UNIVERSITÀ DEGLI STUDI DI TRIESTE

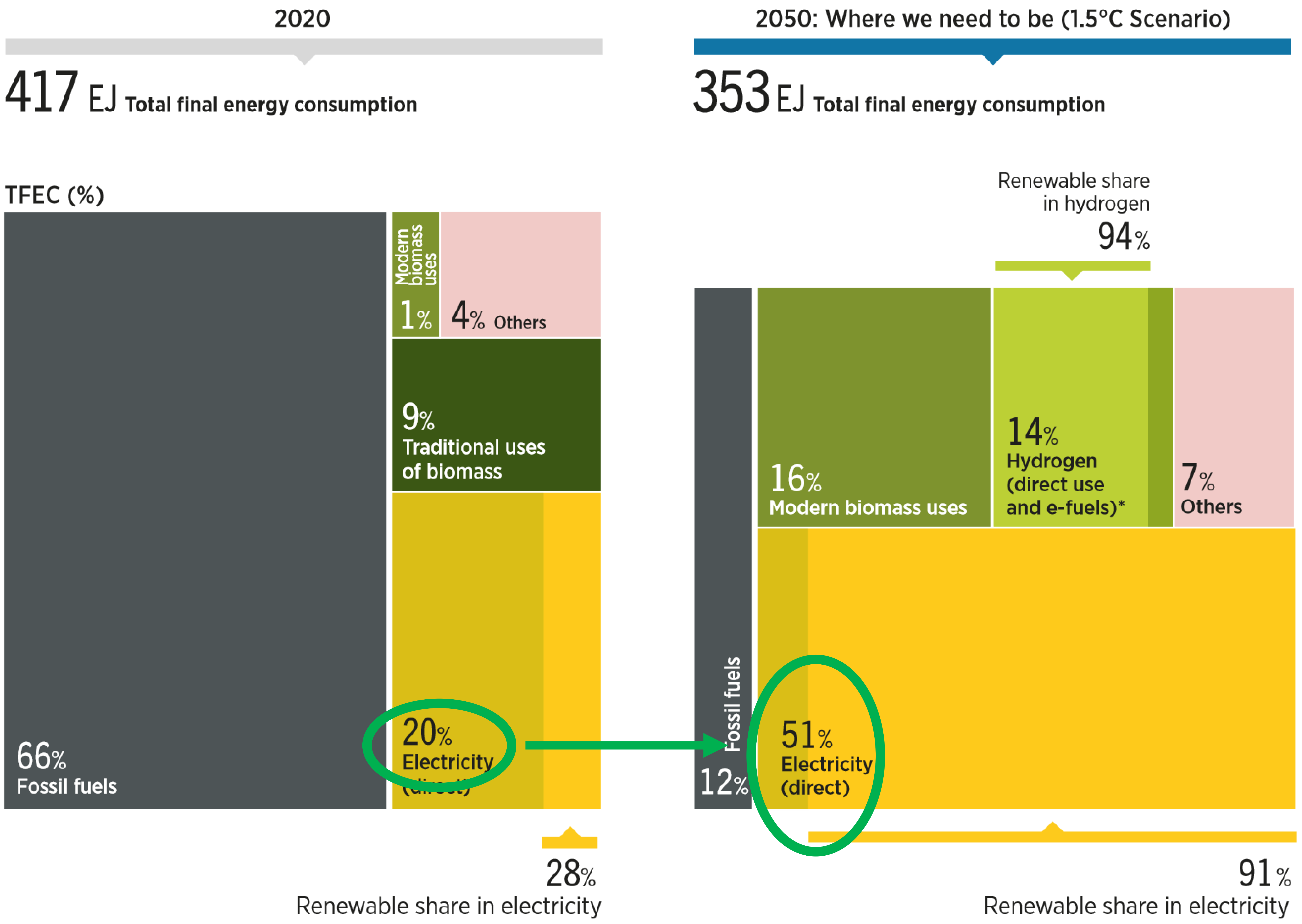
Summer School on Energy Giacomo Ciamician
awarenergy
www.awarenergy.eu

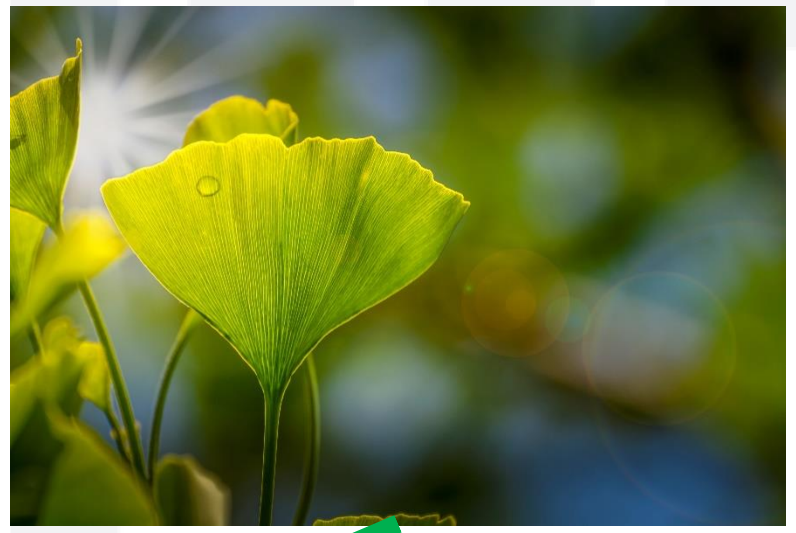
ENERGY STORAGE SYSTEMS
ELETTROTECNICA 2024-2025

Electricity

- Electricity has always been and will always be used as it’s practical and clean when used (no chemical nor acoustic emissions)
- Thanks to transformers and transmission power lines can be easily delivered long distance
- In the last 150 years, AC systems have played a key role
- Today, DC systems contribute more and more to the energy transition and to the hybrid centralized/distributed power generation structure

Renewables and electricity





Electricity

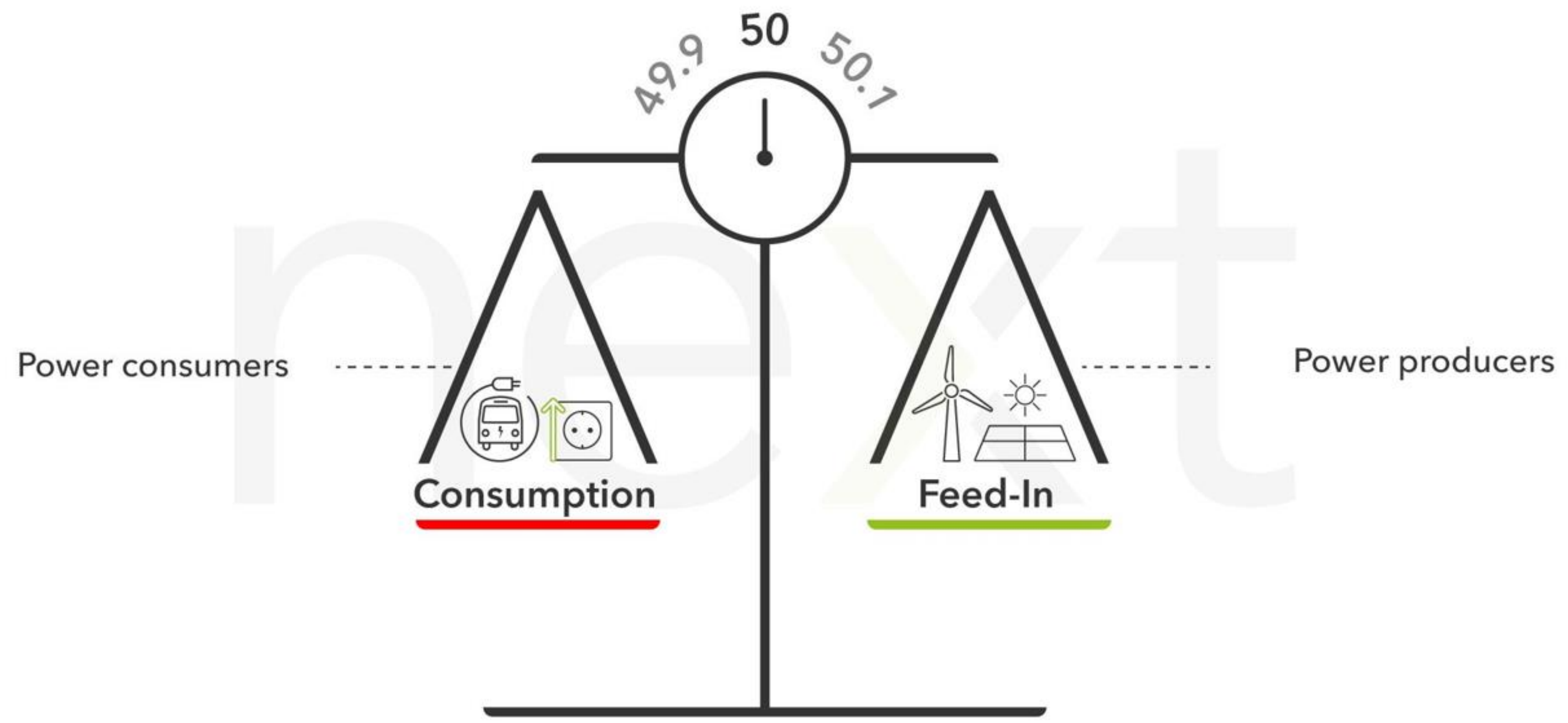
- The weak point of the electricity vector is that electrical currents cannot be stored directly
- It is possible to store **electrostatic energy** (in capacitors) or **magnetic energy** (in superconducting coils) but the storage capacities of these solutions are quite limited
- In order to obtain substantial storage capacities electrical energy must be transformed into another form of energy

Different types of energy

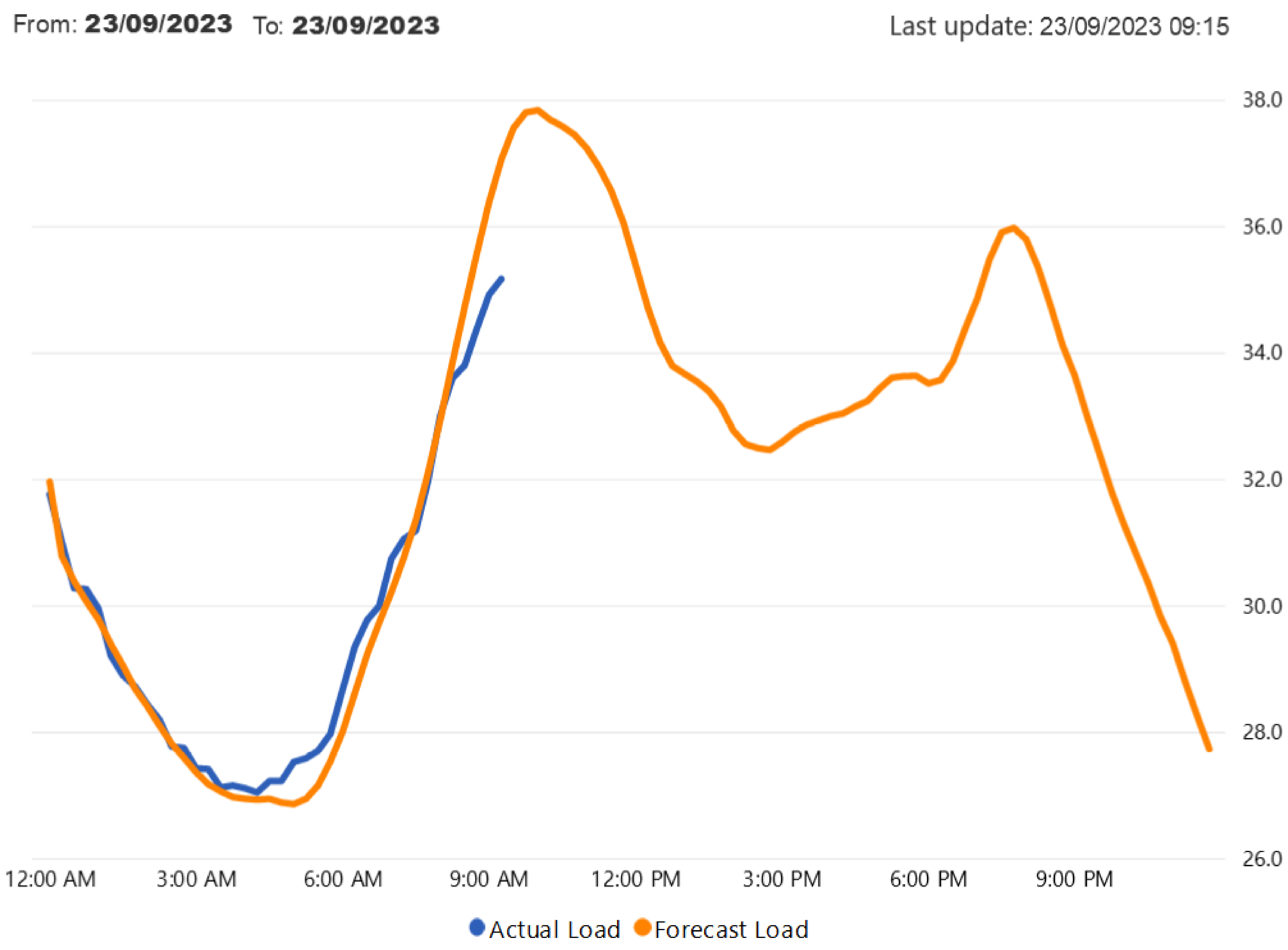
- Storage in the form of **potential energy** by means of turbine (hydro) pumping stations enables large quantities of energy to be stored, but these stations must be located in areas able to provide significant differences in height between two storage tanks
- **Electrochemical storage** using lead acid batteries has long been used for onboard applications and emergency power supplies, and the storage of **kinetic energy** by means of flywheels has also been used

Synchronicity of production and consumption

- The difficulty of storing electrical energy explains why the management of electrical grids has been designed according to the principle of direct consumption even when the distance between production and consumption is several hundreds kilometers (and even thousands)
- As consumption is variable, the power production must continuously adapt



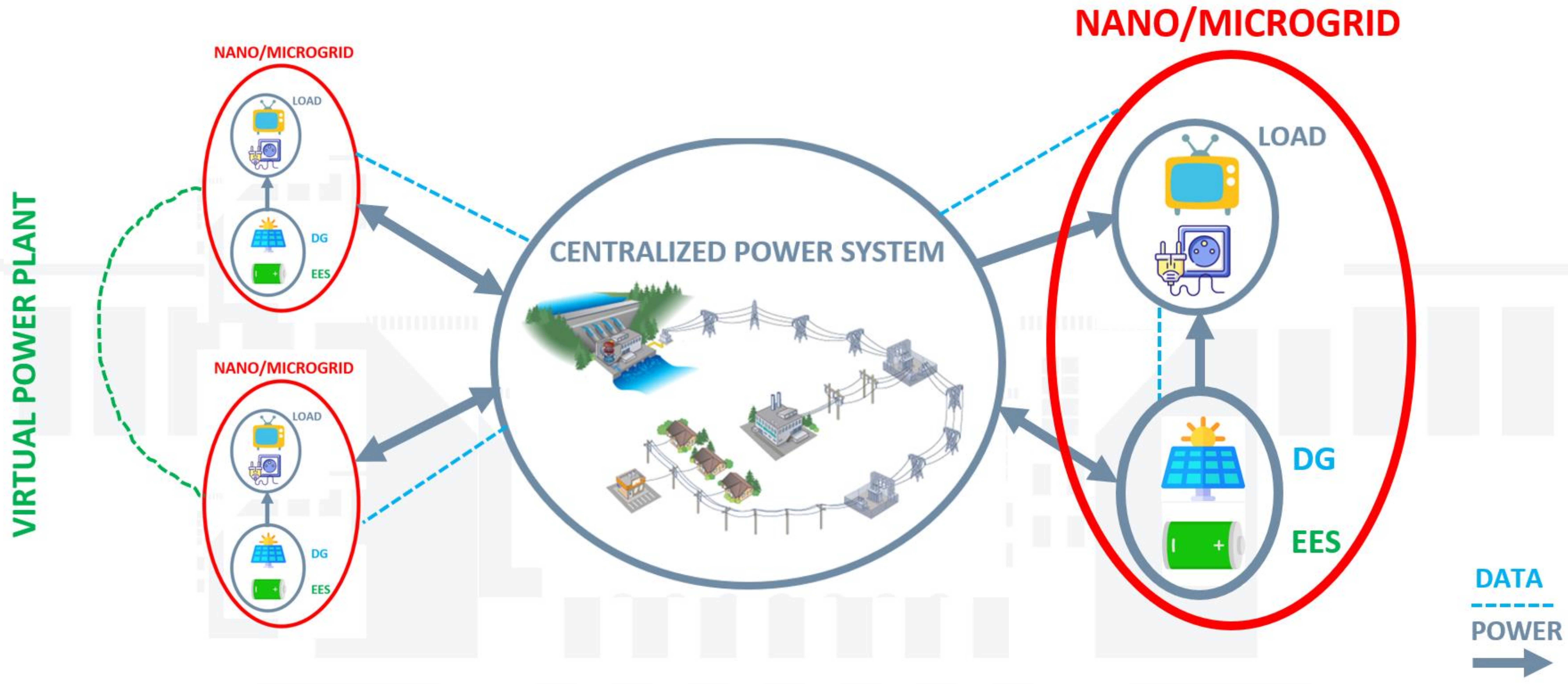
REALTIME ELECTRICITY DEMAND



Evolution of the power sector

Evolution of the power sector

SMART GRID



Evolution of the power sector

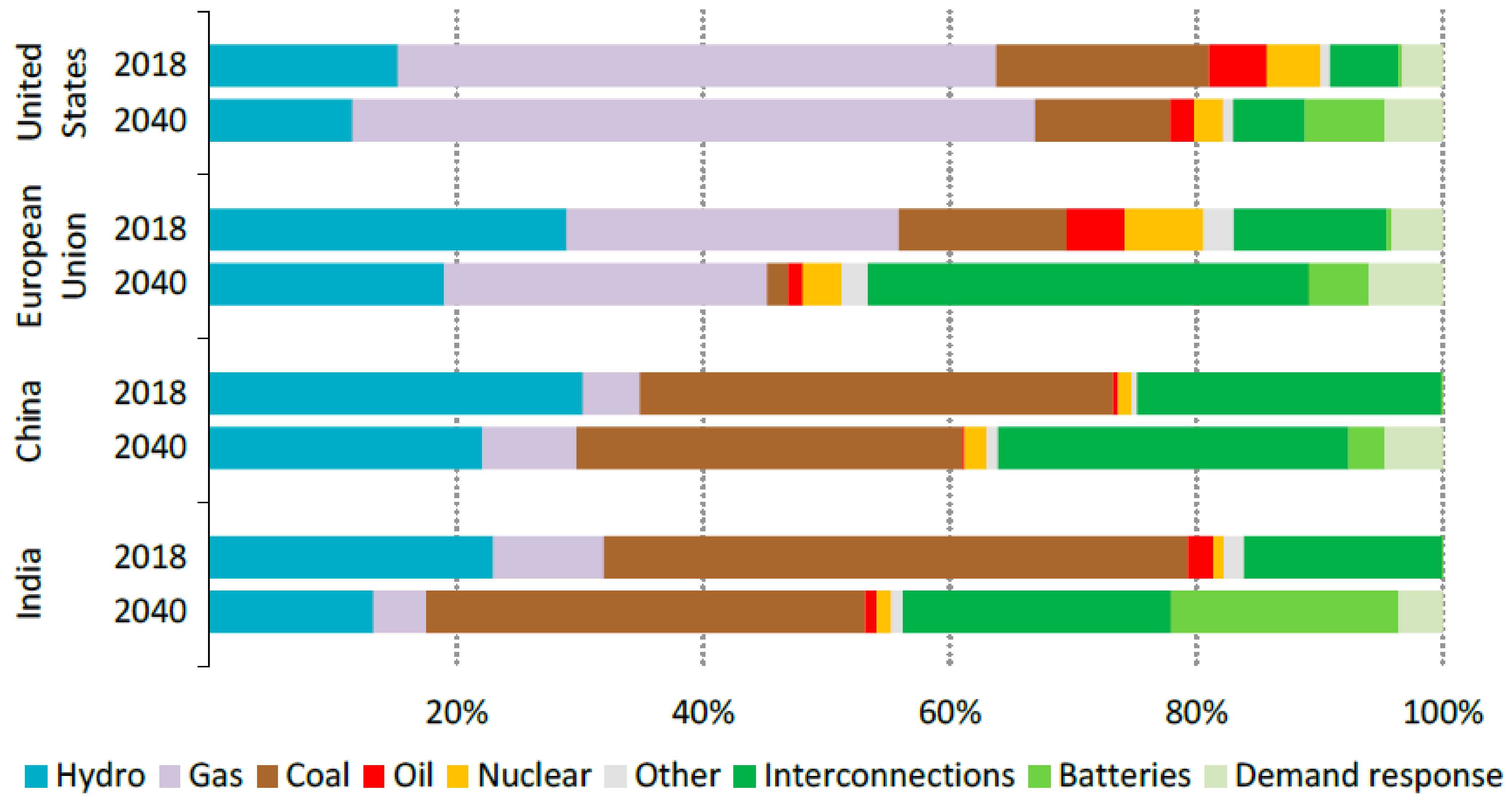
- **Virtual power plant (VPP)**: Different Distributed Energy Resources (RES) or storage systems (or other) at different locations and size can be integrated to a Virtual Power Plant (VPP). The VPP can be deployed as a unique power plant connected to the grid
- **Smart Grid:** is an electricity network that can intelligently integrate the actions of all users – generators, consumers and those that assumes both roles – in order to efficiently deliver sustainable, economic and secure electricity supplies

Micro/nanogrid

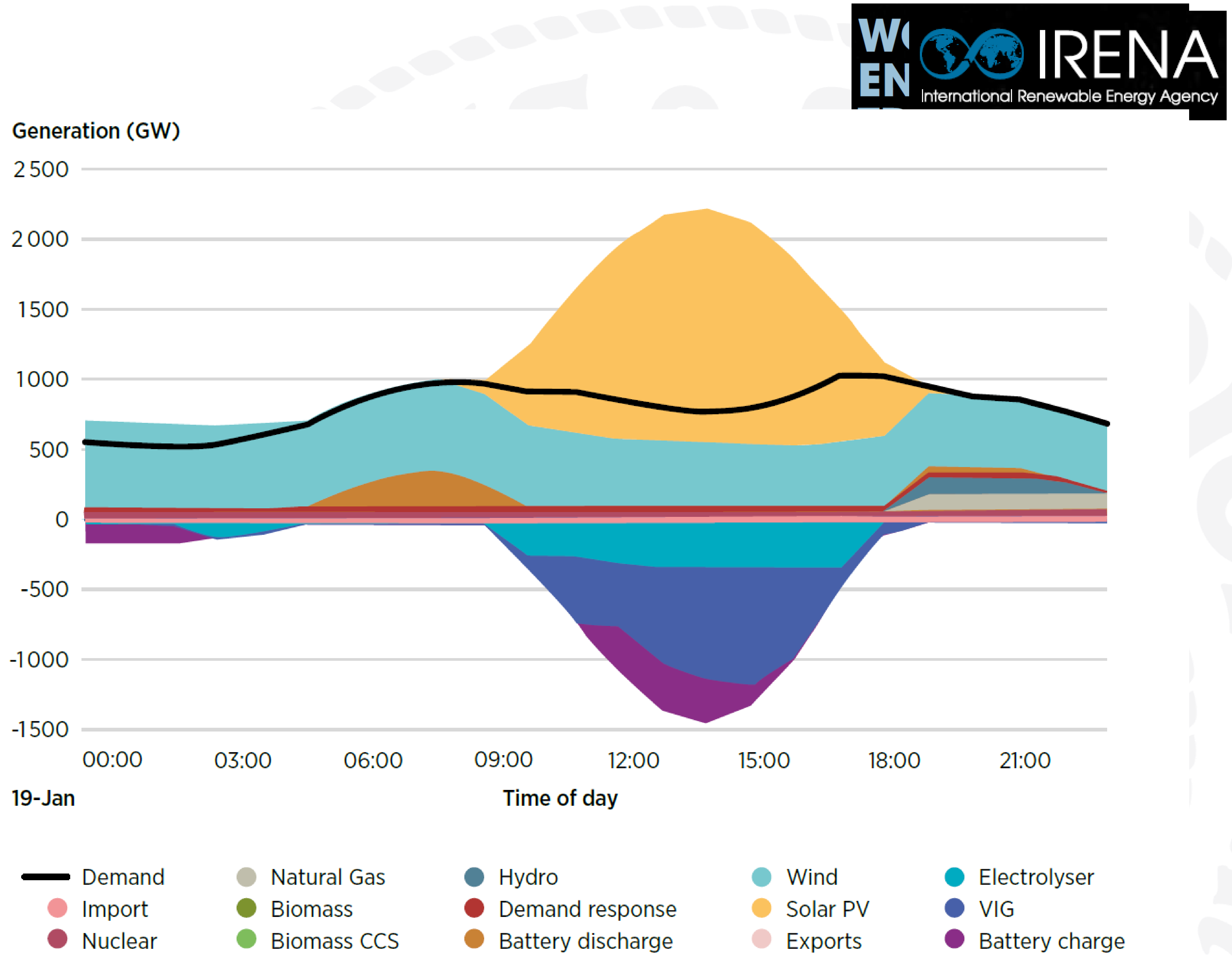
- **Distributed generator (DG)**: renewable energy sources (wind, photovoltaics, hydro, biomass), diesel generator
- **Energy storage system**
- **Electrical load** (controllable)

Enabling technologies

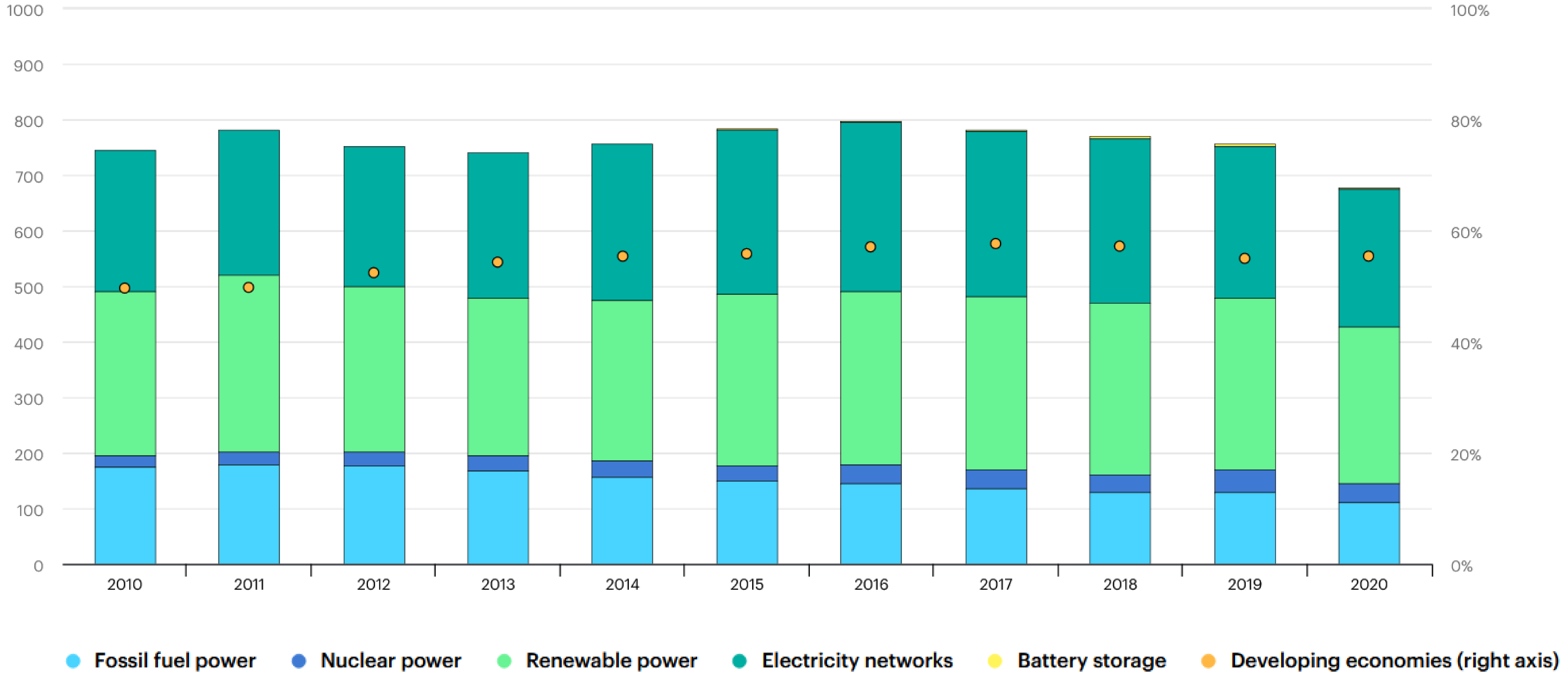
Figure 6.22 ▷ **Sources of flexibility by region in the Stated Policies Scenario**



Thermal power plants continue to provide the bulk of flexibility needs, along with interconnections, but batteries and demand-side response are rising fast



Investments in the power sector



Power applications

- **Grid-connected RES integration**
- **Plug-in e-Vehicles**
- **End-User Bill Management**
- **Peaking Management**
- **Ancillary Services (e.g. frequency regulation)**
- **Spinning Reserve**
- **Uninterruptable Power Systems (UPS)**
- **….**

Power applications

Storage can contribute to shift and or to level the electric energy demand making it somehow **asynchronous** with respect to production

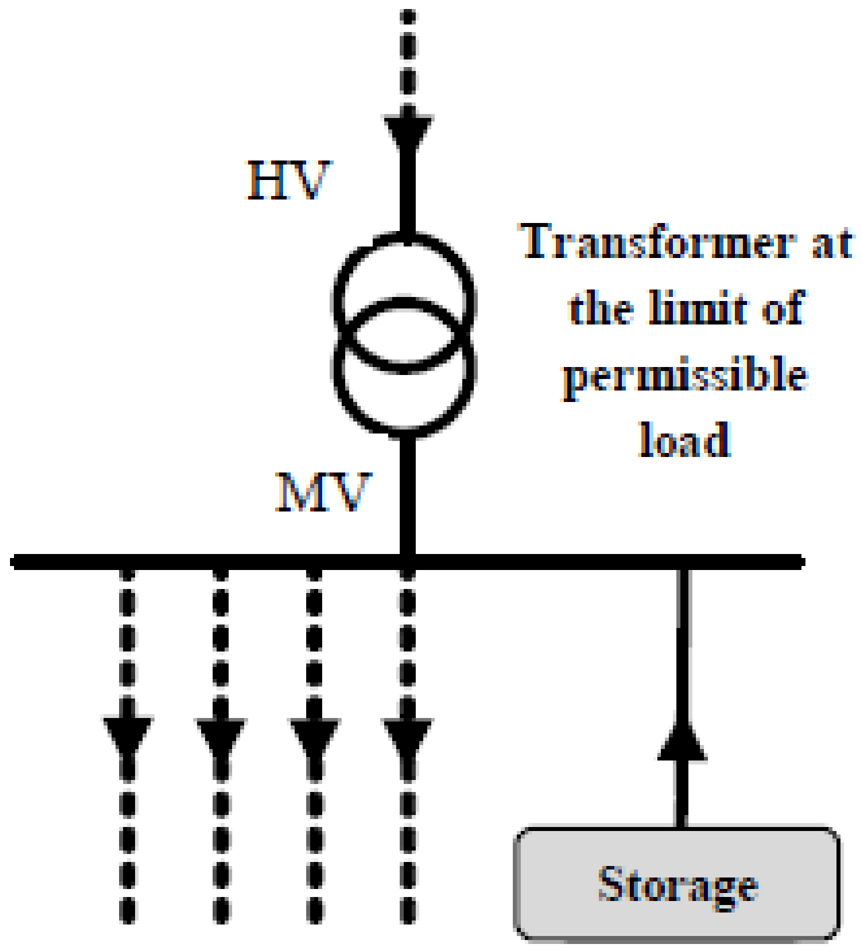
There are two kinds of applications:

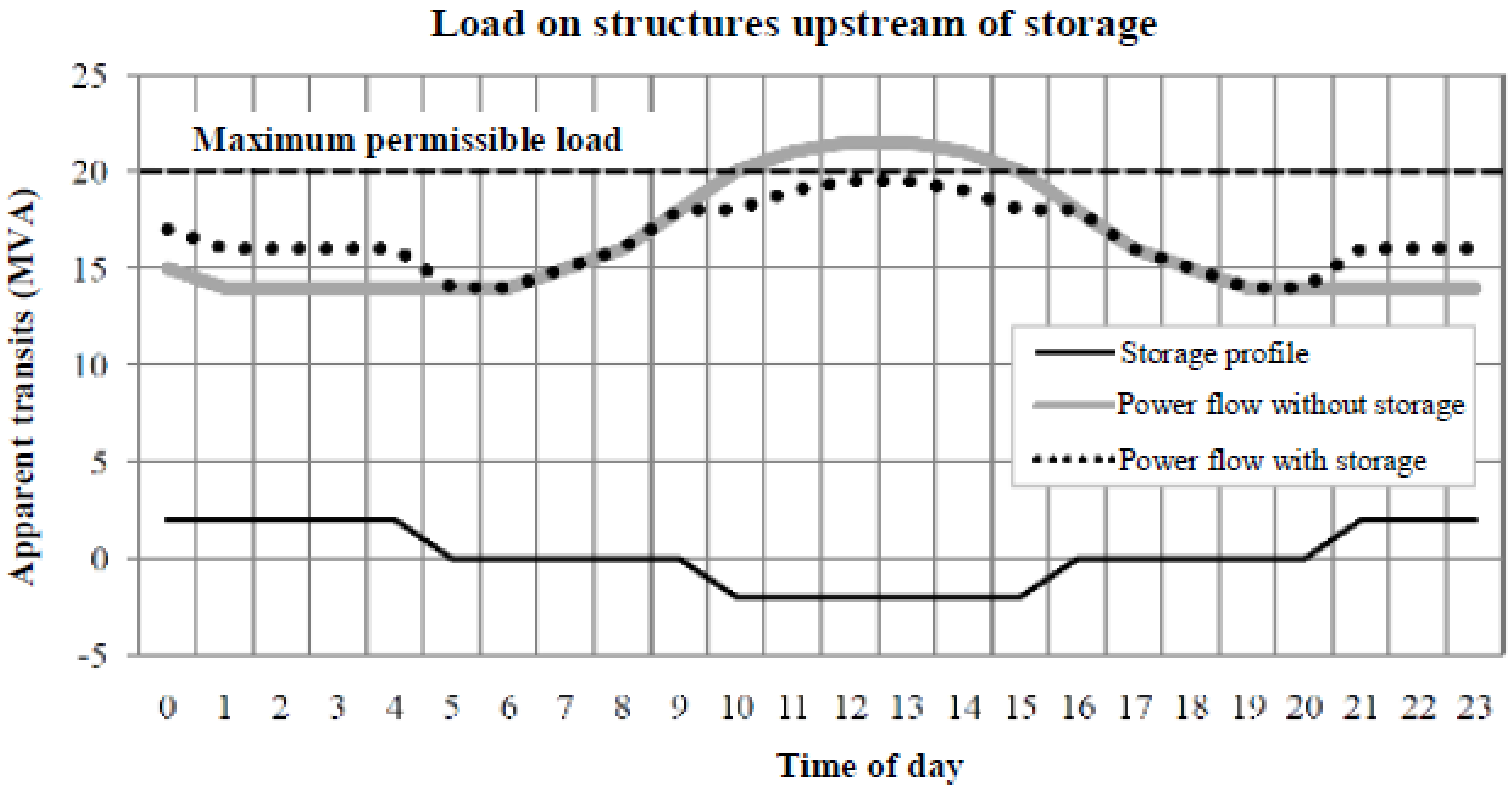
- Power applications: **peak shaving**
- Energy application: **time shift**

Peak shaving

Peak shaving benefits are the reduction of component-system costs.

These are achieved using storage units as a temporary solution to relieve part of the system that have reached their limits





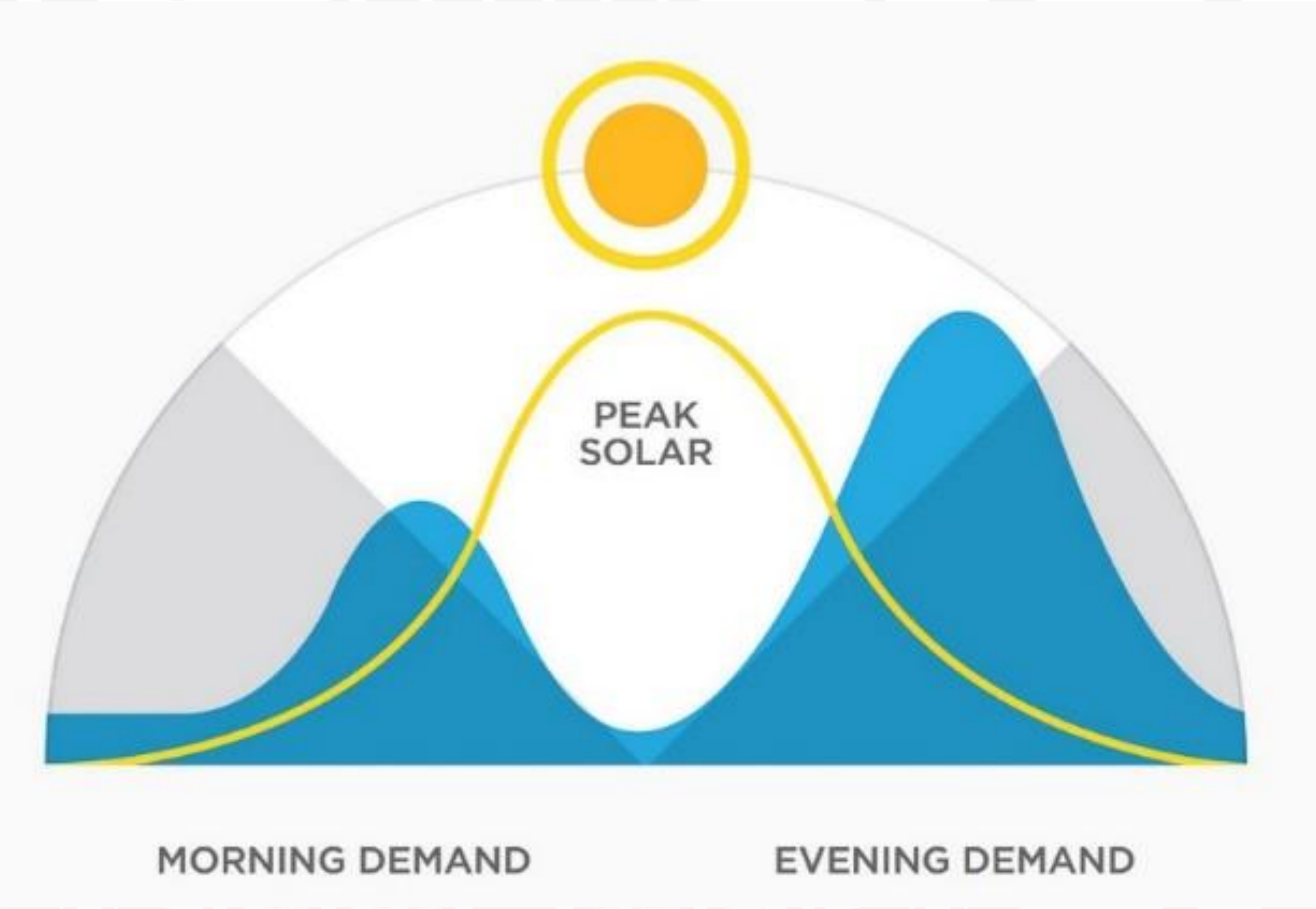
Time shift

Time shift enables (for example) optimal use of renewables in power systems (Utility Scale Systems)

Overgeneration risk may occur when conventional dispatchable resources can not be backed down further to accommodate the supply of variable generation (such as for example wind or PV)

The system operator could decrease the output of wind or PV power

This can be not easy to implement, and it is undesirable as it reduces the economic and environmental benefits of renewable generation



Storage levels

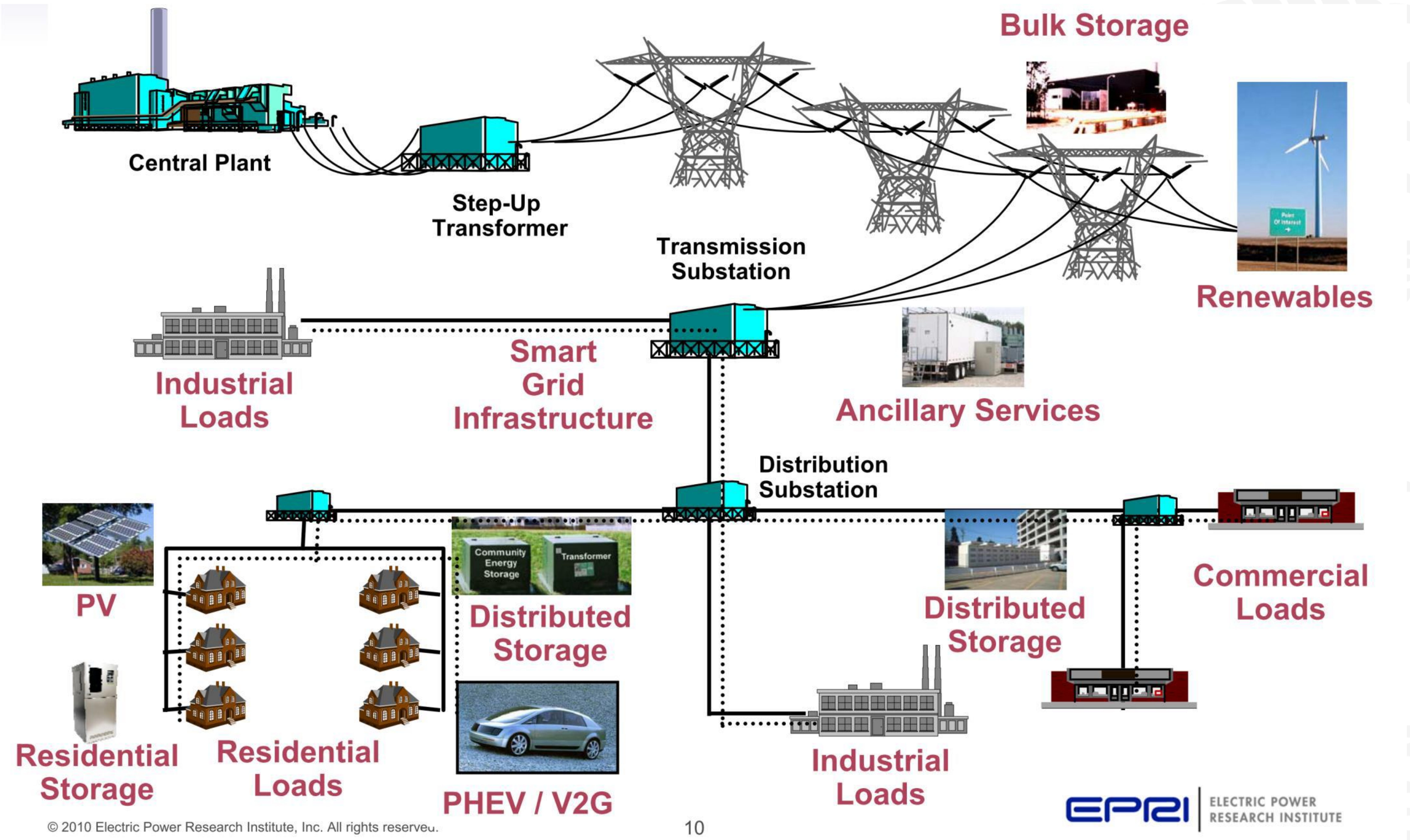
Centralized Storage

- Power Stations
- Transmission Networks (Substations - CP)
- Distribution Networks (Substations CS)

Distributed Storage

- Distributed Generators
- Passive C&I and Residential Customers
- Electrical Vehicles
- …

Storage levels



Storage levels – Lithium battery storage

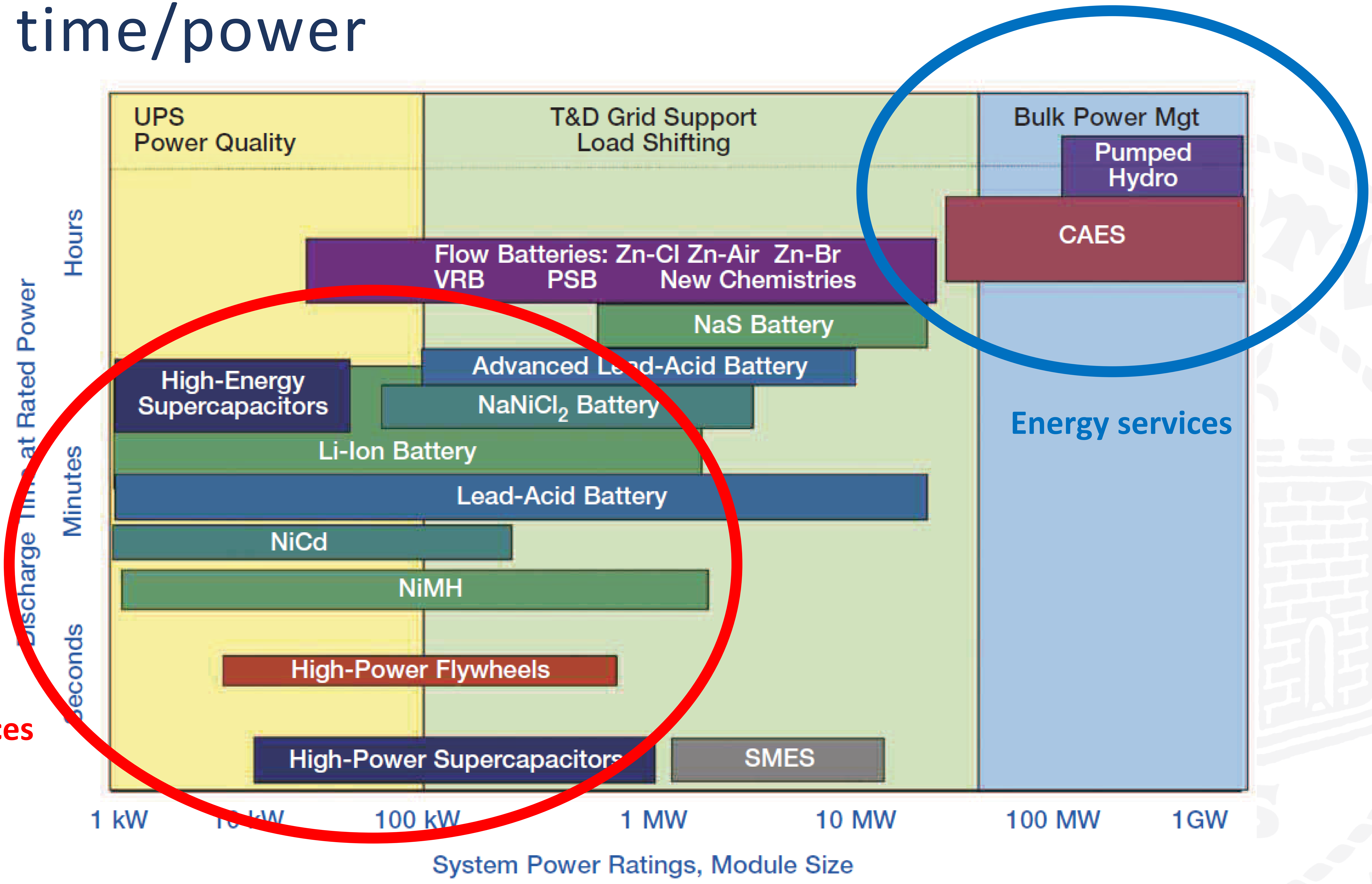
Main technologies

- **MECHANICAL**
  - POTENTIAL → Pumped hydropower, Compressed air
  - KINETIC → Flywheels
- **ELETTRICAL**
  - ELECTROSTATIC → Supercapacitors
  - MAGNETIC → Superconducting coils
- **CHEMICAL**
  - ELECTROCHEMICAL (batteries) → Lead-acid, Zebra, Ni-Cd, Vanadium Redox, Lithium, …
  - POWER TO FUEL (FUEL TO POWER) → Electrolyzers, Fuel cells
- **THERMAL** → Hot water, thermal oil, concrete, sandstone, molten salts

Basic parameters

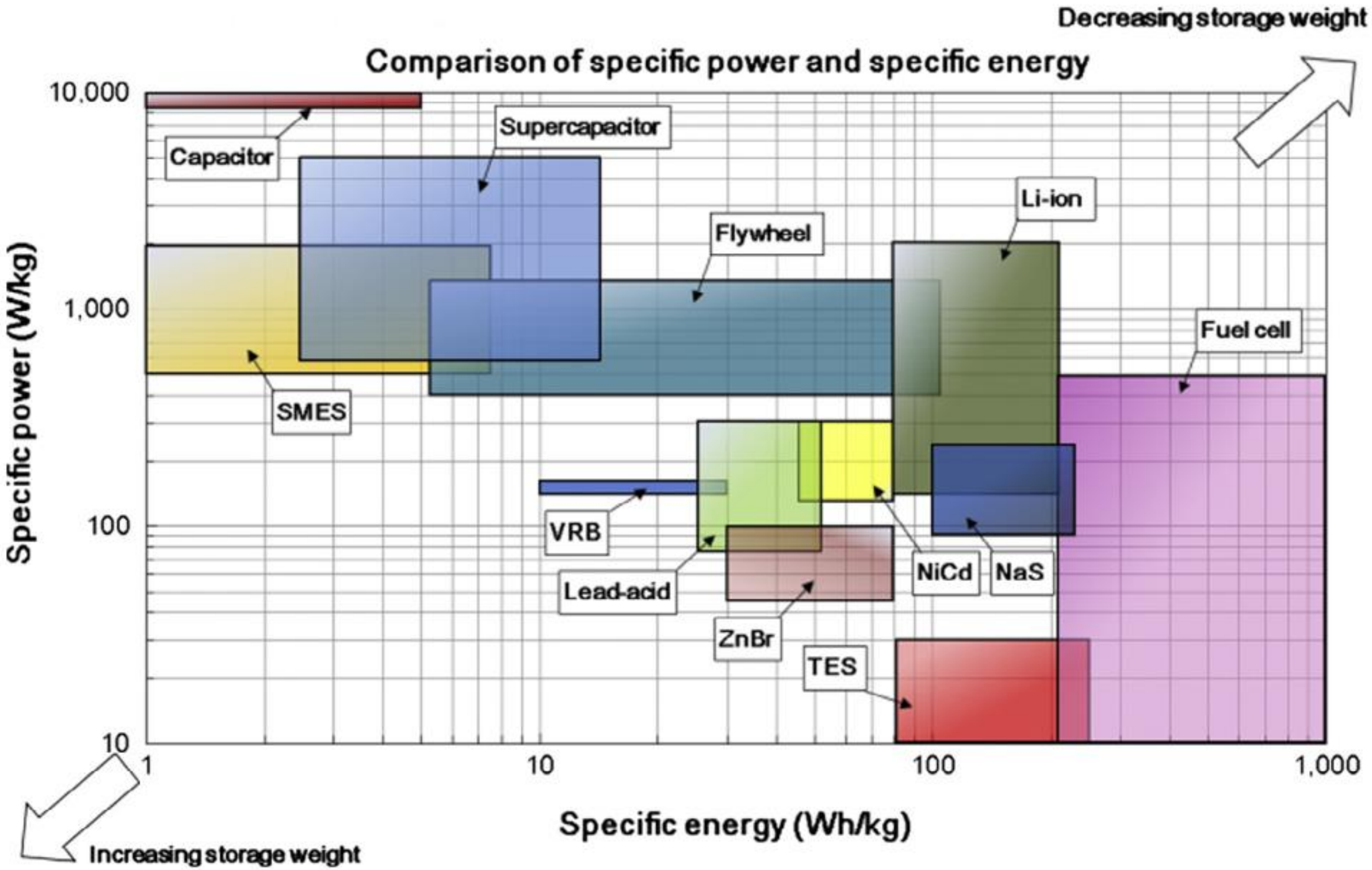
- Specific energy (storage capacity) [Wh/kg]
- Specific power (peak power) [W/kg]
- Capacity [Wh]
- Efficiency [%] (round-trip efficiency)
- Lifespan [ ] (in terms of maximum number of cycles and time)
- Response time [s]
- Maximum depth of discharge [%] – Operating range [V]
- Nominal current at 1-C rate [A]
- Cost [€/kWh] or [€/kW] - O&M Cost [€/year]
- SOC [%] and SOH [%]

Discharge time/power

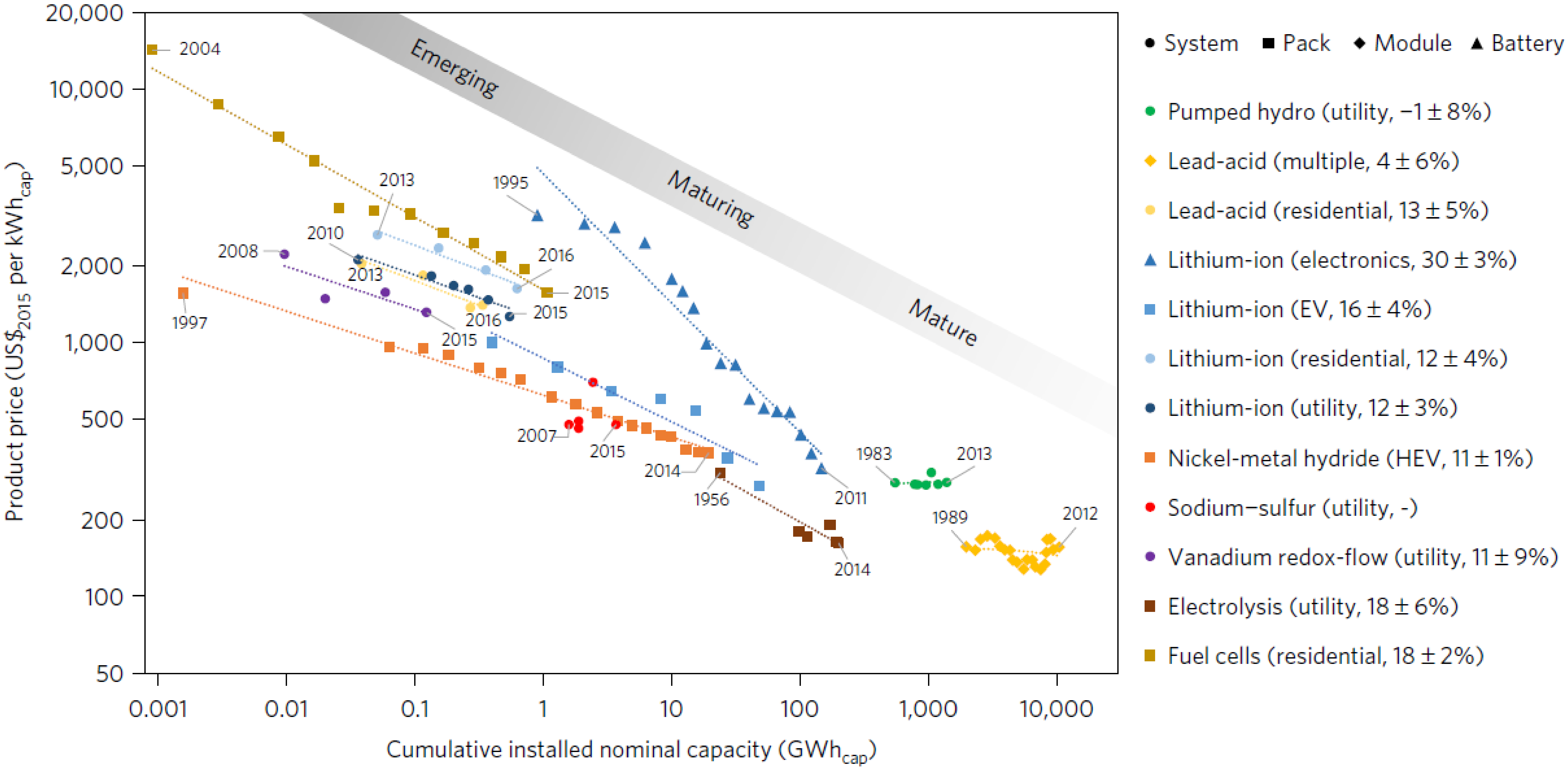


Power services

Discharge time/power

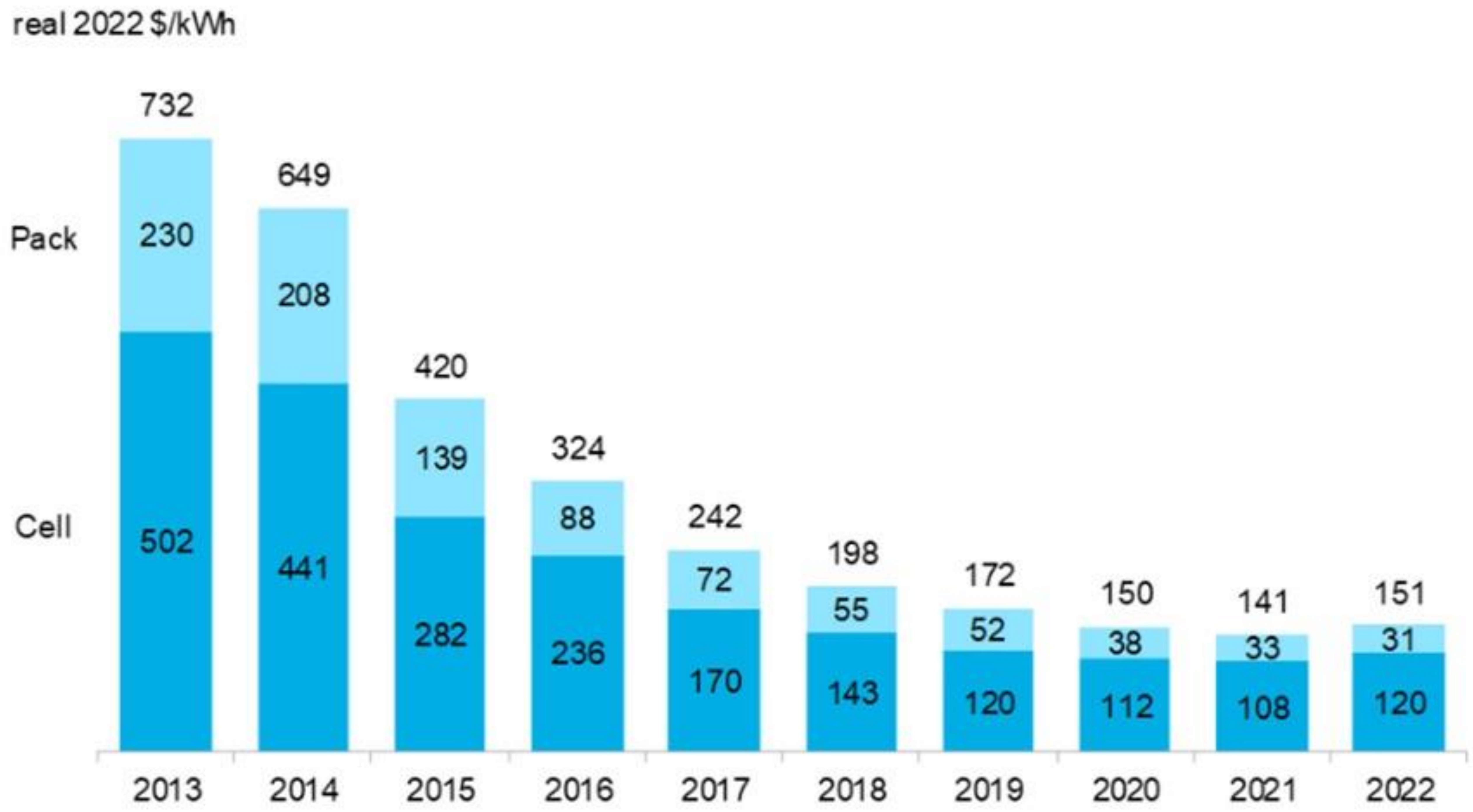


Price and technology readiness level



Levelized Cost Of Storage

Figure 1: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2022



Source: BloombergNEF. All values in real 2022 dollars. Weighted average survey value includes 178 data points from passenger cars, buses, commercial vehicles and stationary storage.

Battery modelling