Appendix I – Energy Storage Label

A description of the energy storage label and a collection of the storage labels developed to date.

Lithium Ion Battery

1 →

Technology name	Electrochemical Storage - Lithium Ion Battery

2 →

Description	Lithium batteries are composed of a graphite cathode and lithium metal anode. Lithium batteries have a relatively high energy density, low self-discharge, high roundtrip efficiency and high cost. Several cells can be connected to greatly increase power rating and Energy storage capacity

3 →

Key characteristics	Lower Range	Unit	Upper Range	Unit
Discharge power	1.00	kW	5,000.00	kW
Charge power	1.00	kW	5,000.00	kW
Energy storage capacity	500.00	Wh	100.00	MWh
Energy density	200.00	kWh/m3	500.00	kWh/m3
Response time discharge	1.00	s	998.00	ms
Response time charge	1.00	s	998.00	ms
Costs power	130.00	€/kW	4,000.00	€/kW
Costs energy	250.00	€/kWh	4,500.00	€/kWh

4 →

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

5 →

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

6 →

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

7 →

Expert properties	Lower Range	Unit	Upper Range	Unit
Operational time	0.50	hours	15.00	hours
Ramp up speed	#N/A	kW/min	#N/A	MW/min
Ramp down speed	#N/A	kW/min	#N/A	MW/min
Cost projection (2020)	55.90	€/kW	1,720.00	€/kW
Cost projection (2020)	107.50	€/kWh	1,935.00	€/kWh
Self-discharge rate	0.10	%/day	0.10	%/day
Roundtrip efficiency	87.00	%	95.00	%
Lifetime	4,500.00	Cycles	100,000.00	Cycles
Lifetime	5.00	Years	15.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months

8 →

Maturity of technology	Research	Demonstration	Deployed	Commercial

9 →

Reliability	Range low	Unit	Range high	Unit
Downtime		days/year		days/year
Reliability		%		%

10 →

Safety of system	Lithium can be flammable if exposed to air. Requires overcharge protection

11 →

Sustainability	
Recyclabilty	Highly Recyclable
Environmental impact	
Resource Depletion	Lithium and graphite are readily available in large amounts.

12 →

Final remarks	Highest energy density in commercially available batteries. High voltage per cell (3.7 V ccompared to 2.0 V in Pb Acid) Low energy loss Very expensive and deteriorates over time

13 →

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper**

Storage Label Design

The label components are described in detail in Section 3.1 and 3.2. To summarize, these include:

1) **Technology Name:** The name typically given to this technology, as well as the broad category this type of storage falls under (i.e. mechanical, electrochemical, electrical, magnetic, thermal or gas storage).
2) **Description:** A general description of the technology, providing fundamental operating principles and typical applications.
3) **Key Characteristics:** Displays the minimum and maximum characteristics in key areas which define the suitability of a technology for particular applications. Key characteristics include **Power Rating Charge**, **Power Rating Discharge**, **Energy Storage Capacity, Energy Density, Response Time Charge**, **Response Time Discharge** and **Costs** (in terms of power rating and energy capacity).
4) **Energy Carrier Type:** The energy carrier stored by and released from the storage system. Energy can be stored in many different forms (i.e. mechanical, potential, chemical, electrical, thermal, etc.) but is typically released from the storage system in the form of electricity, heat, gas or a liquid fuel.
5) **Suitable Applications:** Suitability of technology for typical energy storage applications.

A green cell indicates a technology is highly suitable
An orange cell indicates a technology is moderately suitable or requires further development in this region
A grey cell indicates no suitability.

6) **Sector for Use:** The typical sector of the energy network where this technology is employed, often related to power rating. Different sector include:
   - Supply (100 MW – 100 GW)
   - Transmission and distribution (10 kW – 100 MW)
   - Consumer / Demand (<10 kW)
   - Renewable energy integration (kW – MW)

7) **Expert Properties:** More detailed technology characteristics, which may prove important but less fundamentally defining as the **Key Characteristics**. These include **Max Operational Time**, **Ramp Up/Down Speed**, **Cost Projection**, **Self-discharge Rate**, **Roundtrip Efficiency**, **Lifetime** and **Storage Time**.
8) **Maturity of Technology:** A ranking of how far developed this technology is. From this, many conclusions can be inferred about the technology’s cost and reliability, as well as potential for future developments.
9) **Reliability:** A ranking of the technology’s annual **Downtime** and the **Reliability**, which is a measure of security of supply (i.e. which percentage of time will this technology be accessible throughout a year).
10) **Safety of System:** A description of notable operating risks associated with this technology.
11) **Sustainability:** The environmental friendliness of this technology, in terms of **Recyclability, Environmental Impact** and **Resource Depletion.**
12) **Final Remarks:** Additional remarks, such as important advantages and limitations of this technology, ideal applications and so on.
13) **Sources used for this label**

Flywheel

Technology name	Mechanical Storage - Flywheel
Description	Flywheels store electrical energy by speeding up inertial masses (rotors). Rotating masses typically rest on low-friction bearings in evacuated chambers. Energy is transferred in and out usng a motor-gnerator that spins a shaft connected to the rotor.

Key characteristics	Lower Range	Unit	Upper Range	Unit
Discharge power	0.01	MW	2.00	MW
Charge power	100.00	kW	2.00	MW
Energy storage capacity	1,800.00	kJ	25.00	kWh *
Energy density	-	MWh/m3	-	MWh/m3
Response time discharge	0.06	s	0.06	s
Response time charge	0.06	s	0.06	s
Costs power	100.00	€/kW	3,020.00	€/kW
Costs energy	720.00	€/kWh	6,650.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	Lower Range	Unit	Upper Range	Unit
Operational time	5.00	s	15.00	min
Ramp up speed	#N/A	kW/min	#N/A	MW/min
Ramp down speed	#N/A	MW/min	#N/A	MW/min
Cost projection (2020)		€/Wh		€/kWh
Cost projection (2020)		€/Wh		€/kWh
Self-discharge rate	3.00	%/hr	40.00	%/hr
Roundtrip efficiency	70.00	%	90.00	%
Lifetime	20,000.00	Cycles	10,000,000.00	Cycles
Lifetime	15.00	Years	25.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	Range low	Unit	Range high	Unit
Downtime		days/year		days/year
Reliability		%		%

Safety of system	Must be regularly inspected to prevent catastrophic failure, but reamains a low-maintenance, highly reliable technology.

Sustainability	Range low	Unit	Range high	Unit
Recyclabilty		%		%
Environmental impact	Essentially no direct carbon emissions			
Resource Depletion				

Final remarks	A low maintenance, fast-response method of energy storage. High initial costs, low storge capacity and high self-discharge rate. *25 kWh flywheels are still in development.

Sources used for this label	Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper U.S. Depatment of Energy (2013). Grid Energy Storage. *U.S. Department of Energy.* European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.* Bradbury, K. (2010). Energy Storage Technology Review Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.* Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.* Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.* SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.* Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.* Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250. Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.* Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.* Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171. Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.*

Pumped Hydro Storage

Technology name	**Mechanical Storage - Pumped Hydro Storage**
Description	Pumped hydro stores energy by using electricity to pump water from a lower reservoir to an upper reservoir and recovers energy by allowing the water to flow back through turbines to produce electricity.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	5.00	MW	5.00	GW
Charge power	5.00	MW	5.00	GW
Energy storage capacity	1,200.00	MWh	120.00	GWh
Energy density	0.50	kWh/m3	1.50	kWh/m3
Response time discharge	10.00	s	15.00	min
Response time charge	1.00	min	15.00	min
Costs power	500.00	€/kW	3,600.00	€/kW
Costs energy	40.00	€/kWh	680.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	1.00	hours	100.00	hours
Ramp up speed	10.00	MW/min	60.00	MW/min
Ramp down speed	10.00	MW/min	60.00	MW/min
Cost projection (2020)		€/Wh		€/kWh
Cost projection (2020)		€/Wh		€/kWh
Self-discharge rate	0.00	%		
Roundtrip efficiency	55.00	%	85.00	%
Lifetime			50.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability	Very reliable	%		%

Safety of system	

Sustainability	
Recyclabilty	
Environmental impact	Huge environmental impact
Resource Depletion	

Final remarks	Low cost, long life, high efficiency and lack of cycling degredation makes it a unique storage technology. Highly dependent on limited appropriate construction sites. Requires a sgnificant water source.

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **U.S. Depatment of Energy (2013). Grid Energy Storage.** ***U.S. Department of Energy.***

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Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*

Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.

Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.*

Compressed Air Energy Storage

Technology name	**Mechanical Storage - Compressed Air Energy Storage (CAES)**
Description	CAES was first developed to provide load following and meet peak demand. The basic operation is similar to a conventional gas turbine, but uses pre-compressed air from off-peak electrical power instead of compressing air by burning natural gas.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	50.00	MW	320.00	MW
Charge power	30.00	MW	200.00	MW
Energy storage capacity	360.00	MWh	2,860.00	MWh
Energy density	-	MWh/m3	-	MWh/m3
Response time discharge	5.00	min	15.00	min
Response time charge	5.00	min	0.25	hours
Costs power	400.00	€/kW	1,150.00	€/kW
Costs energy	10.00	€/kWh	120.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Tranportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	3.00	hours	40.00	hours
Ramp up speed	15.00	MW/min	95.00	MW/min
Ramp down speed	15.00	MW/min	95.00	MW/min
Cost projection (2020)	360.00	€/kW	1,035.00	€/kW
Cost projection (2020)	9.00	€/kWh	108.00	€/kWh
Self-discharge rate	0.00	%/day	0.00	%/day
Roundtrip efficiency*	64.00	%	80.00	%
Lifetime	25.00	Years	40.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

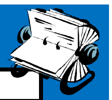
Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact	Three times lower than a conventional natural gas turbine.			
Resource Depletion				

Final remarks	High storage capacity and relatively low cost per unit stored Problematic to obtain appropriate storage media (eg. caverns) Highly suitable for energy management and power quality.

	*The process still consumes natural gas, but this is generally omitted from the roundtrip efficiency calculations (roughly 30% of electricity produced results from the combustion of natural gas). E.g. To produce 1 kWh of electricity, 0.7-0.8 kWh of electicity must be stored to compress air and 1.22 kWh of natural gas must be combusted to retrieve the air; the combustion of natural gas also produces electricity, but the efficiency of this process is not considered when calculating the efficiency of the CAES system.

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **U.S. Depatment of Energy (2013). Grid Energy Storage. *U.S. Department of Energy.*** **European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.*** **Arizona Research Institute for Solar Energy (2010). Study of Compressed Air Energy Storage with Grid and Photovoltaic Energy Generation.** **Bradbury, K. (2010). Energy Storage Technology Review** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.*** **Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.*** **Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.*** **SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.*** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.*** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250.** **Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.*** **Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.** **Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.***

Lead Acid Battery



Technology name	**Electrochemical Storage - Lead Acid Batteries**
Description	Lead Acid batteries are composed of a sponge metallic lead anode, a lead-dioxide cathode and sulfuric acid solution electrolyte. They have a relatively low cost, simple design, good life cycle (if used correctly) and quick reaction kinetics. Several cells can be connected to greatly increase power rating and Energy storage capacity.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	1.00	kW	50.00	MW
Charge power	1.00	kW	50.00	MW
Energy storage capacity	1.00	kWh	50.00	MWh
Energy density	50.00	kWh/m3	80.00	kWh/m3
Response time discharge	1.00	s	1.00	s
Response time charge	1.00	s	1.00	s
Costs power	110.00	€/kW	5,800.00	€/kW
Costs energy	130.00	€/kWh	3,800.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	0.50	hours	10.00	hours
Ramp up speed	#N/A	kW/min	#N/A	MW/min
Ramp down speed	#N/A	MW/min	#N/A	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.10	%/day	0.30	%/day
Roundtrip efficiency	75.00	%	90.00	%
Lifetime	2,200.00	Cycles	100,000.00	Cycles
Lifetime	3.00	Years	10.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

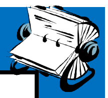
Safety of system	Uses toxic metals (i.e. Lead) and hazardous chemicals (i.e. sulfuric acid). Hydrogen and oxygen gas are produced if over-charged - a potentially explosive mixture in exclosed areas.

Sustainability	
Recyclabilty	Easily recyclable
Environmental impact	Lead can cause severe damage to people and animals if not properly disposed of.
Resource Depletion	

Final remarks	Easy and cheap to produce Very high surge-to-weitgh ratio (can deliver a high jolt of electricity at once). Relatively heavy and bulky Distilled water must be refilled several times per year. Relatively short-lived

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Bradbury, K. (2010). Energy Storage Technology Review** **Leuthold, D. M. (2012). Storage Technologies for the Integration of Renewable Energy. *RWTH Aachen University*** **U.S. Depatment of Energy (2013). Grid Energy Storage. *U.S. Department of Energy.*** **European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.*** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.*** **Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.*** **Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.*** **SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.*** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.*** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250.** **Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.*** **Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.** **Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.***

Lithium Ion Battery



Technology name	**Electrochemical Storage - Lithium Ion Battery**
Description	Lithium batteries are composed of a graphite cathode and lithium metal anode. Lithium batteries have a relatively high energy density, low self-discharge, high roundtrip efficiency and high cost. Several cells can be connected to greatly increase power rating and Energy storage capacity

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	1.00	kW	5,000.00	kW
Charge power	1.00	kW	5,000.00	kW
Energy storage capacity	500.00	Wh	100.00	MWh
Energy density	200.00	kWh/m3	500.00	kWh/m3
Response time discharge	1.00	s	998.00	ms
Response time charge	1.00	s	998.00	ms
Costs power	130.00	€/kW	4,000.00	€/kW
Costs energy	250.00	€/kWh	4,500.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	0.50	hours	15.00	hours
Ramp up speed	#N/A	kW/min	#N/A	MW/min
Ramp down speed	#N/A	kW/min	#N/A	MW/min
Cost projection (2020)	55.90	€/kW	1,720.00	€/kW
Cost projection (2020)	107.50	€/kWh	1,935.00	€/kWh
Self-discharge rate	0.10	%/day	0.10	%/day
Roundtrip efficiency	87.00	%	95.00	%
Lifetime	4,500.00	Cycles	100,000.00	Cycles
Lifetime	5.00	Years	15.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	Lithium can be flammable if exposed to air. Requires overcharge protection

Sustainability	
Recyclabilty	Highly Recyclable
Environmental impact	
Resource Depletion	Lithium and graphite are readily available in large amounts.

Final remarks	Highest energy density in commercially available batteries. High voltage per cell (3.7 V ccompared to 2.0 V in Pb Acid) Low energy loss

	Very expensive and deteriorates over time

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Bradbury, K. (2010). Energy Storage Technology Review** **Leuthold, D. M. (2012). Storage Technologies for the Integration of Renewable Energy. *RWTH Aachen University*** **European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.*** **U.S. Depatment of Energy (2013). Grid Energy Storage. *U.S. Department of Energy.*** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.*** **Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.*** **Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.*** **SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.*** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.*** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250.** **Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.*** **Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.** **Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.***

Vanadium Redox Flow Battery

Technology name	**Electrochemical Storage - Vanadium Redox Flow Battery**
Description	Redox flow batteries employ a reversible fuel cell with the electro-active componenets dissolved in an electrolyte. The design allows a decoupling of power and energy.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power†	5.00	kW	10.00	MW
Charge power	0.01	MW	10.00	MW
Energy storage capacity	0.50	MWh	8.00	MWh
Energy density	20.00	kWh/m3	30.00	kWh/m3
Response time discharge	0.02	ms	0.30	ms
Response time charge	0.02	ms	0.30	ms
Costs power*	3,000.00	€/kW	4,900.00	€/kW
Costs energy*	600.00	€/kWh	1,100.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	4.00	hours	10.00	hours
Ramp up speed	#N/A	MW/s	#N/A	MW/min
Ramp down speed	#N/A	MW/min	#N/A	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.20	%/day	0.20	%/day
Roundtrip efficiency	60.00	%	85.00	%
Lifetime	10,000.00	Cycles	10,000.00	Cycles
Lifetime	10.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed†	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	Safer than conventional batteries because the active materials are stored separately from the reactive point source.

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	†Larger 10 MW systems are still in development, but are expected in the coming years. Smaller 5 kW systems have been deployed. *System costs are expected to fall significantly in the coming years.

	It is possible to design a system with optimal power acceptance and delivery properties.

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage;** **Bradbury, K. (2010). Energy Storage Technology Review** **U.S. Depatment of Energy (2013). Grid Energy Storage. *U.S. Department of Energy.*** **Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.*** **Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.*** **SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.*** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.*** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250.** **Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.*** **Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.** **Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.***

Supercapacitors

Technology name	**Electrical Storage - Supercapacitors**
Description	Supercapacitors store energy in large electrostatic fields between two conductive plates, which are separated by a small distance. Electricity can be quickly stored and released using this technology in order to produce short bursts of power.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	10.00	kW	1.00	MW
Charge power	10.00	kW	1.00	MW
Energy storage capacity	2.00	Wh	1,000.00	kWh
Energy density	0.10	Wh/kg	15.00	Wh/kg
Response time discharge	1.00	s	1.00	s
Response time charge	1.00	s	1.00	s
Costs power	100.00	€/kW	400.00	€/kW
Costs energy	300.00	€/kWh	4,000.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation*

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	598.80	ms	1.00	hours
Ramp up speed	#N/A	MW/min	#N/A	MW/min
Ramp down speed	#N/A	MW/min	#N/A	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/Wh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/Wh
Self-discharge rate	2.00	%/day	40.00	%/day
Roundtrip efficiency	60.00	%	98.00	%
Lifetime	10,000.00	Cycles	100,000,000.00	Cycles
Lifetime	20.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact	Little to no direct environmental impact.			
Resource Depletion				

Final remarks	Can be charged and discharged continuously without degrading, and much more quickly than batteries. *Can be used in Transportation specifically for regenerative breaking.

Sources used for this label	Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.* Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; Bradbury, K. (2010). Energy Storage Technology Review European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.* Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.* Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.* SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.* Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.* Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250. Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.* Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.* Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171. Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.*

Superconducting Magnetic Energy Storage

Technology name	**Magnetic Storage - Superconducting Magnetic Energy Storage (SMES)**
Description	SMES stores flowig electric current in a superconducting coil as a magnetic field. These devices are extremely efficient, fast-responding, scalable to large sizes and environmentally benign, although very costly. There are very low losses except for the parasitic losses to keep the superconducting coil cooled.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	10.00	kW	10.00	MW
Charge power	0.01	MW	10.00	MW
Energy storage capacity	10.00	Wh	1.00	MWh
Energy density	0.20	kWh/m3	2.50	kWh/m3
Response time discharge	100.00	ms	100.00	ms
Response time charge	100.00	ms	100.00	ms
Costs power	100.00	€/kW	400.00	€/kW
Costs energy	750.00	€/kWh	7,000.00	€/kWh

Energy carrier type	**Electricity**	Gas	Heat	Liquid fuel

Suitable applications	**Frequency control**	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	**Uninterruptible Power Supply**	Transportation

Sector for use	Utilities	**Transmission & distribution**	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	5.00	s	5.00	min
Ramp up speed	#N/A	kW/min	#N/A	MW/min
Ramp down speed	#N/A	MW/min	#N/A	MW/min
Cost projection (2020)	#N/A	€/kW	#N/A	€/kW
Cost projection (2020)	#N/A	€/kWh	#N/A	€/kWh
Self-discharge rate	10.00	%/day	15.00	%/day
Roundtrip efficiency	90.00	%	95.00	%
Lifetime	100,000.00	Cycles	100,000.00	Cycles
Lifetime	20.00	Years	30.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	**Demonstration**	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	Possible concerns of the effects of strong magnetic fields on human physiology.

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact	Little to no impact, except possibly from large magnetic fields on human physiology.			
Resource Depletion				

Final remarks	Very expensive, short storage time and requires extremely low temperatures (-255 to -264 C). Fast response times and minimal environmental impact.

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **European Commission Directorate General for Energy (2013). The Future Role and Challenges of Energy Storage. *European Commission Directorate General for Energy.*** **Bradbury, K. (2010). Energy Storage Technology Review** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.*** **Stuurgroep (2014). All Store - De toekomst van elektriciteitsopslag. *Alliander.*** **Wang, W. M., Wang, J. & Ton, D. (2012). Prospects for Renewable Energy: Meeting the Challenges of Integration with Storage. *Elsevier Inc.*** **SBC Energy Institue (2013). Electricity Storage Factbook. *SBC Energy Storage.*** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projects. *Massachusetts Institute of Technology.*** **Ibrahim, H., Ilinca, A. & Perron, J. (2008). Energy storage systems - Characteristics and comparisons. *Renewable and Sustainable Energy Reviews 12,* 1221 - 1250.** **Electric Power Research Institute (2003). EPRI-DOE Handbok of Energy Storage for Transmission and Distribution Applications. *U.S. Department of Energy.*** **Energy Economics Group (2012). Facilitating energy storage to allow high penetration of intermittent renewable energy. *Intelligent Energy Europe.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171.** **Depatment of Trade and Industry (2004). Review of Electrical Energy Storage Technologies and Systems and of their Potential for the UK. *Department of Trade and Industry.***

Thermal Hot Water

Technology name	**Thermal Storage - Sensible Heat - Hot Water**
Description	Sensible heat storage is achieved by adding energy to a material (typically water) to increase its temperature without changing its phase. The quantity of stored heat depends on the quantity of storage material, the heat capacity of storage material and the temperature change. The storage material can be housed in steel tanks or an artificial pit structure.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	10.00	kW	10.00	MW
Charge power	10.00	kW	10.00	MW
Energy storage capacity	5.00	kWh	900.00	MWh
Energy density	10.00	kWh/m3	90.00	kWh/m3
Response time discharge	5.00	min	10.00	min
Response time charge	5.00	min	10.00	min
Costs power	750.00	€/kW	250.00	€/kW
Costs energy	0.50	€/kWh	3.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	2.00	hours	3.00	day
Ramp up speed	1.00	kW/min	2.00	MW/min
Ramp down speed	1.00	kW/min	2.00	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	#N/A	%/day	#N/A	%/day
Roundtrip efficiency	50.00	%	90.00	%
Lifetime	20.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	A simple, low-cost, mature, reliable technology. Can be used to significantly offset peak energy demands. In France, peak heating demands have been reduced by 5% (5 GW) due to hot water storage implementation in households.

Sources used for this label	**International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Interntional Renewable Energy Agency (2013). Therma Energy Storage - Technology Brief.** **Xu, J., Wang, R.Z. & Li, Y. (2014). A review of available technologies for seasonal thermal energy storage. *Solar Energy 103,* 610-638.**

Underground Thermal Storage

Technology name	Thermal Storage - Sensible Heat - Underground Storage
Description	Sensible heat storage is achieved by adding energy to an underground storage media (such as water or rock) to increase its temperature without changing its phase. Heat can be stored in underground aquifers, boreholes or caverns by pumping heat in and out via an energy carrier.

Key characteristics	Lower Range	Unit	Upper Range	Unit
Discharge power	10.00	kW	10.00	MW
Charge power	10.00	kW	10.00	MW
Energy storage capacity	5.00	kWh	900.00	MWh
Energy density	10.00	kWh/m3	90.00	kWh/m3
Response time discharge	5.00	min	10.00	min
Response time charge	5.00	min	10.00	min
Costs power	2,500.00	€/kW	3,300.00	€/kW
Costs energy	0.10	€/kWh	10.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	Lower Range	Unit	Upper Range	Unit
Operational time	2.00	hours	3.00	day
Ramp up speed	1.00	kW/min	2.00	MW/min
Ramp down speed	1.00	kW/min	2.00	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	#N/A	%/day	#N/A	%/day
Roundtrip efficiency	50.00	%	90.00	%
Lifetime	20.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	Range low	Unit	Range high	Unit
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	Range low	Unit	Range high	Unit
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	A simple, low-cost, mature, reliable technology. Comparable to Thermal Hot Water Storage, but requires stable ground conditions and appropriate geological conditions, can be more costly, but requires less infrastructure.

Sources used for this label	**International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Interntional Renewable Energy Agency (2013). Therma Energy Storage - Technology Brief.** **Xu, J., Wang, R.Z. & Li, Y. (2014). A review of available technologies for seasonal thermal energy storage. *Solar Energy 103,* 610-638.**

Molten Salts

Technology name	**Thermal Storage - Sensible Heat - Molten Salts**
Description	Molten salts are regraded as an ideal storage material for use in solar power plants because of their excellent thermal stability under high temperatures, low vapour pressure, low viscosity, hgh thermal conductivities, non-flammability and non-toxicity.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	19.90	MW	19.90	MW
Charge power	53.00	MW	53.00	MW
Energy storage capacity	30.00	MWh	30.00	MWh
Energy density	160.00	kWh/m3	465.00	kWh/m3
Response time discharge	5.00	min	10.00	min
Response time charge	5.00	min	10.00	min
Costs power	0.00	€/kW	11,560.00	€/kW
Costs energy	2.70	€/kWh	16.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	15.00	hours	0.63	day
Ramp up speed	1,990.00	kW/min	3.98	MW/min
Ramp down speed	5.30	MW/min	10.60	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	#N/A	%/day	#N/A	%/day
Roundtrip efficiency	40.00	%	93.00	%
Lifetime	#N/A	Years	#N/A	Years
Storage time	Instantaneous (seconds)	Fast (Minutes-Hours)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	Hgh temperatures can cause issues Molten salts are non-flmmable and non-txic

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	This information is based off of the Gemasolar power plant in Spain, which pairs molten salts with a CSP setup to provide power 24 hours per day.

Sources used for this label	International Energy Agency (2014). Technology Roadmap - Energy Storage. ***International Energy Agency.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update.** ***Renewble and Sustainable Energy Reviews*** **, 532-545** **Tian, Y., & Zhao, C. (2013). A review of solar collectors and thermal energy storage in thermal applications. Applied Energy, 538-553.** **SBC Energy Institue (2013). Electricity Storage Factbook.** ***SBC Energy Storage.*** **Interntional Renewable Energy Agency (2013). Therma Energy Storage - Technology Brief.** http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=40 **Xu, J., Wang, R.Z. & Li, Y. (2014). A review of available technologies for seasonal thermal energy storage.** ***Solar Energy 103,*** **610-638.**

Latent Heat (Phase Change Materials)

Technology name	**Thermal Storage - Latent Heat (Phase Change Materials)**
Description	Latent heat storage is based on the heat release or absorption during phase change of a storage material from solid to liquid or liquid to gas or vice versa.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	10.00	kW	1.00	MW
Charge power	10.00	kW	1.00	MW
Energy storage capacity*	-	MWh	-	MWh
Energy density	50.00	kWh/m3	123.00	kWh/m3
Response time discharge	5.00	min	10.00	min
Response time charge	5.00	min	10.00	min
Costs power	4,500.00	€/kW	11,000.00	€/kW
Costs energy	10.00	€/kWh	50.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	2.00	hours	3.00	day
Ramp up speed	1.00	kW/min	0.20	MW/min
Ramp down speed	1.00	kW/min	0.20	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	#N/A	%/day	#N/A	%/day
Roundtrip efficiency	75.00	%	90.00	%
Lifetime	#N/A	Years	#N/A	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	Latent heat storage has a much higher energy density than thermal heat storage. Phase change materials are typically much mor costly than sensible heat storage materials. *Energy storage capacity depends on the size of future storage systems which

	are currently in development.

Sources used for this label	**International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Tian, Y. & Zhao, C.Y. (2013). A review of solar collectors and thermal energy storage in thermal applications. *Applied Energy 104,* 538-553** **Interntional Renewable Energy Agency (2013). Therma Energy Storage - Technology Brief.** **Xu, J., Wang, R.Z. & Li, Y. (2014). A review of available technologies for seasonal thermal energy storage. *Solar Energy 103,* 610-638.**

Hydrogen Electrolysis

Technology name	**Gas Storage - Hydrogen Electrolysis**
Description	Using excess renewable electricity, hydrogen can be generated and stored using electrolysis. Re-electrification can be achieved through use of a fuel cell; Thermal energy can be produced through combustion.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	100.00	kW	50.00	MW
Charge power	100.00	kW	50.00	MW
Energy storage capacity*	120.00	MWh	1,800.00	GWh
Energy density	5,600.00	MJ/m3	1.56	MWh/m3
Response time discharge	10.00	min	10.00	min
Response time charge	10.00	min	0.17	hours
Costs power	370.00	€/kW	550.00	€/kW
Costs energy	370.00	€/kWh	370.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	#N/A	hours	#N/A	hours
Ramp up speed	10.00	kW/min	5.00	MW/min
Ramp down speed	10.00	kW/min	5.00	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.00	%/day	3.00	%/day
Roundtrip efficiency (gas)†	70.00	%	80.00	%
Roundtrip efficiency (electricity)†	40.00	%	45.00	%
Lifetime	15.00	Years	17.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	Clean way of storing huge amounts of energy for long periods of time. Very low efficiency. *Gas grid can accommodate up to 5% hydrogn content, which is equivalent to 1.8 TWh in Germany.

	†Efficiency depends on whether the hydrogen is converted back into electricity or heat.

Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **International Electrotechnical Commission, „Electrical Energy Storage - White Paper," International Electrotechnical Commission, 2011.** **International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projections. *Massachusetts Institue of Technology.*** **Janssen, A., Lambregts, B., van der Sluis, . & Bos, C. (2012). A complemetary role for natural gas in the electric energy transition. *Energy Delta Gas Research.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.***

Synthetic Methane Storage

Technology name	Synthetic Methane Storage - Methanation
Description	Using excess renewable electricity, hydrogen can be generated and stored using electrolysis. Hydrogen can be further converted to methane by combining it with carbon dioxide in a methanation process. Methanation is not, strictly speaking, a storage technology, but rather a means of converting surplus electricity into an easily storabel medium.

Key characteristics	Lower Range	Unit	Upper Range	Unit
Discharge power	100.00	kW	50.00	MW
Charge power	100.00	kW	50.00	MW
Energy storage capacity*	120.00	MWh	220,000.00	MWh
Energy density	9,326.00	MJ/m3	9,326.00	MJ/m3
Response time discharge	10.00	min	10.00	min
Response time charge	10.00	min	10.00	min
Costs power	1,000.00	€/kW	2,000.00	€/kW
Costs energy	370.00	€/kWh	370.00	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	Lower Range	Unit	Upper Range	Unit
Operational time	#N/A	hours	#N/A	hours
Ramp up speed	10.00	kW/min	5.00	MW/min
Ramp down speed	0.01	MW/min	5.00	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.00	%/day	3.00	%/day
Roundtrip efficiency (gas)†	30.00	%	45.00	%
Roundtrip efficiency (electricity)†	49.00	%	64.00	%
Lifetime	15.00	Years	17.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	Range low	Unit	Range high	Unit
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	Range low	Unit	Range high	Unit
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	Clean way of storing huge amounts of energy for long periods of time. Very low efficiency.

	*Methane can be stored with natural gas, including within the gas grid, which is equivalent to 220 TWh in Germany. †Efficiency depends on whether the hydrogen is converted back into electricity or heat.
Sources used for this label	**Ecofys (2014). Energy Storage Opportunities and Challenges - A West Coast Perspective White Paper** **International Electrotechnical Commission, „Electrical Energy Storage - White Paper," International Electrotechnical Commission, 2011.** **International Energy Agency (2014). Technology Roadmap - Energy Storage. *International Energy Agency.*** **Diaz-Gonzalez, F., Sumper, A., Gomis-Bellmunt, O. & Villafafila-Robles, R. (2012). A review of energy storage technologies for wind power applications. *Renewable and Sustainable Energy Reviews 16,* 2154 - 2171** **Mosher, T. (2006). Economic Valuation of Energy Storage Coupled with Photovoltaics: Current Technologies and Future Projections. *Massachusetts Institue of Technology.*** **Janssen, A., Lambregts, B., van der Sluis, . & Bos, C. (2012). A complemetary role for natural gas in the electric energy transition. *Energy Delta Gas Research.*** **Mahlia, T., Saktisahdan, T., Jannifar, A. , Hasan, M. & Matseelar, H. (2014). A review of available methods and developments on energy storage; technology update. *Renewble and Sustainable Energy Reviews* , 532-545** **Oberhofer, A. (2012). Energy Storage Technologies & Their Role in Renewable Integration. *Global Energy Network Institute.***

Gas Storage - Salt Caverns

Technology name	**Gas Storage - Salt Caverns**
Description	Gas storage facilities created in salt layers which have less working volume than depleted gas fields and are mainly used for peak supply.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	1.00	GW	2.25	GW
Charge power	500.00	MW	1.10	MW
Energy storage capacity	324.90	GWh	758.10	GWh
Energy density	-	MWh/m3	-	MWh/m3
Response time discharge	1.00	hours	1.00	hours
Response time charge	1.00	hours	1.00	hours
Costs power	15.00	€/kW	15.00	€/kW
Costs energy	0.03	€/kWh	0.03	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing*
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	10.00	day	20.83	day
Ramp up speed	16.67	MW/min	37.50	MW/min
Ramp down speed	8.33	MW/min	0.02	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/Wh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/Wh
Self-discharge rate	0.00	%/day	0.00	%/day
Roundtrip efficiency	#N/A	%	#N/A	%
Lifetime	15.00	Years	15.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (10 -30 Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability	Very reliable			%

Safety of system	Systems have been in operation for many decades and have proven to be very safe a reliable Micro-fractures can occur if gas is added or removed too quickly

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	Caverns can be filled and emptied much faster than seasonal storage facilities. Caverns can be built in stages with limited incremental cost for each additional stage.

	Requires cushion gas of 20 - 30%. Caverns can only be built in areas with proper geological formations. **All calcuations assume a gas price of 0.25 €/m3** *Seasonal storage can be provided by a sufficiently large number of cavern storage facilities, although this is likely less efficient than using DGF or Aquifers.

Sources used for this label	**Clingendael International Energy Programme. (2006). The European Market for Seasonal Storage. Clingendael International Energy Programme.** **Janssen, A., Lambregts, B., van der Sluis, . & Bos, C. (2012). A complemetary role for natural gas in the electric energy transition. *Energy Delta Gas Research.*** **Federal Energy Regulatory Commission, Current State and Issues Concerning Underground Natural Gas Storage, 2004** **NaturalGas.org, http://naturalgas.org/naturalgas/storage/, Accessed 07/14/2014** **British Geological Survey, 2008. An appraisal of underground gas storage technologies and incidents, for the development of risk assessment methodology,**

Gas Storage - Aquifers & Depleted Gas/Oil Fields

Technology name	**Gas Storage - Aquifers & Depleted Gas/Oil Fields**
Description	Gas storage facilities created in natural aquifers of depleted gas/oil fields for seasonal storage. Additionally, aquifer storage can serve as a strategic stock or to support low production levels of natural gas.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	7.50	GW	14.00	GW
Charge power	4.50	GW	6.00	GW
Energy storage capacity	21.66	TWh	44.40	TWh
Energy density	-	MWh/m3	-	MWh/m3
Response time discharge	3.00	hours	1.00	day
Response time charge	3.00	hours	1.00	day
Costs power	23.00	€/kW	32.00	€/kW
Costs energy	0.01	€/kWh	0.02	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	80.00	day	150.00	day
Ramp up speed	5.21	MW/min	77.78	MW/min
Ramp down speed	3.13	MW/min	33.33	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.00	%/day	0.00	%/day
Roundtrip efficiency	#N/A	%	#N/A	%
Lifetime	20.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	Requires cushion gas of 50 - 80%. Gas has a maximum extraction rate to prevent damage to the storage structure **All calcuations assume a gas price of 0.25 €/m3**

Sources used for this label	**Clingendael International Energy Programme. (2006). The European Market for Seasonal Storage. Clingendael International Energy Programme.** **Federal Energy Regulatory Commission, Current State and Issues Concerning Underground Natural Gas Storage, 2004** **NaturalGas.org, http://naturalgas.org/naturalgas/storage/, Accessed 07/14/2014** **Janssen, A., Lambregts, B., van der Sluis, . & Bos, C. (2012). A complemetary role for natural gas in the electric energy transition. *Energy Delta Gas Research.*** **Komduur, R. (2012). Dutch go from Swing Production to Storage. *European Energy Review.*** **British Geological Survey, 2008. An appraisal of underground gas storage technologies and incidents, for the development of risk assessment methodology,**

Gas Storage - Liquified Natural Gas

Technology name	**Gas Storage - Liquified Natural Gas (LNG)**
Description	LNG storage involves storing natural gas under high pressure to change its phase to liquid. LNG storage is used when high deliverability is required with a small working volume. Liquid gas storage is relatively expensive and is typically used to cover rare, winter peaks. LNG has a relatively high energy density and can be more easily transported than non-liquefied natural gas, assuming no pipelines are available.

Key characteristics	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Discharge power	2.25	GW	5.60	GW
Charge power	125.00	MW	250.00	MW
Energy storage capacity	541.50	GWh	541.50	GWh
Energy density	-	MWh/m3	-	MWh/m3
Response time discharge	5.00	min	20.00	min
Response time charge	5.00	min	0.33	hours
Costs power	9.00	€/kW	9.00	€/kW
Costs energy	0.09	€/kWh	0.09	€/kWh

Energy carrier type	Electricity	Gas	Heat	Liquid fuel

Suitable applications	Frequency control	Hourly Balancing	Daily Balancing	Seasonal balancing
Transmission & Distribution Congestion Relief	Black Start	Off-grid / Micro grid	Waste Heat Utilization	Off- to On-Peak shifting & firming
Demand Shifting and Peak Reduction	Arbitrage	Reactive Power	Uninterruptible Power Supply	Transportation

Sector for use	Utilities	Transmission & distribution	Demand	Renewable integration

Expert properties	**Lower Range**	**Unit**	**Upper Range**	**Unit**
Operational time	12.00	hours	100.00	hours
Ramp up speed	112.50	MW/min	1,120.00	MW/min
Ramp down speed	6.25	MW/min	50.00	MW/min
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Cost projection (2020)	#N/A	€/Wh	#N/A	€/kWh
Self-discharge rate	0.00	%/day	0.00	%/day
Roundtrip efficiency	#N/A	%	#N/A	%
Lifetime	20.00	Years	20.00	Years
Storage time	Instantaneous (seconds)	Fast (Minutes)	Medium (Days)	Long (months)

Maturity of technology	Research	Demonstration	Deployed	Commercial

Reliability	**Range low**	**Unit**	**Range high**	**Unit**
Downtime		days/year		days/year
Reliability		%		%

Safety of system	

Sustainability	**Range low**	**Unit**	**Range high**	**Unit**
Recyclabilty		%		%
Environmental impact		kgCO2/kW		kgCO2/GW
Resource Depletion				

Final remarks	**All calcuations assume a gas price of 0.25 €/m3**

Sources used for this label	**Clingendael International Energy Programme. (2006). The European Market for Seasonal Storage. Clingendael International Energy Programme.** **Federal Energy Regulatory Commission, Current State and Issues Concerning Underground Natural Gas Storage, 2004**