Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria dell'Energia

Relazione per la prova finale

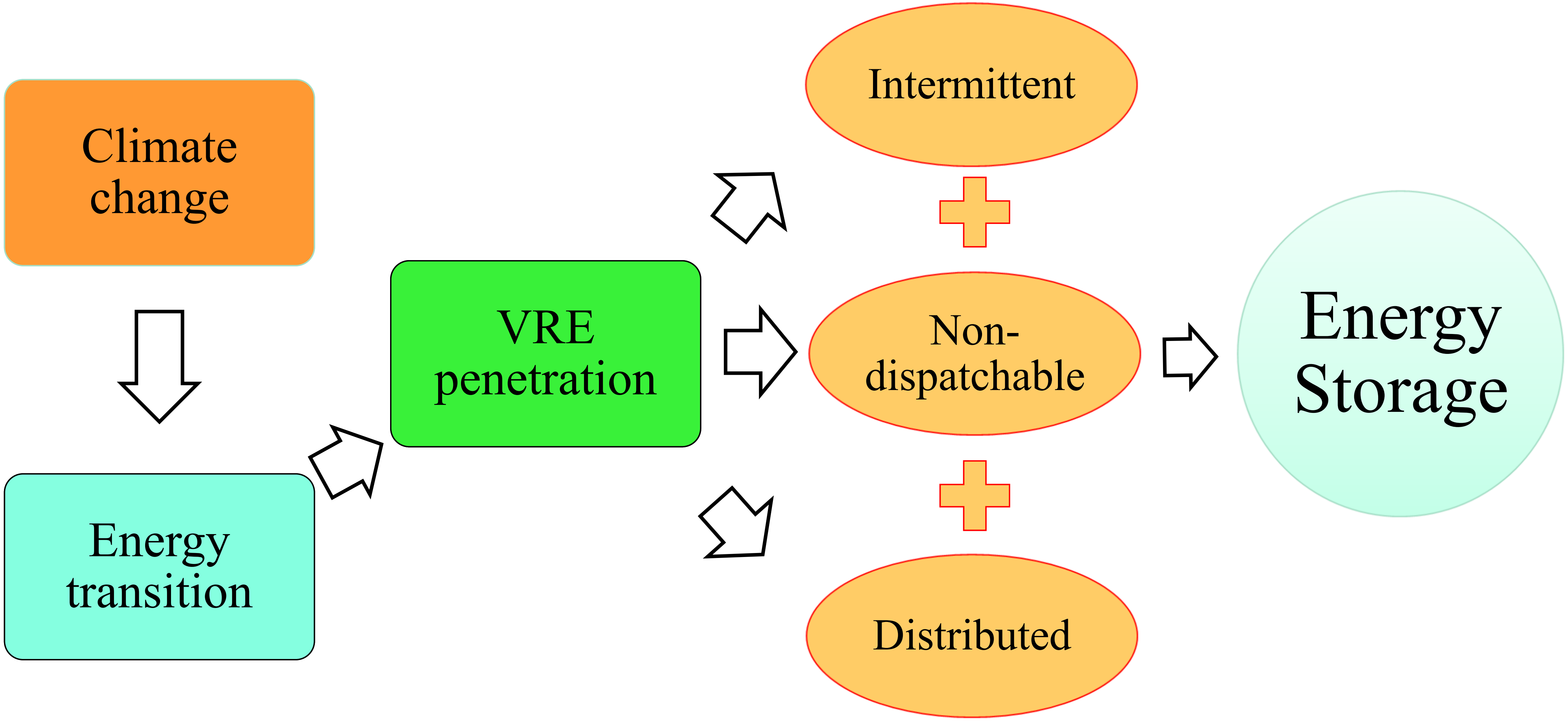
«Energy Storage in the EU: an Overview of Emerging Technologies and Policies Towards Net-Zero Grids»

Tutor universitario:

Prof. Massimo Guarnieri

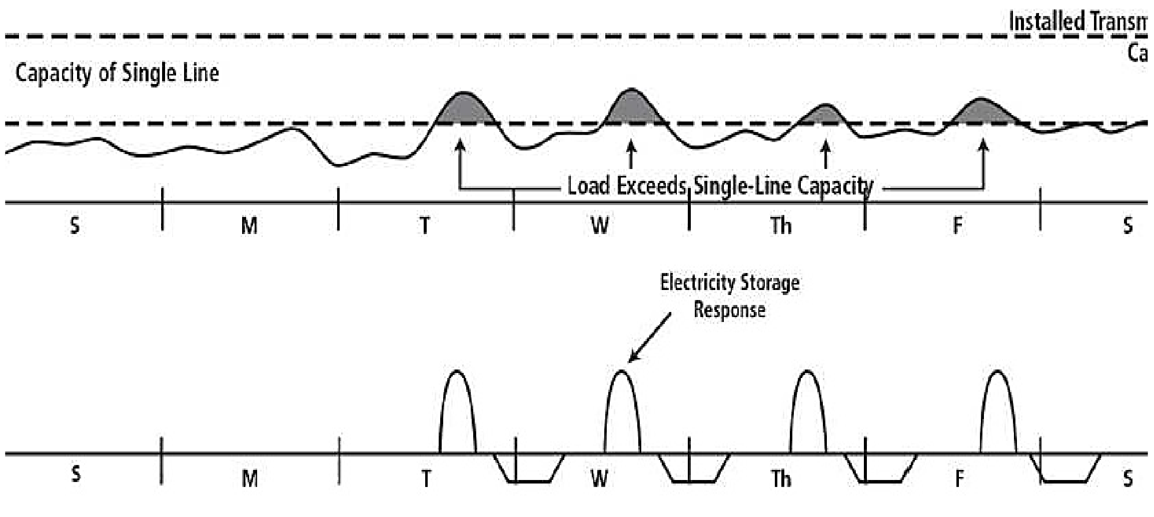
Laureando: *Elia Pederzolli*

Padova, 21/11/2023


Climate change
Energy transition
VRE penetration
Intermittent
Non-dispatchable
Distributed
Energy Storage

ANCILLARY SERVICES

Frequency regulation	• Imbalance in active power causes frequency instability • ESSs can emulate inertia through their power output • Critical requirements: high power rating, fast response time
Voltage support	• Imbalance in reactive power causes voltage to dip • ESSs can inject or absorb reactive power • Greater storage distribution → greater efficiency
UPS	• Uninterruptible Power Supply: emergency back-up generation for power systems that must not be affected by blackouts and outages
Black start	• ESSs can independently re-energize the grid after a blackout

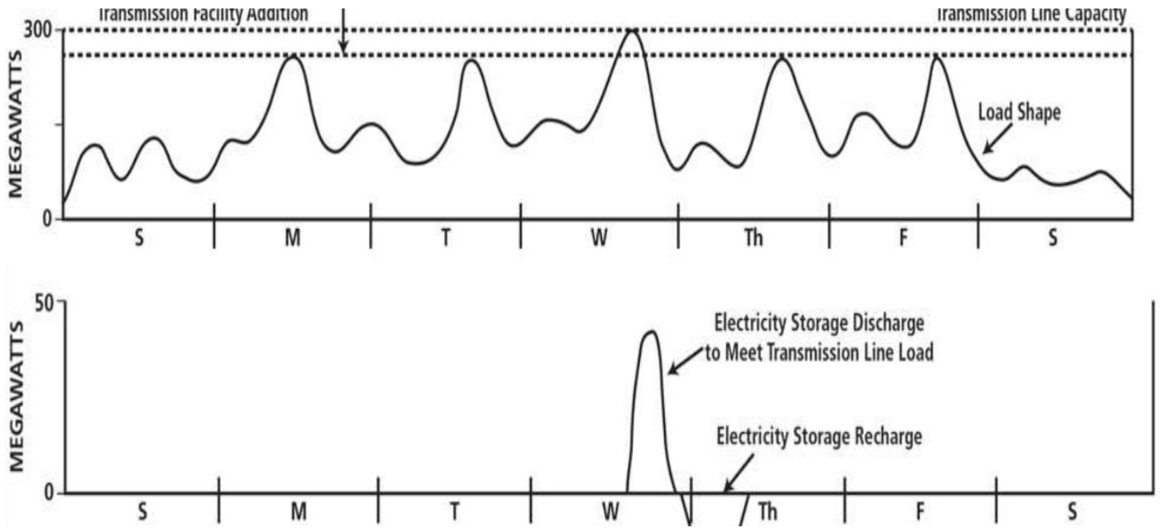


Congestion relief

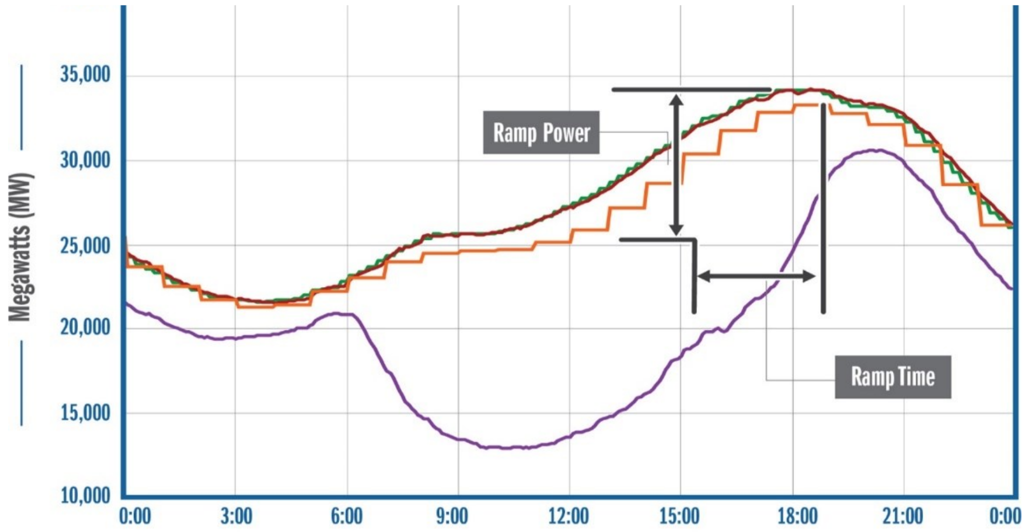
- Increased demand leads to periods in which load on network nodes exceeds capacity
- ESSs can charge off-peak and supply electricity downstream from congested nodes

T&D infrastructure upgrade deferral

- Deferr the need for costly infrastructure upgrades
- Extended life-cycle of grid assets
- Avoid technology lock-in and asset stranding



BULK ENERGY SERVICES

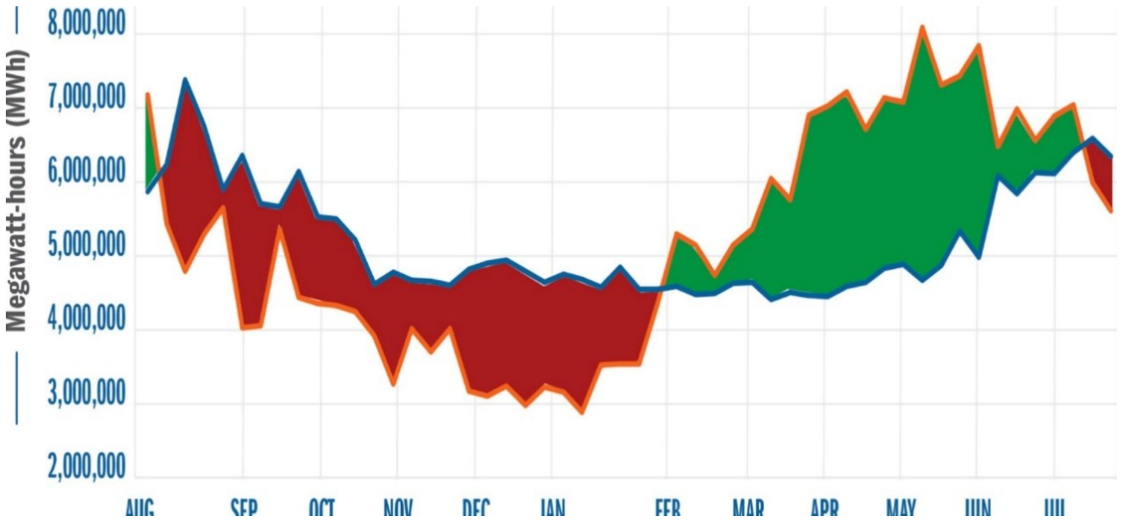


Electricity arbitrage and peak-shaving

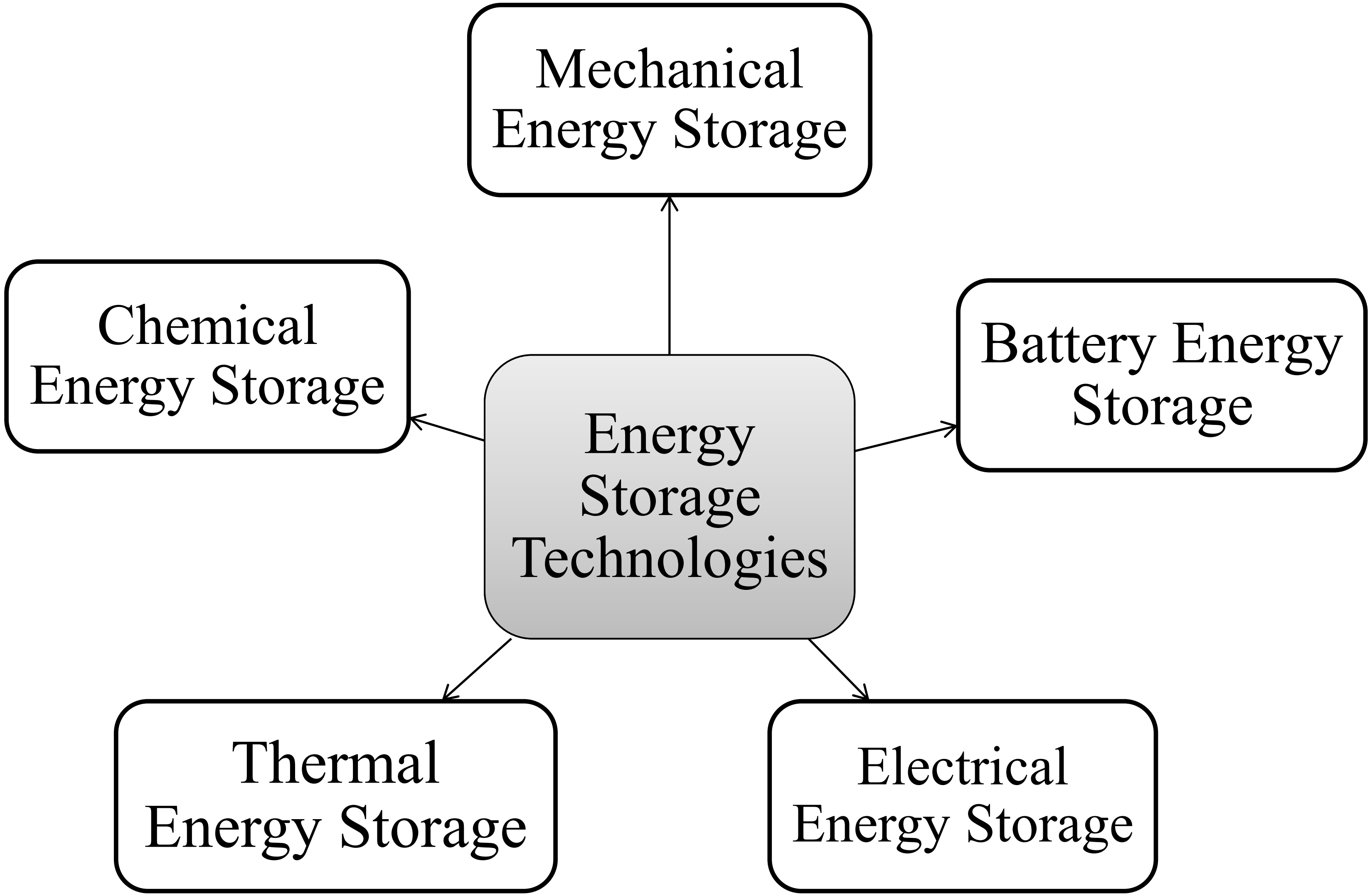
- Demand and prices fluctuate throughout the day
- ESSs can charge off-peak and discharge during peak demand
- Generate profit, match supply with demand, smooth out price fluctuation, avoid curtailment and emissions
- Critical requirements: RTE, performance decline

Seasonal time-shift

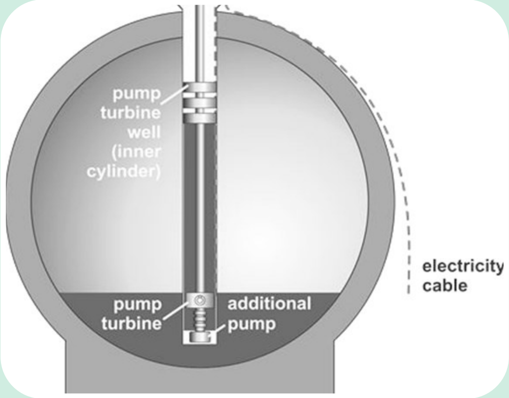
- VRE presents generation imbalances throughout the year
- ESSs can store energy during months and seasons of excess production and discharge during generation deficits
- Highly VRE-integrated grids would require LDES

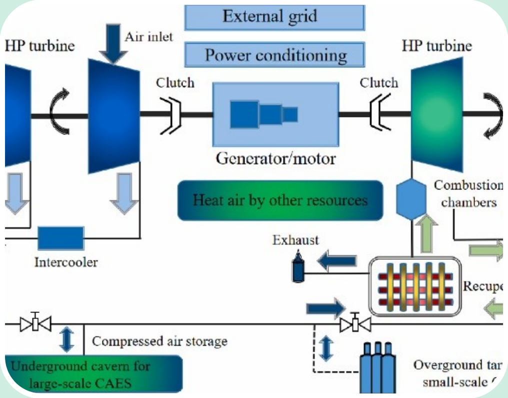


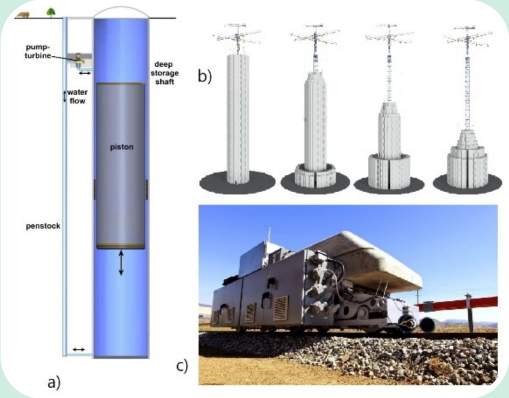
3 Energy Storage Technologies

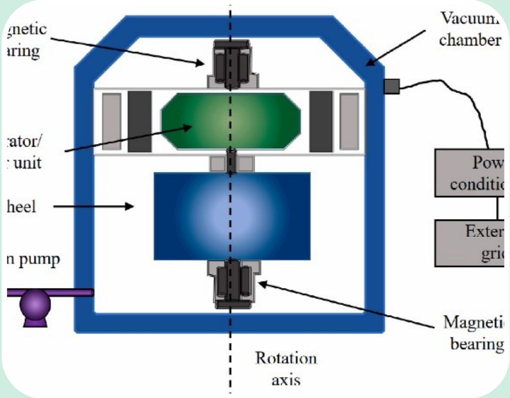


MECHANICAL ENERGY STORAGE









Pumped Hydropower Storage

- Most deployed tech (160 GW worldwide)
- High investment costs and geographical constraints
- New concept: StEnSea

Compressed Air ES

- Diabatic/Adiabatic
- Underground reservoirs/above groud tanks
- Capital costs depend on availability of natural reservoirs
- Promising evolution: Liquid Air ES

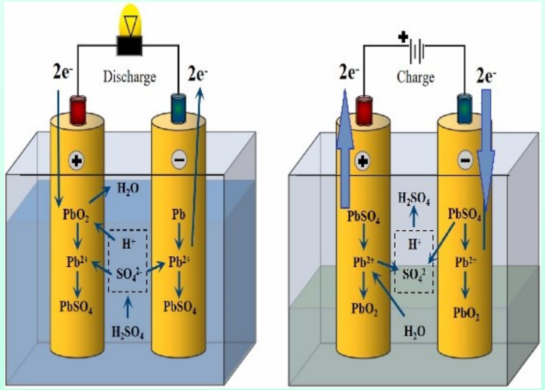
Solid Weight

- Gravity Power Module
- Energy Vault
- Advanced Rail Energy Storage

Flywheels

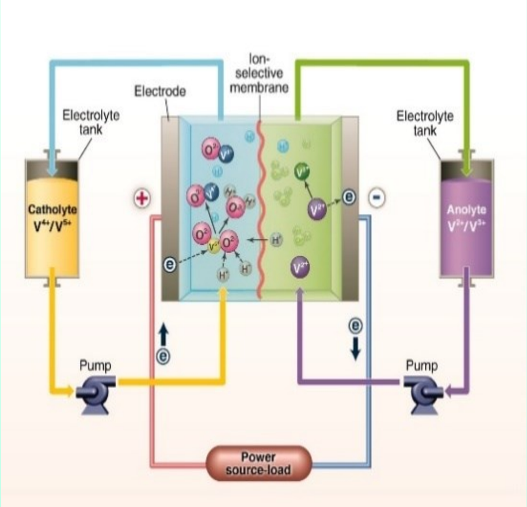
- RTE ~ 90%, fast response
- High rate of self-discharge → short-duration applications

Rechargeable batteries



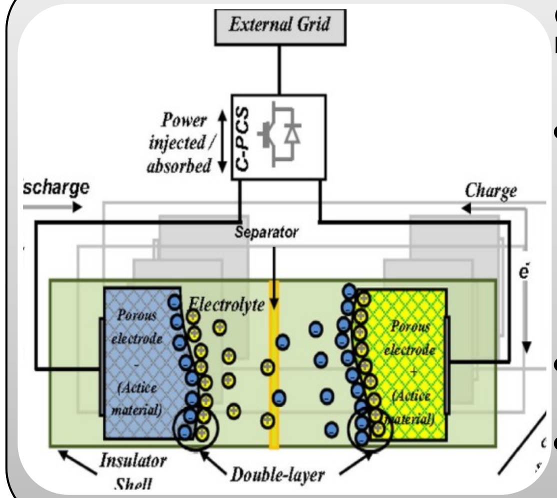
Lead-acid batteries:	RTE ~ 80%, low energy density (~ 30 Wh/kg), Depth of Discharge, short Lyfe-Cycle
Lithium-ion batteries:	Fastest growing ES tech, RTE up to 97%
	New chemistries: iron-phosphate, lithium-titanate
Sodium-sulfur batteries	High energy density, RTE >85% and fast response
	High temperatures, corrosiveness

Flow Batteries



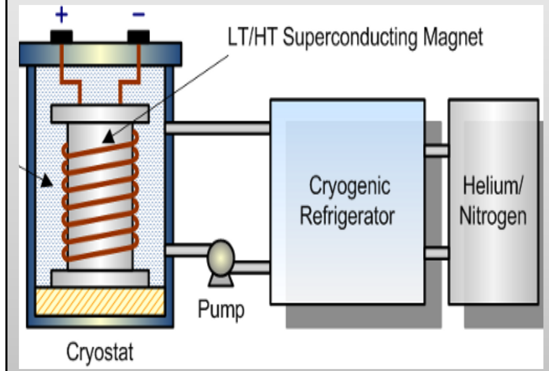
Two electrolyte solutions stored in separate tanks→de-coupling energy rating from power rating

Vanadium Redox Batteries:	RTE ~ 75-85%, up to 20000 cycles, limited energy density (10-50 kWh/m3), capital costs ~ 500 $/kWh
Iron-chromium flow batteries:	Faster rates of degradation, RTE ~ 67%
Zinc-bromine flow batteries:	Higher energy density (30-85 kWh/m3) and low capital costs (150-300 $/kWh), RTE ~ 65-75%



Supercapacitors

- 10-100k times the specific capacitance of conventional capacitors
  a. Electric Double Layer SCs: electrolyte solution and separator
  b. Pseudocapacitors: faradaic electrodes undergoing redox reactions
- High power density, RTE (85-97%)
- 5-40%/day self-discharge → short-duration applications



Superconducting Magnetic Energy Storage

- Low Temperature SMES (niobium-titanium) ~ 10 K
- High Temperature SMES (R&D) ~ 70-100 K
- High power density, RTE (>95%)
- 10-15%/day self discharge, high energy costs

THERMAL ENERGY STORAGE

Sensible Heat Storage

- Water, molten nitrate salts, diathermic oil, concrete
- SHS Integrated CSP accounts for 77% of TES
- Very low costs (4-20 $/kWh), storage efficiency 50 - 90%
- Low energy density (10-50 Wh/kg)

Latent Heat Storage

- Organic PCMs: paraffin wax, fatty acids, alcohols
- Inorganic PCMs: salts, salt hydrates, metal alloys
- 50-150 Wh/kg, 10-50 €/kWh, storage efficiency ~ 75-90%

Termochemical Storage

- Reversible endo/exothermic reactions
- Higher energy density (120-150 Wh/kg), efficiency ~ 75-100%
- Higher costs (8-100 €/kWh)

HYDROGEN ENERGY STORAGE

Electrolyzers (Power-to-Gas)

- Alkaline
- Proton Exchange Membrane
- Solide Oxide (T ~ 700° C)

Hydrogen Storage

- Gas: pressurized tanks (36 kg/m3)
- Liquid: cooling to 20-21 K (70 kg/m3)
- Solid bonding: low energy density

Fuel Cells

- Alkaline (AFC)
- Proton Exchange Membrane (PEMFC)
- Solid Oxide (SOFC)
- Molten Carbonate (MCFC)

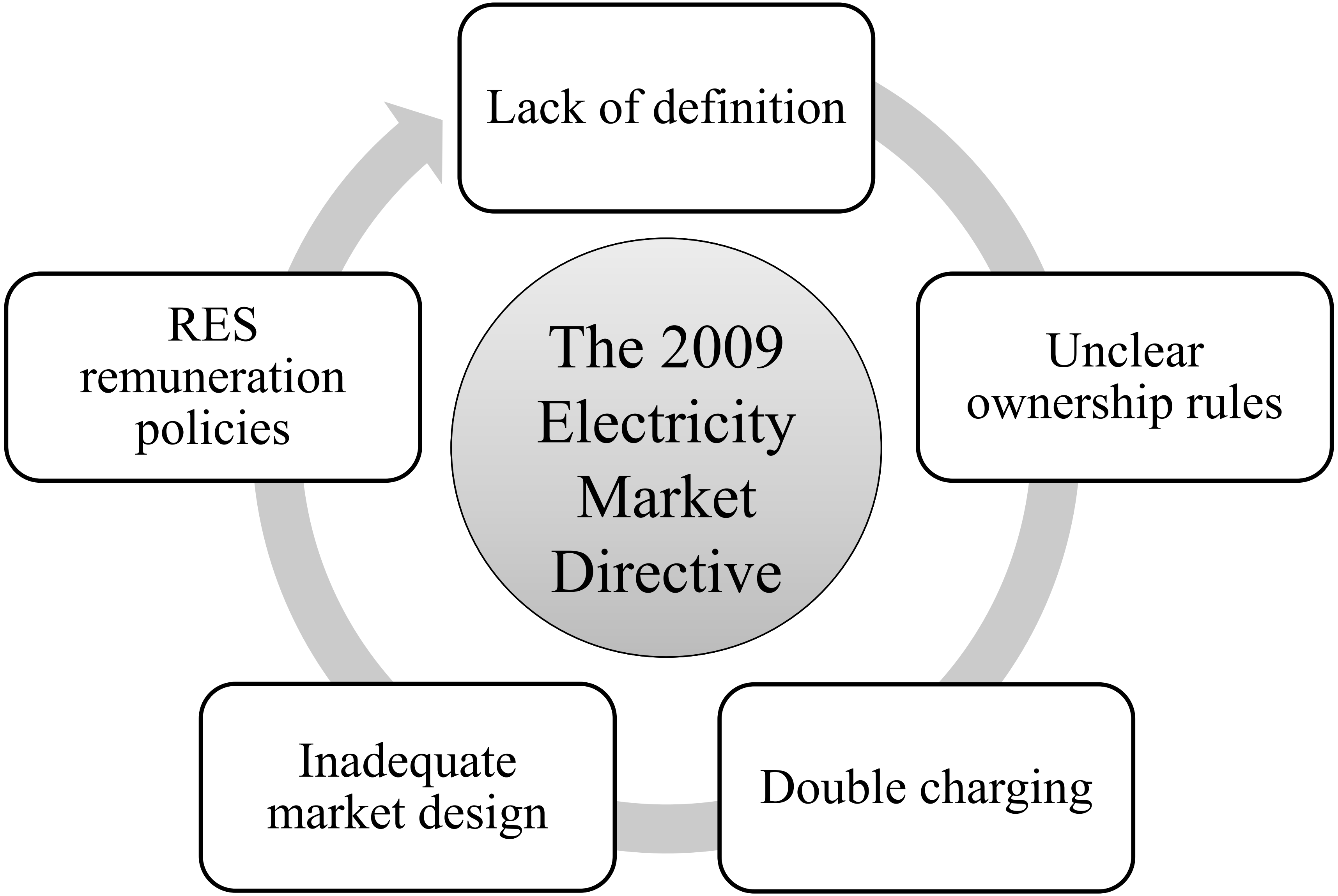
+

- VRE integration, grid applications
- Industrial decarbonization:
  - Chemical
  - Metallurgy
  - Transport
  - Aviation

−

- Electrical RTE ~ 10-20 %
- High capital costs
- High volatility, flammability and explosiveness → complex and hazardous transportation and storage

4 EU's Regulatory Framework for ES



THE 2019 EU ELECTRICITY MARKET DIRECTIVE

- ✓ Provides a technology-neutral definition of Energy Storage
- ✓ Prohibits network operators from owning storage, with 2 exceptions:
  1) ESS as fully integrated network component
  2) After a fruitless tender
- ✓ Prosumers are protected from double charges for self-consumption and provision of flexibility services

The 2019 Directive fails to:

- ❑ outline harmonious market designs for ES applications across EU Member States
- ❑ incentivize benefit-stacking
- ❑ promote utility-scale bulk energy services.

5 Conclusions

- Regulatory barriers to ES deployment at the EU level have been addressed for prosumers (behind-the-meter scale) and grid-firming services, but still persist with regard to utility-scale applications for VRE integration.
- Multiple studies have found that including firm low-carbon (such as nuclear and CCS) in future net-zero generation mixes would greatly reduce overall system costs.

THANK YOU FOR YOUR ATTENTION