## Title

Energy storage for grid-scale applications: technology overview, current technological options, and future challenges

## Abstract

One of the most direct and effective ways to decarbonise human society is to lower the carbon content of the electric energy we use, which is done by increasing the presence of Renewable Energy Sources (RES) in the energy mix. As headliners for the transition towards a net-zero-greenhouse gas emissions economy, the EU countries set very ambitious goals for the fast-approaching deadline of 2050 and while the goals for 2020 were broadly achieved (if not surpassed), much more is still to be done to meet the 2030 and 2050 dates in line with our ambitions.

Decarbonising electric energy becomes even more relevant when we realise that many promising strategies to achieve a net-zero-greenhouse gas emissions economy are based on electrification and that electric energy consumption is most likely to increase. In the future EU strategy, renewables represent from 50% to 70% of 2050 energy production, depending on the level of ambition we will decide to pursue. We know very well that such RES share will mainly be represented by non-dispatchable RES, whose production is difficult to forecast precisely, even in the short term, and it is impossible to control. It is widely acknowledged that energy storage will play a decisive role in helping manage RES variability, making renewable production dispatchable. RES cause many issues compared to traditional fossil fuel-based production, but all of them can be eased with the right storage technology. Different storage technologies are and will be required because of the different nature of the issues, but while for power-intensive uses (forecast errors, balancing actions, frequency regulation), the technological landscape is dominated by one or two well-established options, for what concerns the energy-intensive uses (load shifting) the landscape is much more diverse. The truly emblematic energy-intensive storage technology is pumped-hydro, but, nowadays, most advanced countries struggle to find new sites to build new pumped-hydro facilities. This sparked intense research and development efforts that produced a vast range of interesting storage technologies based on entirely different concepts, mainly thermo-mechanical, than electro-chemical storage (i.e., batteries).

In the seminar, a comprehensive introduction on the issues that must be solved to advance in the RES integration will be provided, trying to identify which storage technologies can be used to solve each problem. After this, the seminar will focus on the energy-intensive uses of storage, and the newly proposed technologies to replace pumped hydro will be reviewed. The pros and cons of the reviewed technologies will be discussed, covering different aspects ranging from the practical and technological limitations to the potential environmental impact and the replicability of the technology. Finally, we will try to identify the future outlook of each technology, also factoring in some economic considerations.

## Seminar Agenda

- First lesson (2 h): 14:30 – 16:30 – 06/12/22
    - Introduction
        - References to the EU path towards decarbonisation, role of renewables and electrification
        - Overview of RES-related issues and their classification in power-intensive and energy-intensive
    - Storage technologies for grid-scale applications (part 1): classification of technologies, power-intensive technologies and pumped hydro
        - Classification of technologies based on characteristic charging and discharging times
        - Overview of technologies for power-intensive tasks, analysis of the commercially available options, references to the already installed facilities and some economic considerations
        - Brief historical references to the energy-intensive storage technologies up to now
        - Pumped hydro: technology overview, overview, limitations and possible solutions (sea water and underground facilities)
- Second lesson (2 h) –14:30 – 16:30 – 07/12/22
    - Storage technologies for grid-scale applications (part 2): Electro-chemical and thermo-mechanical concepts, prototypical and commercial applications and economic outlook
        - Compressed Air Energy Storage (CAES): overview, limitations and possible solutions (Adiabatic, Isothermal and Underwater facilities)
        - Liquid Air Energy Storage (LAES): overview, limitations and possible solutions (Wasteheat/cold recovery)

- Pumped Thermal Electricity Storage (PTES): overview and classification based on the used thermodynamic cycles (Brayton, Rankine, etc.), limitations and possible solutions (Wasteheat/cold recovery)
- Electrochemical (NaS e Flow batteries): overview, limitations and possible solutions (different chemistries and cheaper materials)
- Future outlook, economic feasibility analysis, current support schemes (subsidies) for storage technologies and economic comparison with more traditional storage technologies

## Author's short bio

Guido Francesco Frate received his Bachelor's and Master's degree in Energy Engineering from the University of Pisa (Italy) in 2013 and 2016, respectively, and the PhD from the University of Pisa (Italy) in 2020, with a thesis titled "*Analysis of a pumped thermal electricity storage system with the integration of low-temperature heat sources*".

From 2020 to 2022, Guido Francesco was a postdoctoral researcher in the Department of Energy, Systems, Territory and Construction Engineering at the University of Pisa, where he recently (early 2022) became an Assistant Professor. Guido Francesco teaches *Fluid Machines*, *Energy Systems* and *Applied Energetics* in graduate and undergraduate engineering courses at the University of Pisa. In 2022, Guido Francesco was *Visiting Researcher* at the Centre for Energy Storage at the University of Birmingham (UK) for three months.

Guido Francesco's research focuses on using traditional and innovative energy storage technologies (particularly power-to-heat-to-power and Carnot Batteries) to integrate renewables in energy systems, on the optimal management of energy systems and on the modelling and simulation of components for innovative energy storage and power-production plants.

Guido Francesco co-authored more than 25 journal papers with national and international researchers and industrial partners, presented at several national and international congresses in the EU and USA. He participated in several nationally and internationally funded research projects on energy savings in commercial activities, Innovative power production systems and hybrid electro-thermal energy storage technologies. Finally, Guido Francesco participated in several research activities funded by companies to promote energy savings and develop new technologies for more sustainable power production.