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PERSPECTIVES ON ENERGY TRANSITION AND ENERGY STORAGE

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SUNTO. – Oltre l'80% del consumo mondiale di energia primaria è coperto oggi dai combustibili fossili, il cui consumo, a dispetto delle previsioni più volte formulate in passato, continua a crescere. Stante le enormi riserve disponibili, l'attuale dipendenza da fonti fossili potrebbe continuare ancora per molto tempo, ma ciò potrebbe comportare gravi conseguenze in termini di cambiamento climatico. Tra le alternative all'uso dei fossili, le fonti rinnovabili intermittenti (solare ed eolico) sono destinate a giocare un ruolo particolarmente rilevante, e ciò comporterà l'inderogabile necessità di imponenti capacità di stoccaggio di energia. In aggiunta ai sistemi idraulici di pompaggio e turbinaggio che oggi coprono la stragrande maggioranza della capacità di stoccaggio mondiale, le tecnologie proposte per sostenere la produzione elettrica su grande scala sono riconducibili a quattro tipologie: stoccaggio chimico (idrogeno ed e-fuels); stoccaggio elettrochimico (batterie); stoccaggio termico (accumulatori di calore) e stoccaggio termodinamico (cicli a CO_2, ad aria compressa, ad aria liquida).

EXTENDED ABSTRACT

In 2022, CO_2 emissions from fuel combustion have reached a record of 34 gigatonnes [1]. By mid-2023 fossil fuel demand indicators are back to pre-pandemic levels, with natural gas and oil rebounding and coal hitting new records [2]. At the same time, the energy sector

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has faced a significant upheaval due to the Covid-19 pandemic and the energy crisis following Russia's invasion of Ukraine, leading to volatile fuel and electricity prices [3].

Contrary to many of the predictions put forward in past decades, the consumption of fossil fuels is still rising, and the expected peak that will mark the start of the descent has yet to come. More than 80% of global energy demand is still covered by fossil, non renewable sources, and given (i) the very large reserves still available and (ii) the mature, efficient, reliable technologies available for their exploitation; such dependence may well continue for centuries. Given this context, the rationale for reducing the dependence from fossil sources is not their limited availability, but rather: (a) the environmental implications of carbon-based energy sources, which generate massive emissions of greenhouse gases and thus impact on climate; (b) security of energy supply, which follows from the concentration of fossil sources in unstable / unfriendly countries.

Rationale (a) provides the motivation for the "energy transition" advocated to mitigate climate change. The four basic industrial options that can be pursued to reduce the carbon intensity of the world economy are: (1) reduce CO_2 emissions per unit product or service (*e.g.* increase efficiency); (2) expand the use of renewable sources; (3) expand nuclear energy; (4) carbon capture and storage (CCS).

Given the enormous size of the issue at stake (we must get rid of tens of billions of tons of CO_2 emissions) pursuing all these options at the same time is vital. No matter what the break-down will be, renewable sources will play a major role, with solar and wind providing most of the new capacity. In turn, heavy reliance on intermittent, unevenly distributed sources as solar and wind will require large energy storage capacity as a means to bridge the gap between the time and the location of energy production vs energy consumption.

In 2022, Italian energy storage capacity reached 56 GWh [4, 5]. Most of such capacity was provided by Pumped Hydro Energy Storage (PHES), which delivered 53 GWh out of the 315 TWh demanded [6]) According to SNAM and Terna, achieving EU decarbonization targets will require 95 GWh of storage capacity in addition to PHES by 2030 [7]. Expanding storage capacity to meet national energy demands is crucial for managing expected over-generation and fluctuations of renewable energy production. The most relevant storage technologies currently considered to support large-scale, multi-energy production systems are:

(i) chemical storage (hydrogen and e-fuels); (ii) electrochemical storage (batteries); (iii) thermal storage, and (iv) thermodynamic storage (*Fig. 1*).

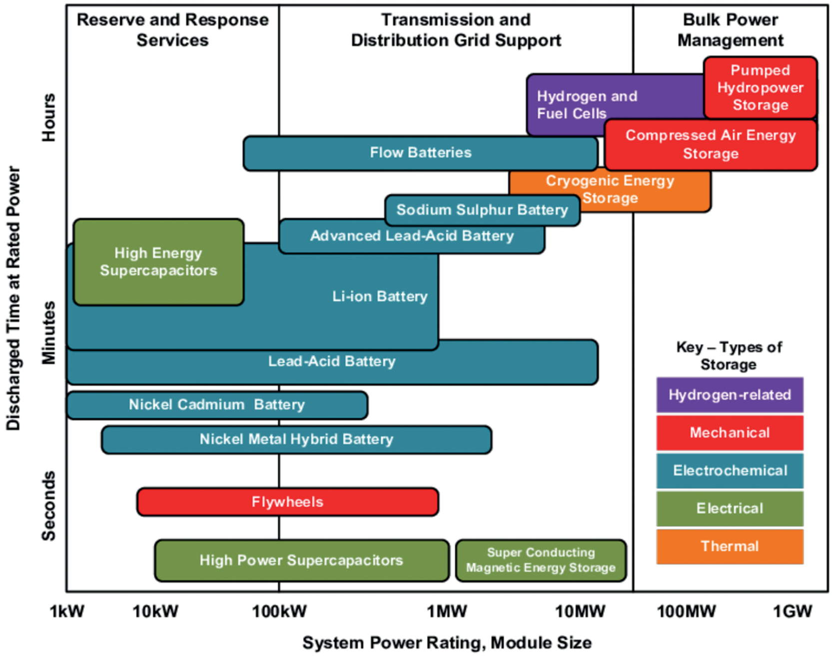

Fig.1. Different energy storage technologies, with applicable power ranges and discharge power duration [8].

Chemical storage by means of power-to-hydrogen and e-fuels offers long storage durations with high capacities, which are particularly interesting for heavy-duty transportation and high-temperature industrial processes [9, 10]. Hydrogen production via electrolyzers is a key technology, but further testing is needed for the dynamic conditions characterizing the direct integration with Renewable Energy systems [11]. Effective management of heat generated during methanation and catalyst performance are essential for the commercial viability of methane production systems [12, 13].

As for **electrochemical storage**, the expected surge in battery electric vehicles and stationary applications offers significant opportunities for synergies, such as the «second life» of car batteries which can still be used for stationary storage [14]. Italy and Europe are exposed to the risk of material shortages and technology supply, because major battery manufacturers are located in East Asia [15]. Enhancing energy density without sacrificing power density and maintaining the integrity of the electrode-electrolyte interface appears critical [16], as well as cost reduction, minimization of the environmental impact and the development of a robust Italian / European supply chain.

Thermal energy storage (TES) systems utilize various technologies. Sensible heat storage enables fully reversible heat exchange but requires large storage volumes, long loading / unloading times and often needs energy to maintain storage conditions [17]. Systems using phase change materials typically offer higher energy densities and temperature control, but feature shorter storage durations and are limited by low thermal conductivity. Thermochemical storage technology has the highest energy density, but is less mature and more complex [17, 18].

Thermodynamic energy storage (CO_2 cycles; CAES = Compressed Air Energy Storage; LAES = Liquid Air Energy Storage) offers long-duration storage at large-scale, although penalized by relatively low energy density [19, 20, 21, 22].

Within this context, Politecnico di Milano and Laboratorio Energia e Ambiente Piacenza (LEAP) have designed an innovation facility to be deployed in Piacenza (DES-Park: Digital Energy Storage Park) to support the Italian industry in developing, testing and certifying energy storage systems, fostering energy transition and meeting EU decarbonization targets.

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