Setting the stage for energy storage in India

The Department of Science and Technology (DST) in India has played an instrumental role in helping the country meet its target of 175GW of renewable energy by 2022 and clean energy storage. This article explores the opportunities and challenges ahead of the energy storage sector and DST initiatives aimed at advancing energy storage in the country.

In the academic forefront, India has been striving meticulously towards development of efficient energy storage systems, particularly batteries. Initiatives by the Indian Institute of Science (IISc), National Chemical Laboratory (NCL), Centre for Materials for Electronics Technology (C-MET), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), CSIR - Central Electro Chemical Research Institute (CSIR-CECRI), Indian Institute of Science Education and Research (IISERs), Indian Institute of Technology (IITs) and National Institute of Technology (NITs) have been in the limelight.

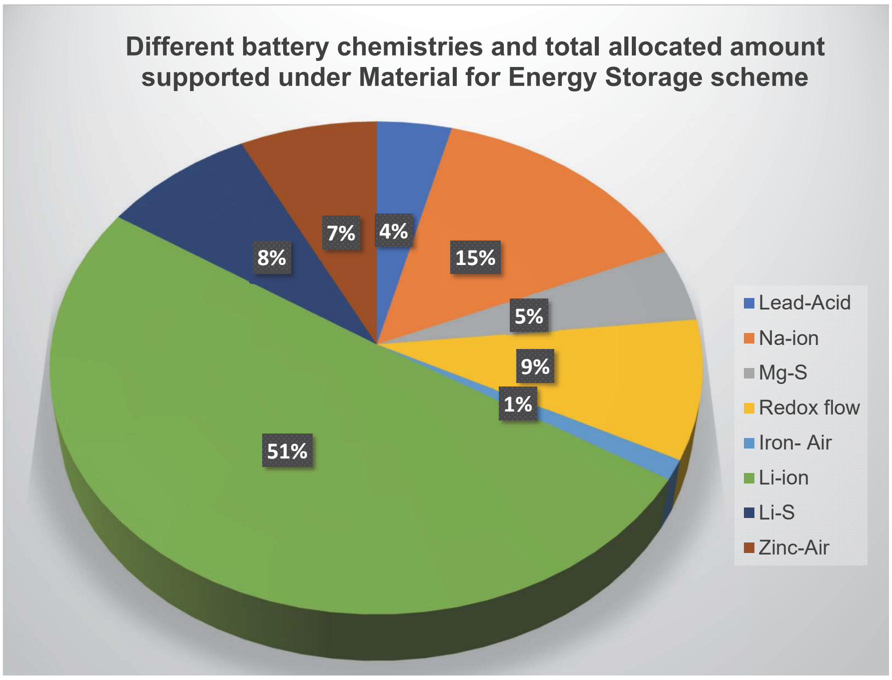
In 2018, Indian Space Research Organisation's (ISRO) Vikram Sarabhai Space Centre (VSSC) successfully developed and qualified lithium-ion cells of capacities ranging from 1.5Ah to 100Ah for use in satellites and launch vehicles. ISRO has signed an MOU with Bharat Heavy Electricals Ltd (BHEL) to manufacture Li-ion batteries for electric vehicles in India.

CSIR-CECRI has developed prototype Li-ion fabrication facility for 18650 cells. It is India's first pilot plant facility which will manufacture the Li-ion cells with a capacity of 1500 mAh/3.7 V, dedicated to improving the capacity of the Li-ion battery. The developed 18650 cells were utilized for powering solar lanterns and hats. CSIR-CECRI has been involved in the development of Zn-Br (zinc-bromide) redox flow batteries for more than a decade.

C-MET Pune laboratory is presently working on development of fuel cell prototype using nano functional materials and high energy density lithium-ion cell/ battery. Centre for Automotive Energy Materials (CAEM), IIT-Madras are developing Li-ion battery for EVs and hybrid electric vehicles (HEVs) by setting up research facility for Li-ion cells and battery packs at pilot plant scale. Private industries such as Ashok Leyland are already engaged in the manufacturing of EVs based on Li-ion batteries and CAEM has initiated the interactions to demonstrate in-house Li-battery technology for EVs.

IIT-Madras has been working on electrode materials and novel redox couples for vanadium-redox flow batteries. IIT-Bombay is primarily focused on developing energy storage materials for Li-ion batteries and fuel cells towards EV applications. Several research groups from IISERs and IITs are also working towards the development of hybrid ion capacitor devices.

India's Oil and Natural Gas Corporation's Energy Centre (OEC) is interested in taking up collaborative research with Indian academic, research and industrial organizations to work on any of these technology options, as well as any other innovative technology option relevant to energy materials, energy generation or energy efficiency.



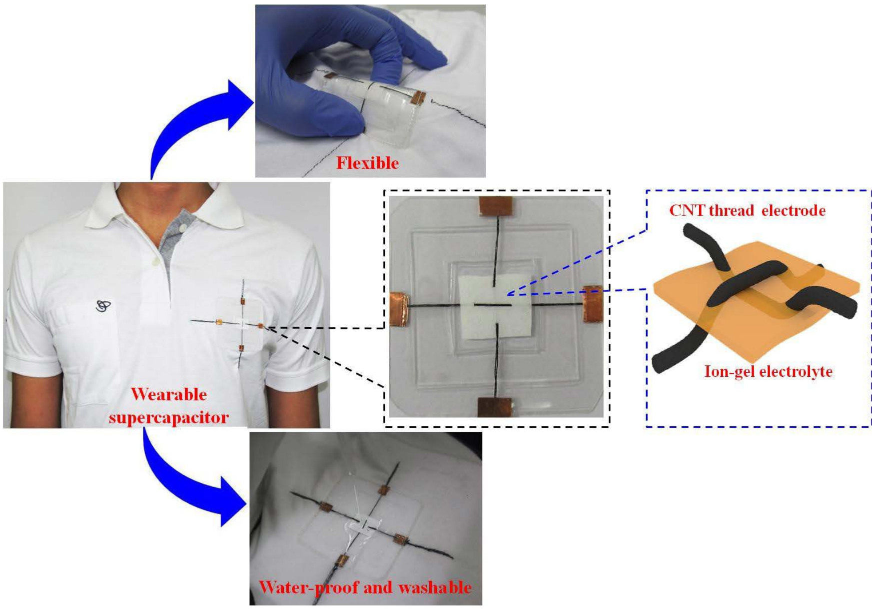
Emerging technologies

There are few technologies that will pick-up momentum in the next 5-10 years.

- Redox flow batteries (RFBs) will emerge as strong contenders as electrical energy storage systems for the utilization of renewable energy. RFBs possess high energy efficiency, deep discharge ability, low self-discharge, and long cycle life. A unique advantage of RFBs is the decoupling of energy capacity and power density, which is not available with other existing conventional systems

- Si and Si composite anode with Vanadium, Manganese and Ni-rich, cobalt free cathode
- All solid-state Li-ion (with ceramic, glass, polymer or composite Li-ion conducting solid electrolyte), even in all solid-state Li-ion Si anode or anode-less configuration will be used
- The separator will get eliminated. The electrolyte will play a dual role of serving as an electronic insulator.
- Bipolar electrode configuration (similar to fuel cells)
- No slurry mixing, coating, etc. The electrodes will be prepared by dry powder coating or automated web coating or R2R like semiconductor industry.
- Lithium battery recycling (a process that is now possible in India also), making the batteries sustainable
- All solid-state Li-S Batteries and anode-less Li-S batteries
- Fuel cells are likely to pick-up beyond 2050. The fuel could be Carbon, Hydro-carbon, CO_1 CO_2 or H_2. Air would be the cathode.

Project sponsored by DST-TMD under the Materials for Energy Storage (MES) program to IIT Bombay has realized supercapacitive energy storage device that is seamlessly integrated into clothing and fabrics for powering wearable electronics. The device is composed of carbon nanotube threads interwoven through solid-electrolyte sheets to achieve an excellent energy density of 50 Wh/Kg and 4400 W/kg. The device is operable at 3V, making it ideal for powering wearable wireless-transmitters and point-of-care diagnostic sensors. Further, the device is packaged to withstand a variety of mechanical and environmental duress such as bending, flexing, impact and laundering.



A wearable supercapacitive energy storage device demonstrating its bendability and washability, with a schematic representation of the device consisting of CNT-thread electrodes interwoven through solid-electrolyte.

Promising joint ventures

In the recent times, India has witnessed a paradigm shift towards electrochemical technologies. Research institutes are enthusiastic about collaborating with industries as well. The lead-acid battery research is well established, and India has highly successful companies in this segment like Exide, Amar Raja, and Luminous, among others.

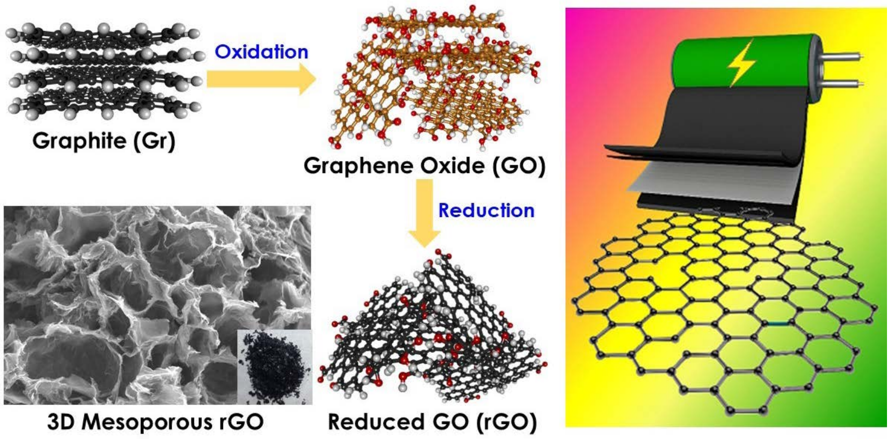
The Hindustan Petroleum Corp Ltd (HPCL) has set-up the prestigious 'HP Green R&D Centre' in Bengaluru, India, with an objective to develop innovative and path breaking technologies and products. Public sector entities like Indian Oil Corp Ltd (IOCL) and BHEL are also teaming up with research institutes. The Centre for Battery Engineering and Electric Vehicles (C-BEEV) stationed at IIT-Madras is proposed to be set up under public private partnership model with lead contribution from the Department of Heavy Industries, government of India.

Table 1: Battery Chemistries currently under investigation

Battery Type	Cathode Material	Anode Material
Li-Air, Mg-Air, Al-Air, Fe-Air, Zn-Air, Lead flow batteries, Vanadium flow batteries, Na-S, Li-S, Thermal batteries, Na-NiCl2 (Zebra batteries), Ag-Zn, Mg-AgCl reserve batteries, Ultra lead acid Batteries, Lead – Carbon, Li-Carbon, dual carbon	Lithium Nickel Cobalt Manganese Oxide (LiNiCoMnO2), Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2), Lithium Cobalt Oxide (LiCoO2), Lithium Manganese Oxide (LiMn2O4), Lithium Iron Phosphate (LiFePO4/C), Lithium Titanium Oxide, Ni-Mn-Co-Al cathode materials, amorphous carbon, hard carbon, graphite (natural, synthetic graphite, Krish carbon), Metal-Organic Frameworks - cathode & composite cathodes	Si – Graphite composite anodes, Tin composite anodes, Li metal anodes, Metal-Organic Frameworks - anode

Next-generation technologies

India is the fifth largest car market in the world, by the end of 2030,



Chemical synthesis of reduced graphene oxide (rGO) for high-performance supercapacitor applications

an estimated 600 million vehicles will be on Indian roads. EV battery industry will play a key role in this e-mobility transformation. Li-ion batteries are now considered to be the standard for modern battery EVs in our country, with ISRO, Amar Raja Batteries, EON, HBL Power Systems and Exide making major advances and emerging as key manufacturers. Further, there is extensive research on several technologies such as Li/Na-S, Li-air, Na-Ion. Looking further ahead and considering possible depletion of Li-based resources in the future, flow batteries and fuel cell technologies are promising alternatives.

Vanadium flow batteries can be quite large and are best suited for industrial and utility scale energy storage applications. The V-flow battery out competes Li-ion, and any other solid battery, for utility-scale applications. They are safer, more scalable, longer-lasting and cheaper when produced on a large scale. IIT-Madras and IIT-Delhi, Rajiv Gandhi Institute of Petroleum Technology, IISc and Indian Institute of Engineering Science and Technology (IIEST) - Shibpur,

Space Heating Prototype

are extensively working for the development of vanadium based redox flow batteries.

Challenges and way forward

At present, the DST is working on reducing the gap between academic research and market demand which is a major challenge that needs to be overcome. Projects that involve the contribution of academia and companies may be encouraged and made mandatory in the near future. This would enable development of innovative and path breaking technologies and in the longer run enable our country to license technologies and become a knowledge hub.

Further, PhD scholars and students may be directed to carry out internships with companies for a short period so that they would be more aware of the requisites for large-scale production. The companies might also want to hire potential candidates based on their performance.

Our country has a vast talent pool and very capable research groups. The Ministry can take efforts to identify potential research groups working on the same battery system and initiate joint projects and startups to achieve specific targets.

Success Stories

IISER Pune and SPEL Technologies, with the support of DST, have developed a process technology for generating functionalized graphene at low-cost for the development of graphene-based supercapacitors for energy storage. This process uses the unconventional method of reducing graphene oxide (GO) leading to the formation of self-healed ambient, stable, reduced graphene oxide (rGO). The cost of raw chemicals for the production of 1 gm of rGO is estimated to be much cheaper than the commercial rGO from reputed international chemical company.

A solar-powered PCM (phase change material) integrated space heating system has been designed by Pluss Advanced Technologies with the support of the DST. The clean energy system designed to provide warmth in high altitude areas where night temperatures may fall to as low as -20°C, is scheduled to be set up in Leh in Ladakh. The developed system has the potential to meet the needs of space heating in residential schools, tourist shelters and for a large number of houses in Ladakh.

The successful application of 50 Ah Li-ion cells in an electric scooter by VSSC in association with Automotive Research Association of India (ARAI), Pune, is worth mentioning.

DST initiatives on energy storage

1. Materials for Energy Storage (MES)

The Materials on Energy Storage (MES) program supports R&D activities aimed at innovative materials for energy storage, and to build energy storage device with enhanced output for multifunctional applications. The initiative works towards the efficient use and further increase of renewable energy, demonstrating its value in terms of flexibility in the energy systems. This is expected to lead to the outputs which would substantially enhance technology readiness of the applied research for targeted application/use. MES scheme has supported 77 projects with a total cost of ₹51.78 crore.

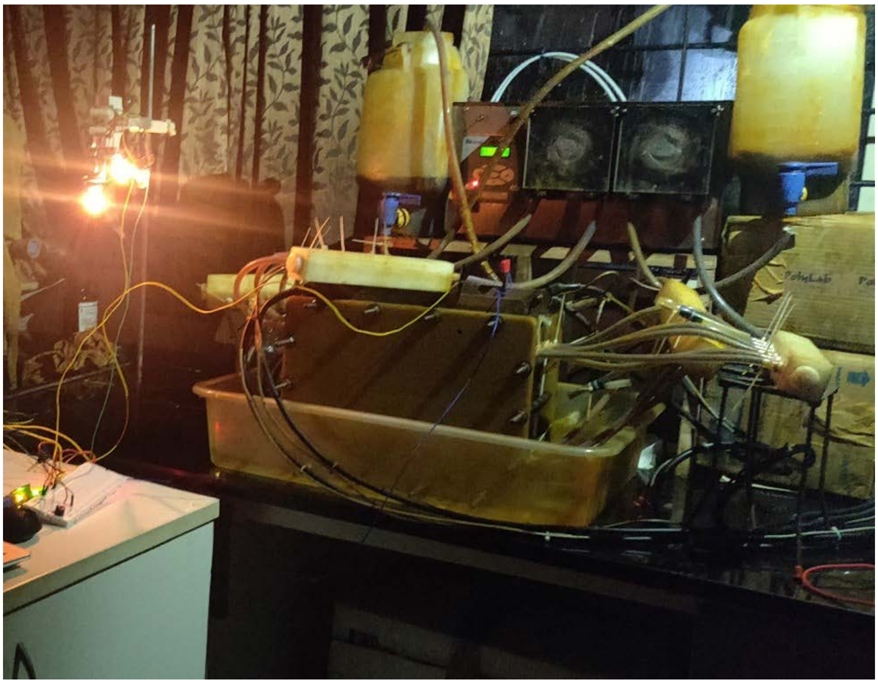
2. Materials for Energy Conservation and Storage Platform (MECSP)

This is a theme-based initiative to support research and development for entire spectrum of energy conservation and storage technologies from early stage research to technology breakthroughs in materials, systems and scalable technologies to maximize resource use efficiency. The purpose of this initiative is to underpin recognized centers of energy materials research, encourage those centers to link with new research groups working in complementary areas, link centers into a coordinated national network and create a strengthened energy materials research community that covers the full breadth of energy research areas that is strongly linked both nationally and internationally. Two centers have been supported.

DST- IIT Delhi Energy Storage Platform on Batteries: DST –IIT Delhi Centre on Batteries aims to carry out R&D to develop three different types of novel materials and their application in electrochemical storage devices. The network of researchers engaged in the center comprise scientists from IIT-Delhi, IISc-Bangalore, Central Glass and Ceramic Research Institute, Indian Institute of Chemical Technology, Institute of Minerals and Materials Technology, ARCI - Centre for Fuel Cell Technology.

DST- IISc Energy Storage Platform on Supercapacitors: The overarching objective of the DST-IISc Energy Storage Platform on Supercapacitors is to develop techno-economically viable electrical energy storage solutions that have the potential to catapult India to a leadership role in energy storage and clean energy technologies through active collaboration and accelerated technology development. IISc-Bangalore, being the nodal center has four partnering institutes, IIT-Hyderabad, IIT-Madras, Central Electro-Chemical Research Institute Karaikudi, Pondicherry University. The center will primarily focus on application-driven research for the development of techno-economically viable electrochemical energy storage solutions with particular emphasis on high power density storage such as supercapacitors.

Center for Incubation, Innovation, Research and Consultancy (CIIRC), Bengaluru has pulled off an arduous milestone in the development of Iron electrolyte based Redox flow Battery (IRFB) funded by DST, under its flagship Materials for Energy Storage (MES) Scheme. The team has successfully tested lighting loads using the developed flow battery and found that the battery has the capacity to power houses across rural India thus having a societal and environmental impact besides being a potential competitor for various household and industrial batteries available in the market. The team has a vision of developing and setting up IRFB charging stations for recharging EV batteries in the country, thereby creating a complete 'well to wheel' green ecosystem. The battery can be promoted as a cost effective and green system considering the materials used for development, electrolyte, and the area of applications (renewable energy sector).



Powering of 105 W bulbs from developed IRFBs

3. Integrated Clean Energy Material Acceleration Platform (IC-MAP)

The objective of setting up Integrated Clean Energy Material Acceleration Platform (IC-MAP) is to accelerate the discovery of high-performance low-cost clean energy materials for energy harnessing, energy storage and energy efficiency for diverse sectors such as power, buildings, transportation, storage, construction etc. Each IC-MAP is expected to focus its activities on a specific segment of thrust areas, identify the gaps and missing links and commit to a tangible output.

DST has conducted several brainstorming sessions in the area of energy storage to bring together industry leaders, policy makers, and leading researchers from across India, on the same platform to focus on multiple aspects of the clean energy materials and its industry applications. The sessions deliberated upon the mechanisms for the two segments to collaborate and develop high-performance, low-cost clean energy materials. ETN

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