PATHFINDER CHALLENGE
Mid to long term and systems integrated energy storage

CHALLENGE GUIDE
Version 14/06/2022

EIC Work Programme reference: HORIZON-EIC-2022-PATHFINDERCHALLENGES-01-02
Call deadline date: 19/10/2022 17.00 CET
EIC Programme Managers: Antonio Marco PANTALEO, Francesco MATTEUCCI
Challenge page: https://eic.ec.europa.eu/eic-funding-opportunities/calls-proposals/eic-pathfinder-challenge-mid-long-term-and-systems-integrated-energy-storage_en

The EIC will hold an online Info Session on this Pathfinder Challenge call on 05/07/2022. Participation in the meeting, although encouraged, is optional and is not required for the submission of an application. Information about how to access the Info Session and on additional dissemination events can be found at EIC Pathfinder Challenges Applicants' Day (europa.eu) **and** EIC Pathfinder (europa.eu)**.**

Table of Contents

1 About this document

The Challenge Guide serves as guidance and background for the common understanding, participation rules and obligations for the EIC beneficiaries that are involved in the Challenge Portfolio. Contractual Obligations are further detailed in the EIC Work Programme https://eic.ec.europa.eu/eic-work-programme-2022_en and collected in the Pathfinder Challenge guidance on contractual issues, available on the Challenge page.

The Challenge Guide is a guidance document accompanying a Pathfinder Challenge call for proposals to provide applicants with additional technical information to underpin the objectives and to provide further information about how portfolio considerations will be taken into account in the evaluation of proposals.

The Challenge Guide is prepared by and under the responsibility of the relevant EIC Programme Manager (information about the EIC Programme Managers is available on the EIC Website https://eic.ec.europa.eu/eic-communities/eic-programme-managers_en). It further details the call by complementing notably the Scope, Specific Objectives and/or Specific Conditions set out in the EIC Work Programme. In no case does the Challenge Guide contradict or supplant the Work Programme text.

2. Background concerning the scope and objectives of the Challenge

This section provides additional information on the background in the relevant policy, scientific and technological domains pertaining to scope and objectives of the Challenges that applicants may wish to take into account. This section should be read as background to the Challenge call in the EIC Work Programme text (attached as Annex). Proposals to this Challenge are expected to explain how they relate to and intend to go beyond the state of the art, and how they interpret and contribute to the objectives of the Challenge.

Policy background

The Green Deal[1] sets ambitious goals for the EU climate neutrality by 2050, pursued also by the 'FIT for 55%' package that increases the EU targets of renewable energy share by 2030 to 40%[2], and by the Repower EU[3] action that specifically addresses the increase of energy prices, the dependence from fossil energy outside EU and the transition to a more affordable, secure and clean energy system. The development of interconnected, sector coupled, or flexible energy systems is crucial to achieve these targets and in particular to enable high penetration of intermittent renewable energy and address the spatial and temporal mismatches between generation and demand. In this context, the possibility to (i) store thermal (heat and /or cold) and/or electrical energy at low cost, high density, high charging/discharging efficiency and enhanced durability (to address temporal mismatches), and (ii) transport this energy in the form of one or more energy carriers which are system integrated, safe and cost competitive (to address spatial mismatches) is a key enabler for a fully decarbonized energy system. Energy storage also enables smart demand response strategies and energy efficiency options, such as waste heat recovery or heating / cooling supply chains optimization, in industrial, commercial and residential sectors.

In July 2020, the EC adopted the Strategy for Energy System Integration, which proposes a vision to accelerate the transition towards a more integrated and clean energy system, in support of a climate-neutral economy. The Energy System Integration strategy addresses the planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors. It sets out several actions to implement the necessary reforms, including the promotion of renewable and low-carbon fuels and energy storage technologies for sectors coupling.

To reach these targets, it is crucial to develop a range of breakthrough solution for thermal and electrical energy storage, that offer high round trip efficiencies and low cost in comparison to the state of the art, minimizing or avoiding the use of critical raw materials and capturing

[1] COM(2019) 640 final
[2] Fit for %5
[3] RepowerEU

process and system integration opportunities. In addition, the European Environmental Agency is fostering research towards a "circular economy" with effective waste and carbon recycling strategies as a core task. The end-of-life commodities should be reused, recycled and resourced for a better life-cycle design[4]. It is therefore of paramount importance to develop breakthrough novel processes and technologies for energy storage, at different scales (centralized at bulk power system level or decentralized at end users' premises) capturing cross sectorial coupling, facilitating the integration of renewable sources, avoiding the use of toxic and critical raw materials, and embracing a circular and life cycle thinking approach.

Technology background

In the following, some not exhaustive examples of processes and technologies for mid-long term thermal, electrochemical and chemical energy storage in scope with the call are presented.

Technologies for mid-term or long-term (seasonal) thermal energy storage are commonly based on sensible, latent or thermochemical (including sorption) storage, or combinations of them. Research challenges include the achievement of high volumetric / gravimetric energy densities, the use of non-toxic, low cost, bio-based, long-term stability and low degradation rate materials, or high heat transfer rates and rapid kinetics. Computational chemistry will help to address some of these challenges through, for instance materials, selection optimization.

In the case of sensible thermal energy storage via packed beds of rocks/gravel, potential challenges include the adoption of buildings or infrastructures integrated solutions (facades, foundations and underground pipes, greenhouses, etc). In the case of latent thermal energy via phase change materials (liquid salts/metals) key research topics include the thermodynamics of phase transition to enable tuneable temperature via electrical or magnetic fields, or thermal conductivity enhancement via metal/carbon foams, porous carbon or other composite functionalized materials[5], and related health / safety issues. Sorption heat storage (via liquid absorption, solid adsorption, reversible chemical reaction or composite materials)[6] implies the use of physical or chemical bonds to store energy and it is particularly promising in terms of energy density, duration, energy losses, operational flexibility and temperature ranges (i.e., very high or low temperature), even if it has less technological maturity[7,8]. In this case, thermal energy can be stored as sorption potential between a working fluid and a solid or liquid sorbent (e.g. zeolites or salt hydrides)[9], or via metal-organic frameworks (MOFs) with tuneable crystalline structure[10]. The limited hydrothermal stability of sorbent materials is often

---

[4] J. B. Zimmerman, P. T. Anastas, H. C. Erythropel, W. Leitner, Science, 80, 2020, 367, 397

[5] P. Zang et al, Applied Energy (165) 2016 ; 472-510

[6] N. Yu, R.Z. Wang and L.W. Wang Prog Energy Combust Sci, 39 (2013), pp. 489-514, 10.1016/j.pecs.2013.05.004 Review

[7] R. McKenna, D. Fehrenbach, E. Merkel, Energy Build, 187 (2019), pp. 38-49, 10.1016/j.enbuild.2019.01.044

8 L. Semple, R. Carriveau, D.S.K. Ting, Energy Build, 154 (2017), pp. 175-187, 10.1016/j.enbuild.2017.08.065

9 C. Bott, I. Dressel, P. Bayer, Renew Sustain Energy Rev, 113 (2019), 10.1016/j.rser.2019.06.048

[10]H. Furukawa, F. Gándara, Y.-B. Zhang, J. Jiang, W.L. Queen, M.R. Hudson, et al., J Am Chem Soc, 136 (2014), pp. 4369-4381,

addressed exploiting also chemical reactions, such as hygroscopic salts[11]. Technological issues such as swelling, agglomeration and corrosion of these materials could be overcome via composite or selective sorbents in porous matrices[12][13]. This class of materials is based on the dispersion of the salt inside the pores of a supporting matrix. Its challenges are to overcome agglomeration effects, improve kinetics of hydration/dehydration and prevent corrosion. However, these materials are often made through impregnation, which can take less than 40% of salt, so hindering energy density, and filling salt into the pores of the matrix reduces the mass transfer of absorbate into the salt particle surface and the overall performance. In turn, mass transfer and manufacturing method represent a relevant research challenge.

Molecule based storage solutions are also very promising, despite being still at their infancy. Some approaches are based on photo-switchable or thermally switchable molecules, where heat (or light) is stored in specific intramolecular mechanical degrees of freedom, eventually applying mechanical forces or electric fields, and can be then released with limited energy losses. Specific research challenges in this field regard the increase of solar spectrum match, the durability at high temperature, or the control of the catalytic energy release.

These technologies, when coupled to thermochemical pumpable fluids, could also enable efficient long distance heat transmission (thermal fuels).

The design of storage systems to enable high heat transfer during charging and discharging through topological optimization of flows and heat transfer surface is also a relevant topic for the call. As an example, solutions based on 3D optimized design of heating/cooling working fluid flow via additive manufacturing for the pipes and metal foams for surface enhancement are in scope with the call.

Thermal or thermomechanical energy storage, in the form of heat or cold, is also a key component for power to heat to power technologies. For instance, electricity could be used to pump heat to a hot store and/or extract heat from a cold store. The stored thermal energy can be discharged to drive a thermodynamic heat engine and generate back electricity, with a good fit for heating/cooling/electricity systems integration. Some key research topics, that could be addressed in response to this call, include the operation of pumps and compressors at very high/low temperatures and pressures (i.e., evaporative cooling) or at extended temperature ranges and combining two or more functions in a single component to reduce costs or enhance efficiency (i.e., pump and compressors). Strategies to increase part load efficiencies, smart charging/discharging and decoupling power and energy elements, in order to enable ancillary services provision to the grid, are also of interest. The proposals could also address unconventional cycles with vapour compression operated by electrochemical, instead of

[11] R.J. Clark, A. Mehrabadi, M. Farid, J Energy Storage, 27 (2020), 10.1016/j.est.2019.101145
[12] Y.I. Aristov, G. Restuccia, M.M. Tokarev, G. Cacciola, React Kinet Catal Lett, 69 (2000), pp. 345-353,
[13] L.G. Gordeeva, Y.I. Aristov, Int J Low Carbon Technol, 7 (2012), pp. 288-302, 10.1093/ijlct/cts050

mechanical means, or by making use of a different form of entropy change, such as via redox couples, thermoelectricity, thermoacoustics or barocaloric materials.

The electricity storage through chemical energy carriers such as (non-exhaustive list) H2, methanol or ammonia (power-to-X) is another possible option for large scale and long-term storage as well as to enable sectors coupling, high intermittent renewable energy balancing and energy systems integration[14]. In fact, these energy carriers can be used not only for electricity production, but also as input materials for the chemical industry or as transport fuels, eventually in combination to carbon capture and use (CCU) solutions. The maximization of the overall (production-storage-utilization) process efficiency and the assessment of new impurity-tolerant low-cost non-critical raw materials are key research challenges[15]. Proposals addressing power to X technologies (e.g., production of renewable fuels of non-biological origin, RFNBO) in response to this call should specifically address the storage and handling of the produced energy carrier and could include the reverse conversion for the final use.

The use of reactive metals as energy storage media has also been explored, in light of their extremely high volumetric energy density. This is particularly true for, all those metals that can be produced via electrochemical processes such as aluminium, sodium and magnesium, but also for other metals (Ca, Fe, Zn, etc). Moreover, metals are easy, safe to store over various time scales, transportable with the existing infrastructure, while concomitantly contributing to a more circular economy through materials substitution and recycling[16]. Reactive metals in many cases are also easy to be recovered (i.e., Na from seawater). However, their optimum exploitation can be achieved through an efficient combination of different energy conversion paths (power-to-metal combined with metal-to-power or metal-to-heat) and industrial symbiosis with metallurgical industries or in secondary batteries such as metal-air batteries (power-to-power configurations). Research challenges on reactive metals as energy storage and carrier material include the thermodynamic and kinetic processes governing the chemistry of these systems or the assessment of the most suitable materials for the different final application on the basis of their energy reactivity, electronegativity, cost, availability, environmental impact and other factors[17].

Redox-flow batteries are other promising options for mid-long term and large-scale electricity storage due to their long lifetime, low cost and capability to decouple power and energy[18]. Research effort is particularly needed in areas such as metal-organic redox molecules, electrode surfaces and electrolytes selection, or aqueous / non-aqueous reactors optimization, in order to reduce costs and increase performance (efficiency, stability, energy/power densities, and smart controls). Also, other batteries components such as highly conductive membranes and more porous electrodes or novel architectures such as membrane-free, semi-solid, hybrid,

[14] CETP SRIA 2020, M. Ferraro, et al.
[15] ACS Energy Lett. 2020, 5,3843-47
[16] J. M. Bergthorson, Prog. Energy Combust. Sci. 2018, 68, 169
[17] M. Baumann, L. Barelli, S. Passerini, Adv. Energy Mater. 2020, 202001002
[18] L. H. Thaller, Electrically rechargeable redox flow cell

metal-air redox-flow batteries, metal-CO_2 or solar redox are under investigation at different technology development stages and can be explored in this call[19,20].

Background on the challenge topics

The call is focused on thermal, electrical or combined thermal/electrical energy storage with duration from days (mid-term) to seasons (long-term) for stationary applications in the mid to large scale size range. Micro, portable, or single building solutions are out of the scope of the call. The call aims to fund non incremental research to produce a proof of concept of a process/technology/material tailored for a specific sector/application and that, from the single component design, has the ambition to address its interactions and integration opportunities at the device and whole systems level. The main target applications are storage for power systems, utility scale renewable power plants, blocks of buildings and greenhouses, industrial facilities. Technologies based on mechanical (e.g., flywheels, gravimetric) or pumped hydro storage are out of the scope of this call. Proposals that aim to spatially decouple the storage charging (from thermal/electric energy to energy carrier) and its discharging (i.e., reconversion from energy carrier to thermal-electric energy) should specifically address the storage of the energy carrier (i.e., hydrogen, ammonia, methanol, reactive metals, thermal fuels etc). In this case, the potential integration with energy carriers transport networks and the sectors coupling opportunities should be also addressed (i.e., combined energy carrier storage and thermal energy management).

Technologies to enable increased flexibility and mid-long term storage capabilities of large-scale centralized power plants, or their refurbishment (in the case of fossil fuel plants) for a reconversion to energy storage assets are also included in the scope of the call. Proposals can also target the integration of long-term energy storage and short-term storage for fast dynamic response, in order to enable access to the energy markets for ancillary grid services.

Secondary benefits of the proposed energy storage solutions, such as cooling management in industrial/tertiary sectors, water management (i.e., desalinization), carbon capture and management (i.e., calcium looping), emissions reduction, environmental remediation or intermediate chemicals production for industrial symbiosis (i.e., reactive metals), will be also in scope with the call.

Storage technologies specifically designed for renewable heating/electricity (solar, geothermal, biomass, wind) or waste heat recovery are in scope with the call, to the extent the primary focus is on storage of produced energy (included its charging/discharging).

Proposals should mention their deployment strategy and the steps required to scale up the process. There should be a preliminary risk analysis to secure the probability of achieving each deliverable in the estimated time frame and within the allocated funding. Proposals should be

[19] E. Sanchez-Diez, et al., J. Pow. Sources, 481, 2021, Redox flow batteries: Status and perspective towards sustainable stationary energy storage
[20] B. Li and J. Liu, National Science Review, 4, 91-105, 2017

flexible in modifying project targets and key directions, if needed, explaining how the DBTL (design-build-test-learn) cycle will be applied. Proposals should also address, if relevant, process or technology certification issues (safety conditions), a life cycle analysis and the use of non-critical raw materials.

3. Portfolio considerations for the evaluation of applications to the Challenge

This section describes how portfolio considerations will be taken into account in the second stage of the evaluation of applications. In the first stage, all applications will be evaluated individually by external experts and scored against the evaluation criteria set out in the Work Programme. All applications that pass the defined thresholds against the criteria will be included in the second stage of the evaluation. At the second stage, all above threshold applications will be considered collectively by an evaluation panel chaired by a relevant Programme Manager. At this stage, the Evaluation Committee will consider which applications to recommend for funding in terms of a coherent portfolio of projects that can interact, reinforce or compete with each other to increase the overall impact.

Categories

The portfolio building process will be based on a balance of complementarities and diversities among the proposals. The evaluation committee will firstly identify a sufficiently broad range of diverse and competing approaches, methodologies, and technologies among the portfolio proposals. In combination to the aim to diversify the range of technologies/ approaches, the evaluation committee will also look at complementarities and/or shared components among them. For this purpose, the evaluation committee will allocate proposals into categories identified during the evaluation process, which will define the overall portfolio architecture:

<u>Technologies</u>: e.g., for thermal or electric energy storage, or a combination of both. Different intermediate storage technologies are possible.

<u>Systems integration</u>: aspects of integration of storage, such as coupling to renewable sources, or to existing power plants, to waste energy recovery, to demand response strategies at end users' level, or to the built environment.

<u>Methodologies for materials and components selection</u>: different approaches, such as computational chemistry, to select the storage materials and their properties (e.g., thermo-physical, chemical), and/or their interoperability at components/devices/system level (e.g., multi-physics simulations).

<u>Methodologies for monitoring and control</u>: such as strategies to charge/discharge systems, to control/monitor the durability/performances of materials/components/device/systems, or for the purpose to enable fast demand response or grid ancillary services.

Portfolio considerations

The Evaluation Committee will aim at composing a portfolio of projects taking into account the following considerations:

- The portfolio should include diverse technologies for thermal and electric energy storage, comparing their relative competitiveness and market uptake potentials for different applications and end-user requirements.
- In the portfolio, diversity will be also sought with respect to methods for integration of storage into energy systems, methodologies for materials selection, dynamic performance and control systems. The aim is to develop a portfolio of potential technology solutions for different applications, contexts and end user requirements.
- The projects in the portfolio should, if possible, share similar or complementary approaches and methodologies in areas where this can be a clear added value for the development of synergies, such as materials, components integration, control systems.
- Other outcomes being equal, preference will be given to proposals which enable increased flexibility of energy systems, higher penetration of intermittent renewable energies and enhanced demand response strategies for final energy consumption.
- Futhermore, potential synergies could be explored in the typology of secondary added values eventually captured by the proposals, such as the combined carbon management, freshwater production, emissions reduction, or industrial symbiosis.

4. Implementation of the Challenge portfolio

Once selected, projects will be expected and obliged to work collectively during the implementation of their projects under the guidance of an EIC Programme Manager. This section summarises some of the key aspects of this pro-active management which applicants should take into account in preparing their proposals.

Grant negotiations

Applicants may be requested to make amendments to their proposed project in order to take into account the portfolio objectives and enhance the portfolio. Such changes may include: an additional work package to undertake common/ joint activities (workshops, data exchanges, joint research, etc) with other projects in the portfolio; adjustments to the timings of some activities and deliverables in order to synchronise better with the implementation timings of other projects; specific target changes to improve complementarity/ comparability with activities and results from other projects; adjustments to the timings of some activities and deliverables in order to synchronise better with the implementation timings of other projects; specific target changes to improve complementarity/ comparability with activities and results from other projects.. All such changes will be discussed during the grant preparation stage with the aim of reaching a consensus between all projects on the adjustments needed.

Challenge portfolio roadmap

Following the selection of proposals to be funded under the Challenge, the Programme Manager will work together with the selected projects to develop a common roadmap for the Challenge. This roadmap will integrate the activities and milestones of the individual projects into a shared set of objectives and cross-project activities. The roadmap serves as a common basis for implementing the projects - including possible adjustments, reorientations or additional support to projects - and can be updated in light of emerging results or difficulties during the implementation. The objectives can be revised, for instance based on projects' unexpected achievements, new technology trends, external inputs (other projects, new calls…).

In particular, the Challenge roadmap will include activities on the transition to innovation and commercialisation, and to stimulate business opportunities. These activities may be supported and reinforced during the implementation with additional funding and expertise through pro-active management.

The EIC energy storage portfolio activities will stimulate the collaboration and synergies among the funded projects as well as the engagement with the innovation ecosystem and with other actions and programmes supported by the European Commission in this field.

Tools for proactive management of projects

Projects in the portfolio may be offered additional support, either individually or collectively, in order to reinforce portfolio activities or explore the transition to innovation. Such additional support includes:

- Booster grants of up to €50k (see Annex 6 of the EIC Work Programme)
- Access to additional EIC Business Acceleration Services (see https://eic.ec.europa.eu/eic-funding-opportunities/business-acceleration-services_en)
- Access to the Fast Track to the EIC Accelerator, the decision for which would follow a project review (see Annex 4 of the EIC Work Programme)
- Access to the EIC Market Place, once operational, to connect with innovators, investors and other selected partners
- Interactions with relevant projects and initiatives outside the portfolio, including other EU funding initiatives as well as those supported by national, regional, or other international bodies.

ANNEX Extract of EIC work programme

II.2.2 EIC Pathfinder Challenge: Mid to long term and systems integrated energy storage
Introduction and scope
Energy storage is required to increase energy systems flexibility, sectors coupling, demand response and smart interoperability solutions. Storage technologies facilitate high penetration of intermittent renewable energy, enable energy efficiency technologies such as waste heat recovery, increase the efficiency of cold supply chains and in turn contribute to the ecologic transition.
Non critical raw materials (CRM)-based systems and processes integrated, life cycle driven technologies are needed, in order to develop low cost and competitive solutions. Particular attention will be paid to high round-trip efficiency, high energy density, stable and reliable solutions for mid to long term energy storage (from days to months), which represent the most needed services for flexible, sustainable and fully integrated energy systems.

This Challenge will support proposals from the following technologies and systems for stationary applications:

- mid/long term energy storage for power systems, with technologies such as metal air or redox flow batteries, power to heat to power, chemical bonds, electrochemical/chemical/thermal hybrid solutions, integration of energy carriers and 'storage to X' strategies; concepts for centralised or decentralised applications at grid, industrial or district scale level are included, excluding micro and small scale or single building solutions.
- mid/long term thermal energy storage (heating or cooling) at different temperature, such as building integrated and process systems integrated solutions, chemical looping or thermochemical storage, solar thermal energy harvesting and storage, combined storage of thermal and electrical energy as well as other energy vectors, storage systems integrated in cold chains and in industrial processes.

Specific objectives
The proposals, through non CRM-based systems integrated, life-cycle and circular thinking driven approaches, should develop a proof of concept (PoC) or lab-scale validated innovative mid to long term storage for centralised or decentralised applications ranging from large to mid scale and excluding small micro scale such as single building solutions. The proposed technologies include, but are not limited to, the following:

- computational modelling and optimisation applied to materials, components and control (i.e., charging/discharging) for storage;
- heating/cooling storage through chemical and thermochemical technologies (adsorption, absorption, etc.) included their integration in buildings or industrial processes and for different temperature;
- integration of energy storage systems into multi-vector energy grids and existing infrastructures, or into industrial processes for waste energy recovery and industrial symbiosis including concepts to enable smart control;

- systems-integrated thermal energy storage technologies for industrial and building applications (i.e., energy storage combined to solar and geothermal energy conversion, to pumped heat technologies, or to combined cooling, heat and power generation);
- innovative concepts for hydrogen (H2) storage/compression combined with thermal energy management and storage.

Expected outcomes and impacts

This EIC Pathfinder Challenge aims at providing solutions that will optimise European energy storage and thus enable demand response strategies and capabilities to host higher penetration of intermittent renewable technologies. Proposed solutions with multidisciplinary and cross-sectorial approaches, looking for inspiration, ideas, and knowledge in a broad range of disciplines are particularly welcome.