fuel (EFL) Ltd.	20	USA
		REVOLT Technology Ltd.	11	USA
		Hitachi Ltd.	10	Japan
		QuantumSphere Inc.	7	USA
	REDOX flow batteries	Sumitomo Electric Ind. Ltd.	137	Japan
		The Kansai Electric Power Co. Inc.	103	Japan
		Samsung Electronic Co. Ltd.	17	Korea
		Batelle Memorial Institute	14	USA
		ENERVAULT Corp	13	USA
		Toyobo Co. Ltd.	12	Japan
		Asahi Kasei E materials Corp.	11	Japan
		Sun Catalytix Corp.	7	USA
	Electrochemical capacitors	TDK Corp.	40	Japan
		Matsushita Electric Ind. Co. Ltd	38	Japan
		Samsung Electro-Mechanics Co. Ltd.	33	Korea
		Daihatsu Motor Co. Ltd.	26	Japan
		Motorola Inc.	24	USA
		NGK Insulators Ltd.	24	Japan
		PANASONIC Corp.	22	Japan
		Sanyo Chem Ind. Ltd.	20	Japan

Within the field of lithium-ion technology, special mention should be made to the patents registered by the company PANASONIC Corp., which have given rise to the Powerwall battery by TESLA Motors, the first domestic-use battery of its kind to hit the market.

With regard to the amount of patents, Figure 20 shows the number of patents registered per type of technology. Here, we can see that most patents have been registered for lithium-ion technology, with over 9,000 patents, followed by lead-acid batteries with over 4,000 and nickel batteries with 2,000.

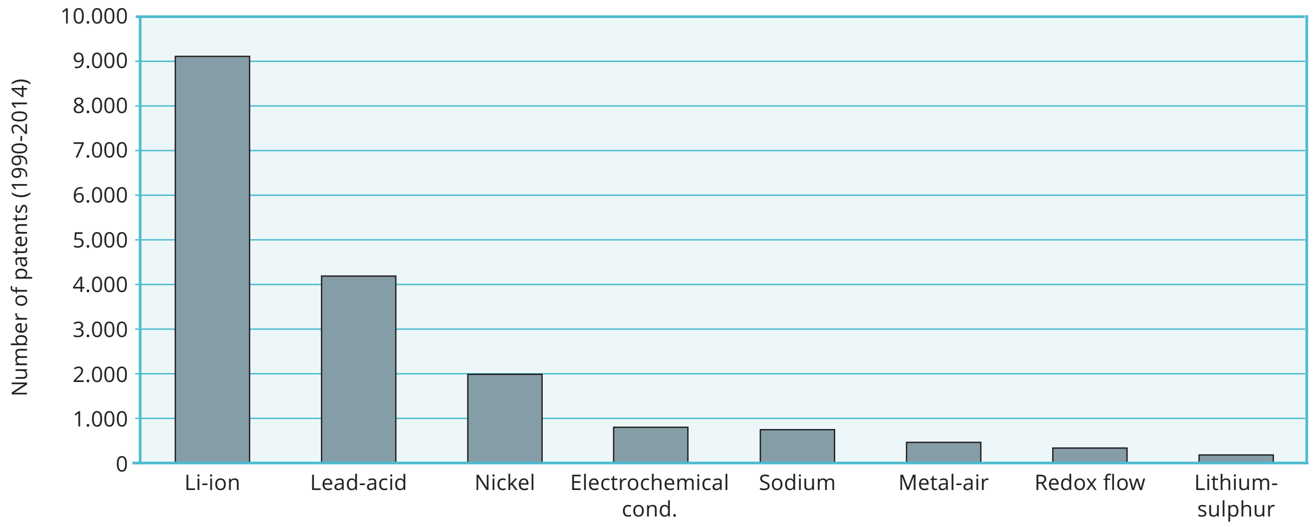


*Figure 20.*Number of patents per type of electrochemical storage technology.

II.2. Chemical storage

The companies with most patents registered in the field of chemical storage are shown in Table 17, broken down by type of technology.

Table 17. Top patent registering countries by type of chemical storage technology.

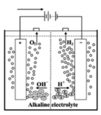
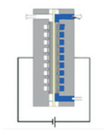
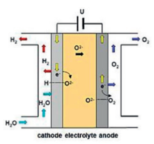
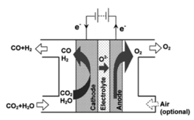
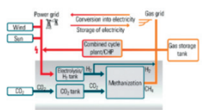
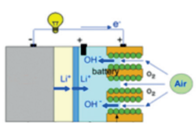
	Hydrogen: alkaline electrolysers	Atawey Volker Alan L. Peter Kraus, Dipi William R. Richards Dornier GmbH	1 1 1 1 1	Japan USA Germany USA Germany
	Hydrogen: PEM electrolysers	Umicore AG & amp Co. KG Next Hydrogen Corp. Proton Energy Systems Robert Bosch GmbH Siemens AG	9 3 2 2 2	Belgium Canada USA Germany Germany
	Hydrogen: high temperature electrolysers	Commissariat Energie Atomique et En. Alt. Toshiba Corp. Ebara Corp. Mitsubishi Heavy Ind. Ltd. Haldor Topsoe AS	7 5 5 2 2	France Japan Japan Japan Denmark
	Hydrogen: co-electrolysers (SOEC)	Commissariat al Energie Atomique Topsoe Fuel CELL Toshiba Corp National Institute for Materials Science Technical University of Denmark	6 5 2 1 1	France Norway Japan Japan Denmark
	Methane: Power to Gas	Matsushita Electric Ind. Co. Ltd. Honda Motor Co. Ltd. Toyota Motor Corp. Fuji Electric Co. Ltd. Panasonic Corp.	14 12 11 7 6	Japan Japan Japan Japan Japan
	Solar fuel: artificial photosynthesis	The Regents of the Univ. of California Sogang University Research Foundation Masteridea S.A. Nara Institute of Science and Technology Mazda Motor Corp.	2 1 1 1 1	USA Korea Chile Japan Japan

Figure 21 shows the number of patents registered for each type of technology. Power to Gas has the most patents with roughly 180, followed at a distance by high temperature electrolysers with less than 40 patents, and PEM electrolysers with 30 patents.

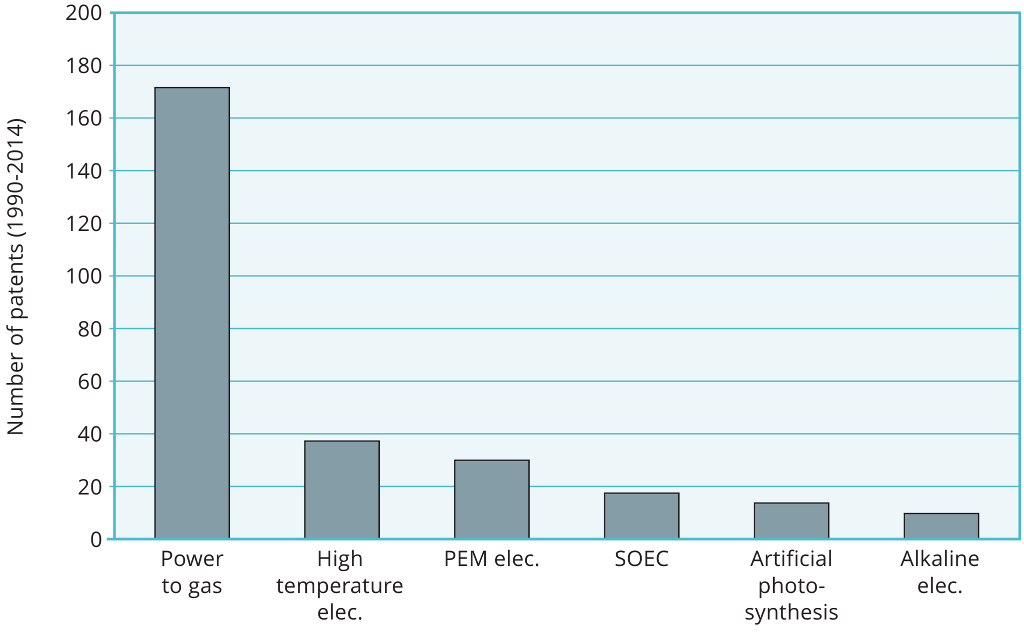
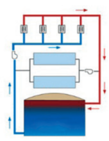
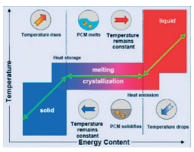
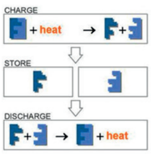


Figure 21. Number of patents per type of chemical storage technology.

II.3. Thermal storage

Table 18 shows the companies that have registered the most patents within each group of thermal storage technology. They have been classified into three major groups: sensitive heat storage, latent heat storage and thermochemical materials.

Table 18. Top patent registering countries by type of thermal storage technology.

	Sensitive heat	DINICHI Co. Ltd.	3	Japan
		Nippon Furnace Kogyo Kaisha Ltd.	3	Japan
		NKK Corp.	3	Japan
		Toyota Central R & amp; D Labs Inc.	1	Japan
		Kawasaki Steel Corp.	1	Japan
	Latent heat	Matsushita Electric Works, Ltd.	17	Japan
		Mitsubishi Chemical Corp.	8	Japan
		NOK Corp	7	Japan
		SK Kaken Co. Ltd	5	Japan
		JFE Engineering Corp.	4	Japan
	Thermochemical materials	Intervep S.A.	4	Venezuela
		HEVATECH	3	France
		Alliance S.A Saint – Vit, FR	2	France
		CIEMAT	2	Spain
		Paul Scherrer Institute	2	Switzerland

Spain is the third patent registering country in the field of thermochemical storage, thanks to two patents registered by CIEMAT. In terms of the number of patents per type of technology, Figure 22 shows that latent heat patents are the most numerous at 180, followed by sensitive heat patents with nearly 60, and phase-change materials bringing up the rear with 30 patents.

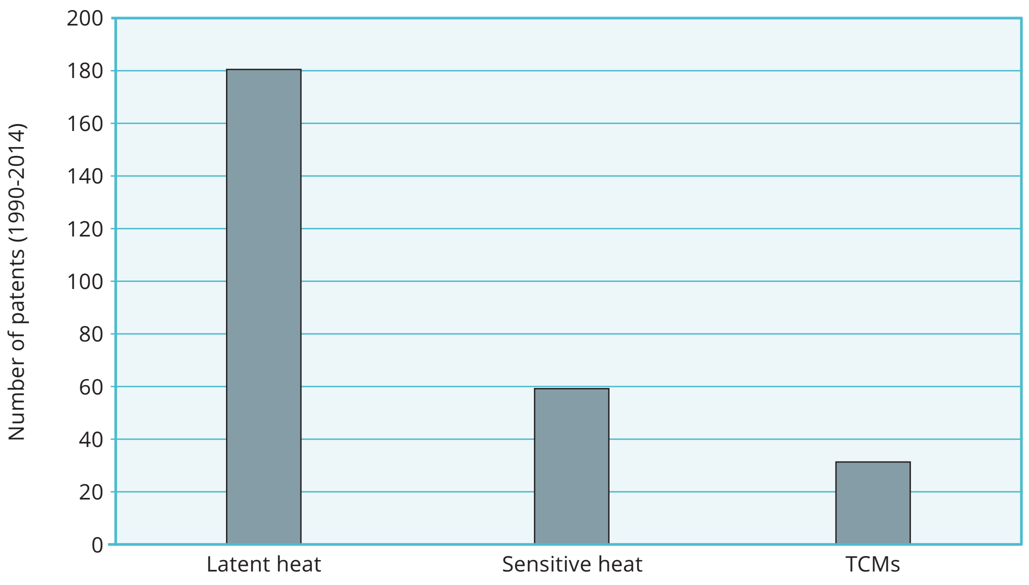


Figure 22. Number of patents per type of thermal storage technology.

II.4. Mechanical storage

The two types of mechanical storage technology studied are inertia flywheels and hydrogen pumping. The main countries to have registered patents in these categories are shown in Table 19.

Table 19. Top patent registering countries by type of mechanical storage technology.

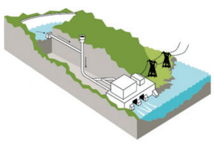
	Inertia flywheels	Active Power, Inc.	12	USA
		Mitsubishi Electric Corp.	8	Japan
		RAILWAY TECHNICAL RES Institute	7	Japan
		TOSHIBA Corp.	7	Japan
		IHI Corp.	5	Japan
	PHS	Toshiba Corp.	4	Japan
		Electric Power Co. Ltd.	3	Japan
		Tokyo Electric Power Company Inc.	3	Japan
		Mitsubishi Electric Corp.	2	Japan
		William Riley	1	USA

Figure 23 shows the number of patents registered per type of technology. It is clear to see that most research activity has focused on developing inertia flywheels (KESS) with just under 200 patents, as compared to less than 50 patents in PHS technology.

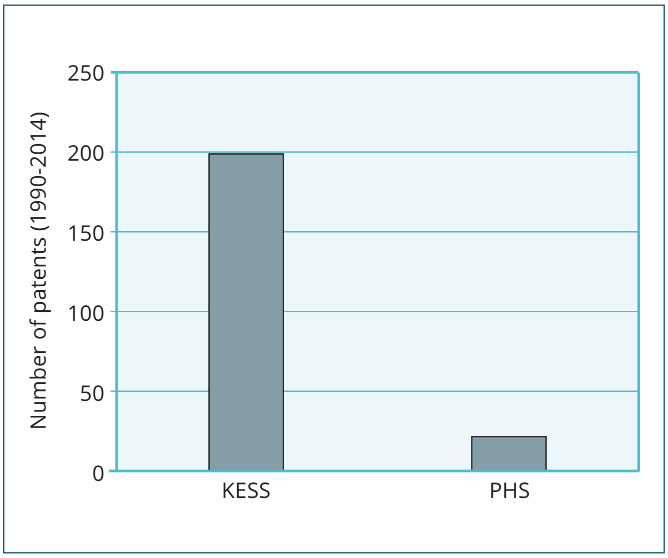
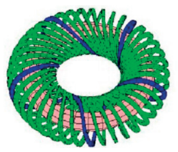


Figure 23. Number of patents per type of mechanical storage technology

II.5. Magnetic storage

Within the field of magnetic storage, Toshiba is the firm with the most patents for magnetic supercapacitors, as shown in Table 20.

Table 20. . Top patent registering countries by type of magnetic storage technology.

	SMES	Toshiba Corp.	11	Japan
		ABB AB	3	Switzerland
		National Institute for Materials Science	3	Japan
		Westinghouse Electric Corp.	3	USA
		Tokyo Electric Power Company Inc.	3	USA

The total number of patents in this field amounts to 70, as illustrated in Figure 24.

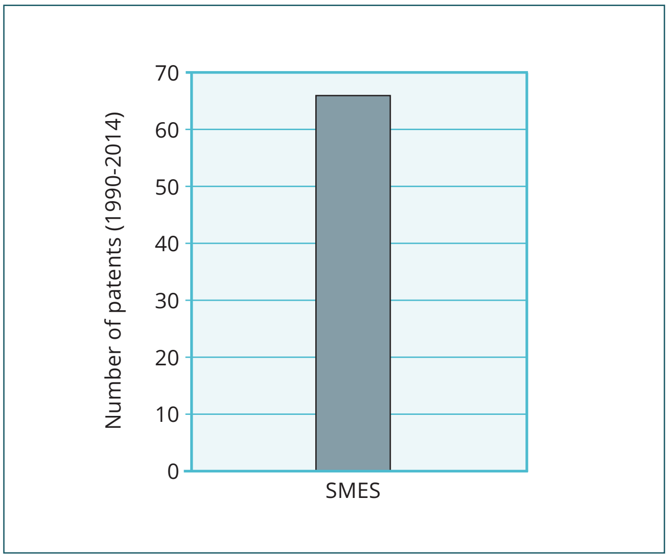


Figure 24. Number of patents per type of magnetic storage technology.

AIII. SUMMARY OF CAPABILITIES AND PROJECTS IN SPAIN

Over the course of the work carried out by the Storage Inter-Platform Group, it has identified 99 projects by Spanish institutions linked to the various types of storage technology and has defined the capabilities of 22 different institutions. The data drawn up is available on the FutuRed web site (www.futured.es), where the documents found are free to be viewed and updated.

Below is a visual classification of the projects identified:

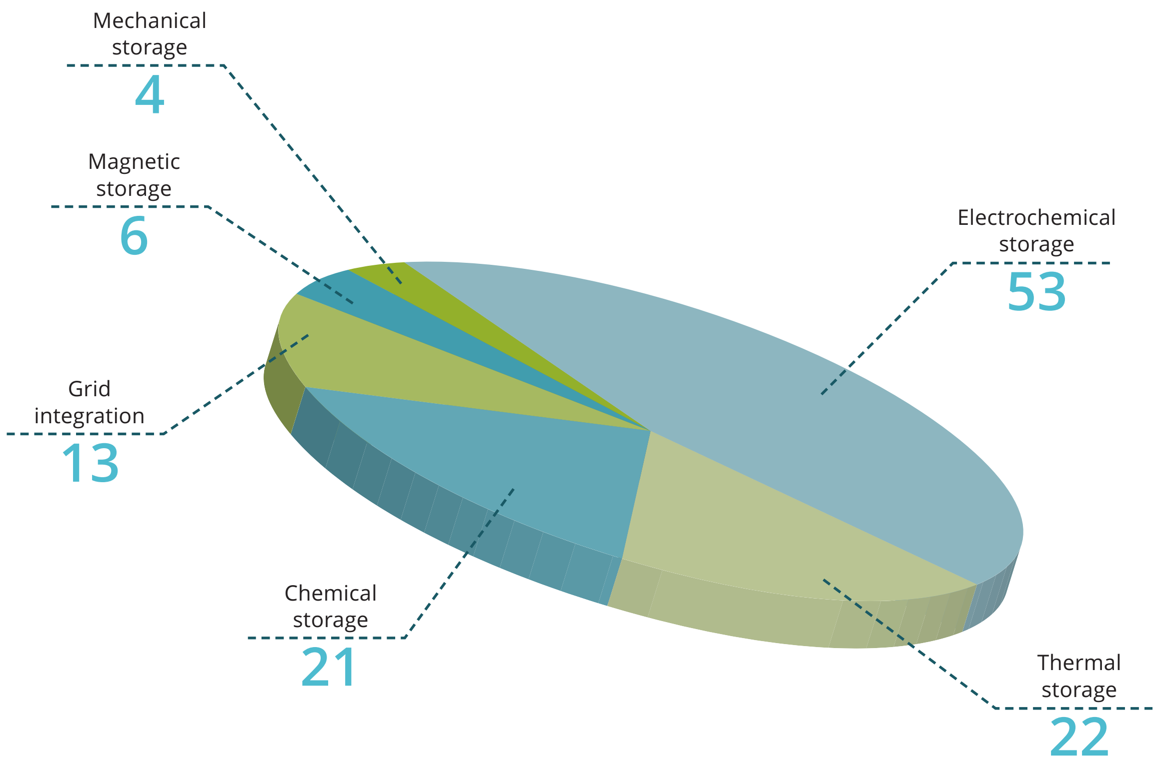


Figure 25. Number of projects per type of technology in Spain.

AIV. PARTICIPATING INSTITUTIONS

Coordinators of the Storage Inter-Platform Group (GIA)

edp

FutuRed

circe
CENTRO DE INVESTIGACIÓN
DE RECURSOS
Y CONSUMOS ENERGÉTICOS

Work Group Leaders

FutuRed
Regulation Group

CENER ADItech
Grid Integration and Applications Group

instituto imdea energía
Electrochemical Storage Group

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

I3A Instituto Universitario de Investigación en Ingeniería de Aragón
Universidad Zaragoza
Thermal Storage Group

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
Mechanical Storage Group

ICMAB INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA (ICMAB)
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
Magnetic Storage Group

Work Group Participants

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ceit IK4 Research Alliance	cemitec Multidisciplinary Centre of Technologies for Industry ADItech	CENER ADItech	Centro Nacional del Hidrógeno
CIC energiGUNE energy cooperative research centre	Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	ceit IK4 Research Alliance	edp
EMELCAT	endesa	Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos	EXIDE BATTERIES
gasNatural fenosa	FOTOPLAT	FutuRed	Ha

AV. GLOSSARY OF TERMS

CAES	Compressed Air
DSOs	Distribution System Operator
EASE	European Association for Storage of Energy
EDLC	Electric double-layer capacitors
EERA	European Energy Research Alliance
KESS	Inertia flywheel
L/A	Lead/Acid
Li-Ion	Lithium ion
LIQHYSMES	Hybrid systems with liquid hydrogen
Na-S	Sodium-sulphur
Ni-Cd	Nickel-cadmium
Ni-MH	Nickel-metal hidride
PCM	Phase Change Materials
PHS	Pumped Hydroelectric Storage
RE	Renewable Energy
RFB	Redox Flow Battery
SMES	Magnetic storage
TCM	Thermochemical materials
TRL	Technology Readiness Level
TSOs	Transmission System Operator
UPS	Uninterruptible power supply
VDSF	ventilated façade
VRB	Vanadium redox battery
ZEBRA	Sodium nickel chloride
Zn-Br	Bromine battery

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