Energy Storage Systems Summary

**Terms**

**Energy reserves** are well recorded energy quantities which can be obtained with current technical possibilities in an economical and legal way.

**Energy resources** are potential energy sources which haven’t been exploited yet or might never be exploited.

**Primary energy source** is an energy source which can be found in the natural environment and which hasn’t been subjected to any conversion (e.g. oil, sun, wind, coal, etc.).

**Secondary energy sources or energy carriers** are forms of energy which have been produced from primary energy sources after they have undergone one or more transformations (e.g. electricity, hydrogen, etc.).

**Global Energy supply**

**Oil:** The world’s oil reserves were given as 1,354 billion barrels in late 2009. The reserves have never been higher: they have more than doubled since 1980 and have risen by a third in the last decade. Half of the increase since 2000 is due to the opening up of Canadian oil sands. Such unconventional oil reserves (and also unconventional gas reserves) are often found in ecologically sensitive areas, and partly under problematic conditions.

**Gas:** Compared to the oil reserves, the gas reserves can be judged as productive. The definitely confirmed reserves have increased steadily in recent years. At the end of 2008 they were estimated at 184 trillion cubic meters, which is about double the assessment of 20 years ago. With today’s production rates, this results in a static lifetime of 58 years.

**Coal:** The coal resources are estimated at around 82% of all non-renewable energy resources. The reserves are about 1,000 billion tons, enough to cover the current demand for another 150 years. In contrast to conventional oil and gas, coal reserves are geographically diversified: the largest deposits are located in the United States, China, Russia, India and Australia.

**Uranium:** The uranium reserves are now estimated at around 5.5 Mio tons. With an annual consumption of around 66,000 tons these reserves are sufficient to cover the current demand for approximately 83 years.

**Renewable Energy:** Like many other studies, the WEC (World Energy Council) comes to the conclusion that the technical potential of renewable energy exceeds the world needs many times. There is no question of the potential, but the opening up of it is crucial. The IEA (International Energy Agency) assumes that independent of which scenarios are considered, renewable energies will see a strong increase by 2035.

**Swiss Energy Strategy 2050**

**Going on as up to now:** Autonomous trends of the past will be observed and updated according to the current market conditions. Further on, they will be reinforced by the energy policy instruments, which are either already in force at the present time, or planned.

**Policy measures:** The adopted measures drawn up by the Federal Council on 18 April 2012 will have been analyzed, giving special consideration to their legislative basis (e.g. provisions for building standards, CO2 emission limits for new vehicles).

**New energy policy:** The targeted policy variant, ”New energy policy”, examines how to achieve the target of reducing energy-related CO2 emissions in Switzerland to around 1.5 tonnes per head by 2050.

*On 25 May 2011 the Federal Council decided to abandon new nuclear power plants (no new constructions, continuous operation of existing power plants, as long as the reliability is ensured) and confirmed the turnaround in energy policy. The contents of this turning point are:*

1. Reduction of the consumption of energy and electricity,
2. increasing the share of renewable energies,
3. ensuring access to international energy markets,
4. strengthening international cooperation,
5. strengthening of energy research,
6. leading role of the public sector in transforming the energy supply and
7. expansion and conversion of electricity grids and energy storage.

***By 2050, Switzerland seeks to be a 2000-watt and a 1-1.5 ton CO2 society*** *(in comparison, today each and every Swiss consumes 6400 watts of power and produces around 6 tonnes of CO2 per year). Thus, energy storage will play an important role in the framework of the Energy Strategy 2050. Since electricity (or energy) production from supply-dependent energy sources not necessarily coincide with the consumption, there is an increased need for intermediate storage of electricity (or energy).*

**Ancillary Services** are the services necessary to ensure reliable supply of electricity from the provider to the consumer while maintaining the integrity of the transmission and distribution grid. Such services include voltage control, frequency regulation, reserve power etc.

**Arbitrage** is the business model that takes advantage of the electricity price spread by storing energy when prices are low and selling it back when the prices are high.

**Black** **Start** refers to the ability of an energy supply system to start operating without the need to draw energy from the grid in order to sup- ply the emergency power required to restore the grid operation after a failure.

**Day-ahead** **Market** is the auction-based electricity trading market, handling time slots for the next day with price calculation of every hour (or quarter hour). Switzerland is part of the Epexspot exchange market.

**Energy applications** are the storage technologies designed to provide a relatively moderate output power for longer periods of time (e.g. for peak shaving purposes).

**Energy density** is the amount of energy stored in a system per volume or mass (given in Wh/m3 and Wh/t respectively)

**Frequency of discharge** refers to the amount of discharges (and therefore cycles) a storage performs in a specific period of time.

**Frequency regulation** is the act of continuously balancing the energy supply and demand to maintain the grid frequency at normal levels and avoid damaging the grid. The management is done automatically in a minute range or shorter.

**Intraday market** is the electricity trading market where time-slots of the current and next day are traded. The exchange acts as an intermediary between buyers and sellers with continuous trading of orders. Switzerland is

part of the Epexspot exchange market.

**Life-cycle/Lifetime** **costs** are the overall costs of an energy storage system including the capital and operating costs for the expected lifetime of the technology.

**Market deregulation** the act of removing or reducing government control in a market to increase competition.

Power applications are the applications requiring high power output for a relatively short period of time (e.g. flywheel).

**Power curtailment** is the act of reducing electricity generation of a facility below its production capabilities to avoid excess electricity supply which could cause overload in the transmission grid.

**Ramping** is the increasing and decreasing of the energy output of a storage or generation unit in order to match the energy demand. Ramping can have a significant impact on the efficiency of the system.

**Regulated market** is a market where the government exerts a level of control on the supply and demand, for example on the price levels and on who is allowed to enter the market.

**Residual load** is the difference between energy supply and demand in the grid at a given moment.

**Response time** describes the reaction time of a storage to a charging or discharging signal.

**Round-trip efficiency** is the ratio of energy supplied after complete discharging of the storage divided by the total amount of energy provided for its complete charging.

**Self-discharge** is the portion of energy stored which is dissipated through

losses during a specific storage period.

**Smart Grid** is an electricity network which can react to the local changes in demand and supply by utilizing digital communication systems.

**Storage Benefits**

*It is important to distinguish between energy storage applications and storage benefits. A benefit can be a revenue stream, a cost reduction or an avoided cost. A technology implemented in a specific application can provide several benefits.*

**Industrial peak shaving** aims at flattening the power demand (reducing power peaks) of the industrial site and is of particular interest for applications characterized by a strong variation of energy demand throughout the day. The storage unit is typically designed to charge during off-peak hours and supply the power during peak-demand hours (see Ice Storage case study). The revenue streams for a storage in such applications can result from: (1) reducing cost by consuming lower-priced, off-peak electricity (2) reducing investment cost by decreasing equipment size (e.g. heat pump, chiller, cooling tower etc.) and (3) decreasing grid-connection fees which are proportional to the maximum power consumed.

**Seasonal storage** refers to the storage of heat, cold or electricity for periods up to several months. It can be broadly defined as a system that stores energy during one season to deliver it in another season and therefore reducing seasonal fluctuations in supply and demand. A typical example is storing heat during the summer in an underground thermal energy storage (UTES) using solar collectors to release it in the winter when the solar irradiation is lower but the heat demand is higher.

**Waste heat utilization** refers to the storage of waste heat which can’t be utilized at the time of its production and would normally be rejected to the environment. The energy stored can be used at a later point when it is needed. A typical example is storage of process heat for batch industrial processes, where the process heat from one batch can be stored to heat the next batch, drastically increasing the process efficiency.

**Combined heat and power (CHP).** CHP plants produce fixed ratios of electricity and heat which typically don’t match the corresponding energy demands. Thermal and electricity storages can be implemented in such plants to bridge the gap between supply and demand.

**Types of Energy Storages**

**Energy Storage Classification**

**Energy output.** As discussed in the previous chapter, storage systems are often classified according to the form of output energy. We distinguish between (1) electrical storages (storages that supply electricity),(2) thermal storages (storages that supply heat) and (3) fuel.

**Form of stored energy.** Storage systems can also be classified according to the energy form which is used for the storage itself irrespective of their energy input or output.

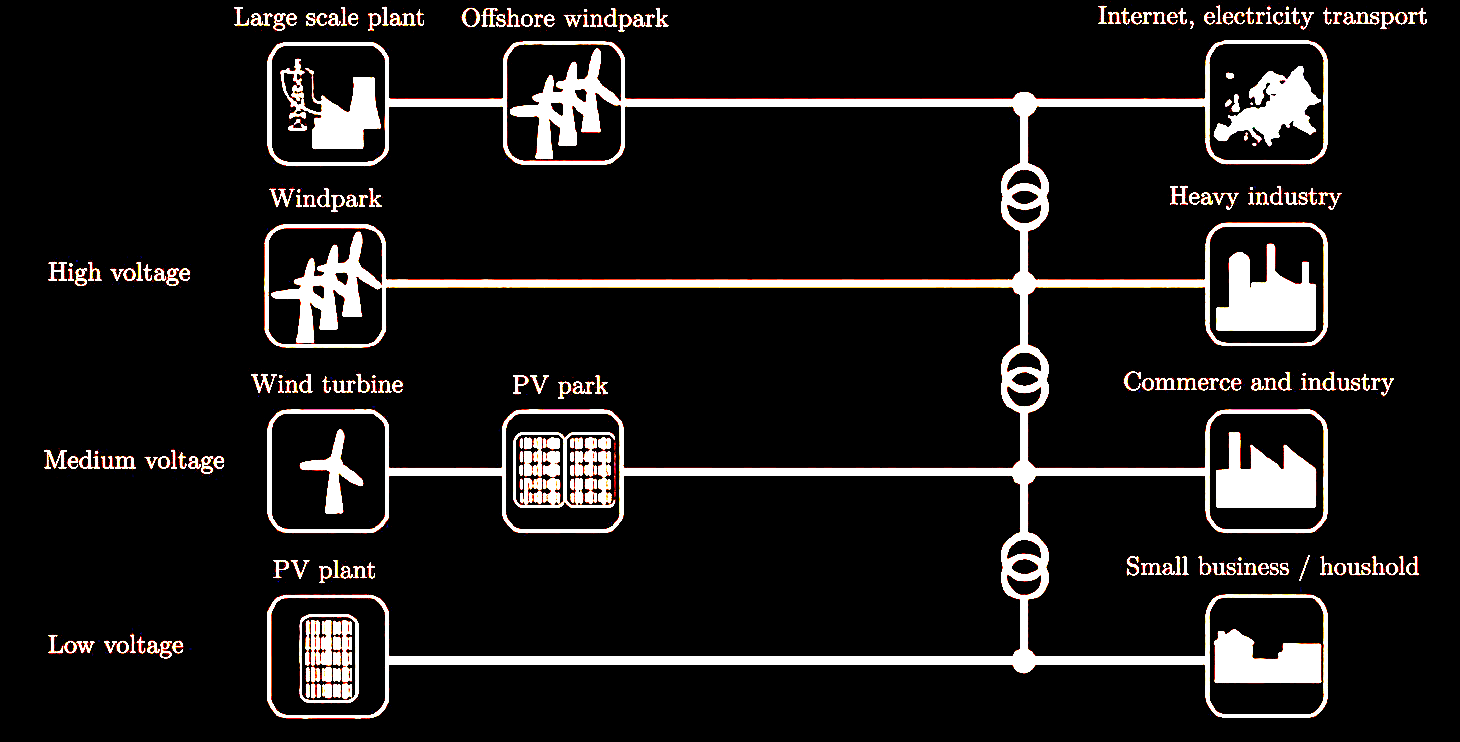
**Location on energy system.** Energy systems can be separated in centralized and decentralized (distributed). Centralized electricity storages are larger-sized systems located in the supply and T&D section of the grid whereas decentralized are the smaller scale electricity storages that are located on the demand side and are connected at the edge of the network. For thermal energy storages the term centralized refers mostly to large storages (hundreds of kW to MW) connected to a heating/cooling network (e.g. district heating and cooling), while the term distributed refers to smaller units that are places on the demand side of the energy system.

**Power output.** According to BFE, energy storage systems can be classified according to their power output in micro-storage, small-scale storage, medium-scale storage and bulk storage.

**Response time.** This classification applies mostly to electricity storage systems where response time is often crucial to the type and quality of services a storage can provide. The response time ranges from milliseconds to days.

**Storage period** refers to the period during which the energy re- mains stored before it is released and is related to the discharge frequency. Short term storages (second-minutes) are mostly applied to grid-stabilization applications whereas longer term (hours-seasonal) for energy shifting applications. Longer term storage systems are required to have very low self-discharge and high energy densities (e.g. thermo- chemical, chemical).

**Level of Energy Storage Applications**



**Energy and Exergy balance**

(for TES the velocity *c* and the height *z* are not important and can be neglected.)

Energy balance:

Exergy balance: