THE ENERGY CONSORTIUM
IIT MADRAS

An Institute of Eminence Center

Unlocking a 24x7 Renewable Energy Future

Annual Report **2025-26**

www.energyconsortium.org

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CO2

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Foreword

Prof. Satyanarayanan Seshadri

Faculty-in-charge - The Energy Consortium

Head - School of Innovation and Enterpreneurship

Professor - Dept. of Applied Mechanics and Biomedical Engineering

IIT Madras

The Energy Consortium was established in 2021 to accelerate India's transition to net zero. Sustainability defined the early agenda: decarbonisation, emissions reduction, cleaner energy systems. But the last two years have surfaced questions that sustainability alone does not answer. Where does India's energy come from. Who controls the supply chains behind it. How resilient are these systems under stress. Energy security and energy sovereignty are not competing priorities. They are the conditions under which sustainability becomes durable.

The Centre for Sustainable Energy at the IITM Discovery Campus at Thaiyur, supported by the Coal India Limited, formalises the expansion of our remit. It consolidates work on indigenous storage materials, critical mineral recovery, grid resilience, and domestic technology development. Our flow battery programmes target 80% indigenisation. We are converting coal into battery-grade graphite and hard carbon with Coal India and building zinc-iodine and zinc-bromine chemistries on materials abundant in the subcontinent. Sustainable energy that depends on imported supply chains is not sovereign energy.

The year delivered material progress on both fronts. Industry membership grew to twelve companies across four continents, with BP, Caterpillar, and E. NI joining as core and framework partners. Across eight Centres of Excellence, sixteen multilateral and over twenty-five bilateral projects are active. The TRENDsetter program funded new work in CO_2 methanation, microbial biomass valorisation, and synthetic biology, the kind of early-stage research that industry alone will not fund at this risk level. The VRFB pilot at Trichy was commissioned at 10kW/50kWh, and the Triveni Turbomachinery Centre advanced our supercritical CO_2 test infrastructure.

On the innovation and entrepreneurship front, E.NI partnership along with Infosys expands our search from within to external start-up innovators, making the consortium a vehicle to support technology translation across the world.

Our research is increasingly shaping national policy. The DST CCUS Roadmap contribution, the PEM electrolyser lifecycle study proposing a green hydrogen classification framework, and the two-part marine spatial planning report on offshore wind in Tamil Nadu were built from Consortium work rather than commissioned externally. Our startups gained ground in parallel. Sthyr raised $1 million for grid-scale zinc-air storage, Wankel Energy Systems closed a $1 million pre-seed round, and IndusDC announced a ₹100 crore commitment to co-build deep tech clean energy ventures with TrigenDC, an Industrial Heatpump Company, being the first portfolio company to be supported.

Thirty-eight patents, 178 journal publications, and forty-five affiliated faculty define the base we work from. With the convergence of multiple research centres start-ups and other enablers, we will pursue the themes on security and sovereignty along with sustainability, using the same industry partnership model pioneered by the Consortium. These three will define the energy transition strategy for the years ahead.

Ringside View

Dr Nikhil S Tambe

CEO – The Energy Consortium

Adjunct Faculty – Dept of Applied Mechanics and Biomedical Engineering

IIT Madras

The Energy Consortium has had another powerful year overall, its fourth since establishment, and one that has evidenced a number of developments consolidating our core agenda of driving global industry-academia collaborative efforts. We have a number of highlights that cover technology translation, research and innovation, partnerships with industry majors and startups incubation.

It was a year when we onboarded two global majors in the energy transition arena, Caterpillar and British Petroleum, as Core members, further strengthening us in two important areas – low carbon fuels and electrification. The Energy Consortium's first two founding members, Baker Hughes and Shell, also both renewed their membership for another three years. These are extremely exciting developments, and we look forward to working closely with the faculty team and other industry members on guiding and directing research, technology, and innovation efforts. Additionally we have created a number of new strategic partnerships, such as the bilateral framework agreement with Italian integrated energy major Eni, partnership with the UK's Energy Systems Catapult, joint commitment with GRIDINDIA to develop training curricula for Tanzania & East Africa, and to work on joint research topics that will best bring out our strengths for addressing the specific requirements of the region, and the effort on Green Skilling that is funded by the Denmark Energy Agency.

The Energy Consortium continues to be deeply involved in working with government agencies and policy making think tanks, contributing through high powered committees. Prof Rajnish Kumar was a member of the national CCUS R&D roadmap committee constituted by DST, Prof Satya Seshadri

was engaged with Bureau of Energy Efficiency on the India Carbon Markets Framework deployment committee and Dr Nikhil Tambe contributed on the Long Duration Energy Storage committee constituted by NITI Aayog.

On overall public outreach and engagement with the broader communities, we crossed 10k followers on LinkedIn. This stands as a strong reminder of our continued commitment and single-minded focus on decarbonization while underscoring our approach for proactively striking global collaborations and strategic partnerships. Our followers represent all 11 categories within the Sustainable Industry Classification System (SICS®) of the Sustainability Accounting Standards Board (SASB) — reflecting our broad reach across sustainability domains. Our ability to encourage diverse professionals spanning multiple job categories, functions, and organizations of every scale — from startups to global enterprises, from over 100 regions worldwide- gives us additional pride and a shared sense of purpose.

We are proud of our affiliated faculty members, many of whom assumed increasing leadership opportunities in the past year. Starting with our Faculty Head Satya Seshadri who was appointed to Head the School of Innovation and Entrepreneurship. Prof Preeti Aghalayam took on Dean of Global Engagement role, Prof Rajnish Kumar assumed leadership of the School of Sustainability.

India's Nationally Determined Contribution (2031-2035) to be communicated to the United Nations Framework Convention on Climate Change have been recently approved by the Union Cabinet. India commits to 1) reduce Emissions Intensity of its GDP by 47 percent by 2035 from 2005 level, 2) achieve 60 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2035, and 3) create Carbon Sink of 3.5 to 4.0 billion tonnes of CO_2 eq. through Forest and Tree Cover by 2035 from 2005 level. This will drive a renewed focus on renewable energy integration into grids and the associated challenges as well as corresponding viable technology solutions that it entails. We have chosen the specific theme for this year's annual report aligned to this need!

Leadership Corner

Baker Hughes has been a founding member of the Energy Consortium from 2022 and since then, I have been impressed with the continued spirit of frugal innovation delivering its promises year upon year. Looking forward to what's coming next

Chris Pin Harry
Vice President - Technology, Industrial & Energy Technology, Baker Hughes

At Shell, innovation drives how the energy system functions today and shapes its evolution for the future. As a founding member of the Energy Consortium at IIT Madras, we are immersed in a vibrant open innovation ecosystem, collaborating with researchers and industry peers to address critical challenges and accelerate practical solutions for lower-carbon energy systems. Through this partnership, we have also created the Shell IITM Centre for Energy Research (SICER), further strengthening our shared commitment to advancing impactful, scalable energy innovations.

Ajay Mehta
Vice President Research & Innovation, Shell

Our collaboration with IIT Madras reflects Technip Energies' long-term commitment to advancing innovation and technology development for the energy transition. India is playing a defining role in shaping the global decarbonization agenda, and through our presence at IITM Research Park, we are fostering a strong ecosystem of industry, academia and startups to drive scalable innovation.

Collaborative Initiatives with IIT Madras Energy Consortium such as the 'Accelerating Green Hydrogen in India' stakeholder workshop, focused research programs in Carbon Capture & Utilization, and targeted startup engagement platforms reflect our shared commitment to transforming bold ideas into impactful, sustainable solutions for the future.

Wei Cai
Chief Technology Officer, Technip Energies

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About Energy Consortium

Established in Dec 2021, The Energy Consortium became an Institute of Eminence centre at IIT Madras in May 2023. It spans a broad spectrum of energy technologies including energy generation, storage, conversion, and distribution. Its central purpose is Accelerating Net Zero with a global industry-academia-government collaborative effort that it drives.

At The Energy Consortium, we firmly believe that technology solutions when deployed at scale in India will become technology solutions for the world. Our expertise emanates from affiliated faculty and includes carbon capture and storage, gas hydrates, renewable energy systems, distributed power, microgrids, electrolyzer technologies, and energy storage and conversion technologies.

45
affiliated faculty

Industry Funding
₹ 109.8 Cr.

India's largest
Energy Transition focused Industry Consortium

13
Industry members representing **4** continents and **6** sectors

4 faculty recognized with national level awards

7
multilateral and **33** bilateral active projects

318
journal publications
28 Patents

The Energy Consortium is helping accelerate net zero for hard to abate and hard to electrify sectors.

We are a channel for technology translation, licensing and start-ups creation.

Charter of the Consortium

National impact with global lessons learnt – Shape India's national energy research priorities and what it means for the rest of the world

Research leadership – Broaden the research portfolio for the 8 centers and identify research adjacencies for Consortium membership

Research infrastructure – Establish common infrastructure (e.g. lab space, shared resources) that make the centers cohesive and stronger

Create and implement an outreach plan to other academic institutions, industry and prominent academic/ industry conferences

Engage IITM's network of industry partners, public policy leaders and alumni to bring in perspectives that shape the future of the IITM energy consortium

Ecosystem building – Build deeper connections with other institutions and broader public, private partnerships

Raise the profile of the energy consortium nationally, regionally and globally

Resource development – Drive greater industry engagement

Shape the ongoing debate on national energy priorities

Global Partnerships

The consortium is a strategic partner to help incubate and groom technology that is in the discovery and feasibility stages and to assist those in the pilot demonstration levels through use case scenario validations and techno-economic studies geared to understand scaling and commercialization aspects. The idea is to enhance and accelerate R&D efforts of the consortium members on topics of mutual interest/ benefit by partnering with IITM.

The Energy Consortium has ten industries participating as our founding & core members. They are global energy majors focused on various sectors including O&G, power & utility, construction, transportation & digital enterprises and representing North America, Europe, Asia, Middle East regions. The current members are Shell, Baker Hughes, Infosys, Chevron, Chennai Petroleum Corporation Ltd, Technip Energies, NLC India Pvt Ltd, Saudi Aramco Caterpillar and bp.

We currently have more than 50 funded research projects that are ongoing with industry partners. In addition, we have conducted various consultancy projects and have collaborations with global strategic partners that includes Australia via its Department of Foreign Affairs and Trade, Denmark and broadly the Nordics via the Denmark Energy Agency and the Embassy of India in Copenhagen, UKs Energy Systems Catapult and our own campus at IIT Madras Zanzibar that gives us a vantage point for East Africa. The Energy Consortium provides its expertise in an advisory capacity with the Bureau of Energy Efficiency, Department of Science & Technology, Guidance Tamil Nadu, NITI Aayog. We are also officially observers at the UNFCCC on behalf of IIT Madras.

Governance

The Energy Consortium is run by an Industry Advisory Board (IAB) that has voting representation from all our founding and core members. The IAB oversees the overarching research direction of the consortium and directs funding as well as provides advisory inputs on the programs. The overall objective for the IAB is to accelerate technology translation. The IAB approves 3 year strategic plans and directs them through well-articulated key strategic initiatives and key performance indicators. The first such plan was for 2022-2025 and currently the 2025-2028 plan is in play.

For monitoring performance, the IAB has formed sub-committees with representation of the IAB members and faculty affiliated to the Energy Consortium.

Sub-committees led by industry representatives and IIT Madras faculty

TRENDsetter program that oversees predictable delivery and execution for the flagship research and technology programs funded by the consortium.

Pilot scale development committee that oversees scaling of successful TRENDsetter programs into mid TRL containerized or modularized pilots.

External engagement committee that oversees strategic engagements that enable unlocking funding from government and other sources, both nationally and internationally, that can augment the research and technology focus of the consortium.

Government engagement committee that is tasked with interfacing with government agencies and supporting in national missions.

2

CENTERS OF EXCELLENCE

2.1 About our Centers

Advanced Gas Turbine Engine Technologies

The Center focuses on advancing technologies for next-generation gas turbine engines that enhance efficiency and reduce carbon emissions. Key areas include combustor designs for hydrogen and sustainable aviation fuels, advanced thermal management systems, high-performance seals and rotors, and hybrid-electric propulsion components while addressing key challenges such as higher combustion temperatures, increased flow velocities to prevent flame flashbacks, enhanced safety measures, and advanced thermal management. The team is also working on high-temperature seals, high-rpm and high-pressure capability rotors, and innovative electrical machines that serve as both starter motors and generators. By developing these technologies and establishing dedicated test facilities, the Center aims to make the country self-reliant in hydrogen-powered gas turbine technology.

Carbon Capture, Utilization and Storage

The Center is driving innovation in carbon dioxide capture, utilization, and storage technologies to address global climate challenges. In CO_2 separation projects include calcium looping, solid absorbent-based capture using advanced materials like MoFs and amine-based composites, and physical solvent and hydrate-based processes for high-pressure mixtures. These efforts employ a multiscale approach, from atomistic simulations to pilot-scale demonstrations. In CO_2 utilization the focus is on catalytic hydrogenation for converting CO_2 to methanol or hydrocarbons, direct conversion to olefins, and the development of catalysts and reactors for selective and scalable reduction. Given the challenges in immediate large-scale CO_2 utilization, the Centre also emphasizes safe storage methods, including deep ocean sequestration, leveraging natural analogs like methane hydrates to ensure long-term stability. This comprehensive approach aligns with global efforts to meet Paris Agreement goals.

Energy Storage and Conversion

The Energy Storage and Conversion Center at IIT Madras focuses on developing novel materials and methods to address challenges in lithium-sulfur (Li-S) battery technology and photovoltaics in Li-S batteries, the Center aims to overcome limitations such as dendritic growth of lithium metal during charging, dissolution of lithium polysulfides into the electrolyte, and enhancing sulfur loading at the cathode. In photovoltaics, the emphasis is on creating organic and hybrid organic-inorganic perovskite solar cells with high power conversion efficiencies, low production costs, and improved stability against atmospheric degradation. By innovating in these areas, the Center seeks to advance energy storage and conversion technologies for both commercial and space applications.

Photo and Electro Chemical Energy

The Center for Photo and Electro Chemical Energy Services at IIT Madras focuses on developing advanced energy storage and conversion technologies. Key research areas include polarization electrochemistry for solar fuel generation and mechanically rechargeable metal-air batteries for electric vehicles. The Center aims to create efficient catalysts for water splitting to produce hydrogen fuel and to design high energy density metal air batteries utilizing abundant resources like aluminium and zinc. By integrating these technologies, the Center seeks to promote sustainable energy solutions and reduce dependence on fossil fuels, contributing to India's energy security and environment goals.

Microgrids & Resilient Energy Systems

The Center is advancing the next generation of microgrid technologies by focusing on collaborative, multi-source power systems. Moving beyond traditional diesel-dominated grids, it explores integrating diverse capacity-level sources with innovative control and management strategies. A key emphasis is on developing efficient, high-power density power electronic interfaces, along with primary control methods and protection strategies, to seamlessly connect multiple energy sources. The Center also prioritizes resilience through novel energy storage solutions and the integration of marginal capacity sources, including low-head water turbines, low-speed wind systems, steam-based generation, and waste-to-energy technologies. Decentralized control approaches are being investigated to reduce dependency on communication infrastructure. Leveraging emerging power electronic devices like SiC and promising GaN technologies, the Center aims to enable compact, efficient, and robust microgrid systems for sustainable energy solutions.

Renewable Energy Enhancement

The Renewable Energy Systems project at IIT Madras focuses on accelerating the adoption of renewable energy (RE) in India's commercial complexes. With solar and wind energy costs now competitive with coal, the project aims to develop commercially viable mechanisms enabling approximately 40,000 commercial complexes to transition entirely to RE. This initiative emphasizes integrating energy storage solutions to manage the intermittent nature of solar and wind power, ensuring a reliable 24/7 energy supply. By promoting large-scale RE development, the project seeks to reduce dependence on fossil fuels, decrease greenhouse gas emissions, and position India as a global leader in sustainable energy practices.

Jaisri and Venkat Rangan Wind Energy CoRE

India aims to achieve 302 GW of wind power in the near future, which requires new ideas and technologies suitable for our conditions. The power from a wind turbine is competitive in comparison to other sources. This new Center tackles the full spectrum of wind power, from rooftop turbines bringing clean energy to remote locations to large-scale offshore wind farms. The Center will also emphasize research into both onshore and offshore wind energy innovations, aiming to advance technological solutions that maximize energy generation efficiency and minimize environmental impact across diverse geographical landscapes.

Energy Systems Modelling and Risk Assessment

The research goals of ESMRA are broadly a) to leverage data-driven analysis and quantitative modelling in optimizing India's energy transition and decarbonization strategy, b) to generate novel insights that drive energy efficiency and material circularity in India's industrial sectors, c) to determine the optimum ways of balancing CO2 emissions targets with operating costs and viability, and d) to quantify climate-induced risks to critical assets and devise mitigation solutions. In alignment with these goals, the ESMRA group is undertaking efforts to develop a state-of-the-art framework - the Climate Action Tool (CAT)

6.2 New Lab Facilities

Triveni Turbines Centre of Excellence in Turbomachinery

The Energy Consortium, IIT Madras, in collaboration with Triveni Turbine Limited, advanced pilot-scale research infrastructure for supercritical carbon dioxide (sCO_2) technologies during the year. The initiative focused on strengthening existing transcritical sCO_2 test loop and high-pressure testing capabilities, while also supporting the development of a high temperature sCO_2 test facility and an integrated sCO_2 circuits test lab.

VRFB pilot facility at High Energy Batteries (India) Ltd, Trichy

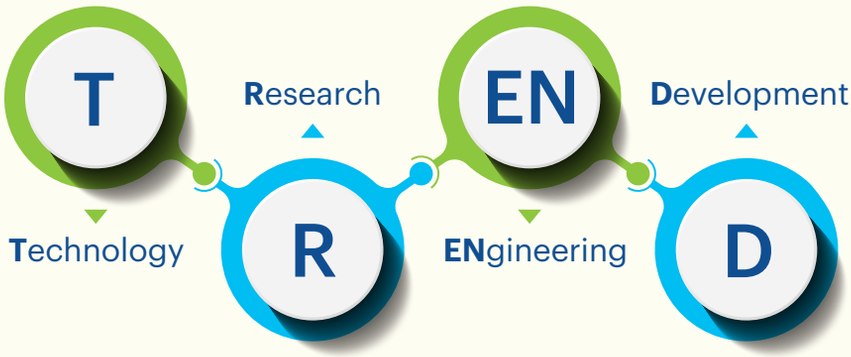
The Energy Consortium, IIT Madras continued its efforts in long-duration energy storage through the VRFB pilot initiative at Trichy. The pilot supports ongoing research and testing activities related to Vanadium Redox Flow Battery technologies and their potential applications in renewable energy integration and grid-scale energy storage.

Prof Kothandaraman Ramanujam and team in collaboration with engineers from High Energy Batteries (India), Trichy have leveraged funded support from ONGC and The Energy Consortium, IIT Madras in design, build and commissioning of a containerized version in Sep 2025 at HEB factory in Trichy. The pilot is vanadium flow battery system that supports a 10kW/50kWh (expandable to 40 kW / 0.1 MWh) configuration for scalable energy storage.

3

RESEARCH & TECHNOLOGY

3.1 TREND Setters



Technology **R**esearch
ENgineering and
Development
(TREND) setter program

The TREND setter program supports exploratory, industry-aligned research that can develop into scalable energy-transition solutions. In 2025, the program highlighted faculty-led work across biotechnology, carbon utilization, sustainable fuels, and industrial decarbonization. The program is designed to encourage deeper collaboration between IIT Madras researchers and industry partners, while supporting bold, high-risk ideas with real-world application potential.

As per the charter of the consortium, a majority portion of the industry membership funding is intended for exploratory and collaborative research that enables the Energy Consortium to become one of the key technology hubs. The TREND setter program aims to identify a few areas aligned with the long-range research initiatives of the industry and build capability within the consortium. It is anticipated the work done through this grant will enable the faculty teams to develop follow-on larger proposals for external funding. Industry and institutional partners can be identified and enabled by the consortium. The Energy Consortium is working closely with industry partners and will provide the requisite network and solicit expression of interest for developing large proposals such as are solicited by DST, DBT, MNRE, ANRF and EU Horizon calls, to name a few.

Length Scale: Reactor, Catalyst and Active Site


INDUSTRY DAY 2025

3.2. Key highlights of our faculty research projects

Engineering Microbial Systems for Biomass Valorization and Sustainable Chemical Production.

Prof. Guhan Jayaraman

Prof Guhan Jayaraman of the Department of Biotechnology is a recipient of the 2024 TRENDsetter program award under the High Risk High Reward track that is designed to encourage principal investigators to develop deeper collaboration with founding members of the consortium while delivering technologies that are at mid TRL.

Prof Guhan's research focuses on harnessing the potential of synthetic biology to engineer microorganisms capable of producing bulk chemicals from lignocellulosic biomass. The overarching goal is to replace petroleum-based chemical synthesis with renewable, biologically driven alternatives, thereby advancing the principles of a circular bioeconomy and contributing to climate change mitigation.

Through targeted genetic engineering, several microbial strains—primarily Pseudomonas taiwanensis, Acetobacter baileyi, and Lactobacillus plantarum—were developed to convert both lignin and the sugar fractions of lignocellulosic biomass into high-value chemicals. The first two organisms were specifically engineered to metabolize depolymerized lignin, a complex polyaromatic compound that is typically resistant to bioconversion and toxic at high concentrations. These engineered strains successfully produced rhamnolipids and muconic acid, key platform chemicals with wide-ranging applications in the bioplastics and textile industries. In parallel, Lactobacillus plantarum was modified using CRISPR-based tools to redirect its metabolic pathways toward overproduction of D-lactic acid and acetoin, by knocking out competing routes in its native metabolism.

The results achieved so far demonstrate the feasibility of producing these target metabolites in laboratory-scale bioreactors at high titers and yields. Efforts are now underway to scale up production to the pilot stage (200–1000 L), which would make these processes commercially viable and attractive for industrial technology transfer. In this work some essential monomers are developed that will help in synthesizing polylactic acid (PLA), a biodegradable plastic that can serve as a sustainable alternative to conventional petroleum-derived plastics such as PET. This dual impact—replacing fossil feedstocks and mitigating plastic pollution—highlights the environmental and industrial significance of the research.

Beyond these achievements, the work represents one of the few successful demonstrations of lignin valorization through microbial engineering, an area that remains underexplored compared to cellulose-based biomass conversion. The ability to design microorganisms that can tolerate and transform aromatic compounds into useful products marks a major advancement in sustainable biomanufacturing.

Prof Guhan added on the intrinsic motivations and rewarding aspects of the TRENDsetter program: **"The research itself is a reward of working. The fact that we are able to accomplish the objectives we set out to accomplish was definitely rewarding. And this particular project provided the impetus.** It catalyzed the proposals that we are able to write and submit based on the results that we got from this project for scaling up the production of some of the chemicals. Some of the other rewards, like we got some very good publications and one of the most rewarding things where this project also contributed is the fact that we are going to set up a bio foundry with help of substantial funding from BIRAC, which is mainly a facility to engineer organisms and develop processes with engineered organisms in partnership with industry"

The 'BioE3 (Biotechnology for Economy, Environment and Employment) Policy from Government of India for 'Fostering High Performance Biomanufacturing' has laid down the framework for the implementation of the Biomanufacturing and Bio-foundry Initiative and will enable start-ups, SMEs, industries and academia with access to shared infrastructure/facilities and resources for pilot & precommercial scale biomanufacturing of viable commercial bio-based products. One of the 6 hubs under this initiative is planned at IIT Madras and the focus will be leveraging expertise in bio based chemicals and enzymes towards energy and sustainability applications. The establishment of a state-of-the-art Bio Foundry, supported by substantial funding from BIRAC, will serve as a collaborative platform for engineering organisms and developing biomanufacturing processes with strong industrial partnerships. As one of the few such facilities in India, it will significantly accelerate innovation in synthetic biology and industrial biotechnology.

On the potential of the industry-academia collaborations that have been unlocked by the Energy Consortium via its flagship TRENDsetter program, Prof Guhan adds: "One of the very nice experiences is that I actually got to meet people from a lot of different areas who are working in the area of energy and climate change, etc., and working on a lot of different technologies. So, this kind of network and interaction has certainly opened up avenues for possible collaborations with some of them. This kind of industry-academia partnership is perhaps a way forward where we have the energy consortium now being set up with several key industry players and the fact that these industry players are able to give extremely valuable inputs and feedback into what you are doing and help us focus better on taking our research from bench scale to commercial application."

Looking ahead, the focus of the work underway by Prof Guhan and his co-PIs is on scaling up both the scope and the impact of engineered biological systems. By advancing microbial strain engineering and integrating process optimization, this line of research aims to multiply production capabilities and expand the portfolio of biochemicals derived from renewable sources. The work exemplifies the transition from laboratory innovation to industrial application, demonstrating how biological design can transform low-value biomass and waste streams into sustainable, high-value products for a cleaner, circular economy.

Microbial Engineering for CO_2 Sequestration and Metal Utilization in Sustainable Biofuel Development

Prof Richa Karmakar of the Department of Biotechnology is a recipient of the 2025 TRENDsetter program award under the early career track that is designed to encourage principal investigators to develop deeper collaboration with founding members of the consortium. This award is a 'seed grant' to work on new bold, high-risk research ideas within the proposed areas of interest

Prof Richa is engaged on emerging directions in a broad field that includes the application of synthetic biology for microbial strain engineering, bioelectrochemical systems for CO_2 reduction, and the integration of microbial carbon capture with biofuel production. Supported by advances in omics technologies and metabolic modelling, these developments are paving the way for the rational design of high-performance microbial systems. Her research demonstrates how biological innovation can transform environmental challenges into opportunities for sustainable energy generation and waste mitigation.

The TRENDSetter project led by Prof Richa presents an innovative approach to sustainable biofuel production through the development of engineered microbial systems capable of simultaneous CO_2 sequestration and trace metal utilisation. It seeks to address two pressing environmental challenges—greenhouse gas emissions and industrial metal waste—by employing specially adapted microorganisms as biological solutions. Conventional methods for carbon capture are typically energy-intensive and costly, while industrial processes generate metal-rich waste that can cause long-term ecological damage. The research introduces a sustainable, scalable, and cost-effective biological alternative to these issues.

Prof. Richa Karmakar

At the centre of this research is the use of Bacillus species isolated from a mud volcano, demonstrating exceptional tolerance to elevated CO_2 levels and toxic metals such as aluminium and chromium. Through adaptive laboratory evolution, these strains were repeatedly exposed to controlled high-stress environments, mimicking industrial conditions. Over successive growth cycles, the microbes exhibited improved survival, metabolic flexibility, and structural adaptations, as confirmed by scanning electron microscopy. The evolved strains showed enhanced abilities for CO_2 fixation and metal detoxification, establishing their potential as biocatalysts for sustainable bioremediation and energy production. **By converting waste CO_2 into valuable products such as biofuels and acetic acid, while simultaneously neutralising toxic industrial byproducts, the project advances the principles of a circular bioeconomy**—where waste streams become resources. This approach contributes directly to global carbon neutrality goals and sustainable industrial practices. It bridges the gap between microbial biology and applied energy science, offering tangible solutions for climate resilience and environmental protection.

Advancing CO_2 Methanation Catalysts for Real-World Utility

Prof. Sagar Sourav

Prof Sagar Sourav of the Department of Chemical Engineering is a recipient of the 2025 TRENDsetter program award under the early career track that is designed to encourage principal investigators to develop deeper collaboration with founding members of the consortium. This award is a 'seed grant' to work on new bold, high-risk research ideas within the proposed areas of interest

Prof Sagar's broader research focus lies in designing novel catalytic materials. About half of this work is directed toward CO_2 utilization to produce fuels, fuel additives, and chemicals, while the other half explores the valorization of natural gas and light hydrocarbons. These catalysts are designed to address critical application challenges, such as atom efficiency, product purity, and process stability, which in turn improve overall energy efficiency. What excites us most is leveraging molecular-level understanding to design better catalysts, enabling the translation of fundamental science into practical, real-world solutions.

The most recent trends in catalysis and process design show a major shift toward the development of novel catalysts and sustainable processes for converting waste streams—such as CO_2, biomass, and plastics—into fuels and value-added chemicals. These efforts align with global goals of circular economy and carbon neutrality, and are central to the future of energy and chemical industries.

The TRENDSetter project led by Prof Sagar focuses on advancing CO_2 methanation catalysts for real-world utility. The key objective is to develop a novel catalyst architecture for the hydrogenation of CO_2 to methane, thereby contributing to renewable energy production and sustainable fuel generation.

The main challenge we addressed was CO_2 methanation is a highly exothermic reaction, which means it generates significant amounts of heat during the chemical transformation. While manageable at laboratory scale, at larger scales this excessive heat leads to problems such as hot spot formation, catalyst deactivation, reactor choking, and compromised product selectivity. These issues limit the practical scale-up of the process. The project specifically aimed to address the challenge of heat dissipation while maintaining high catalytic activity—closing the gap between laboratory studies and industrial implementation.

The outcomes of the research are significant. The team has successfully developed a unique catalyst that integrates both chemical and engineering functionalities. Beyond enabling the transformation of CO_2 to methane with hydrogen, the catalyst design allows effective heat dissipation, ensuring stable catalyst performance and process efficiency during extended operation.

This project is addressing energy transition and climate change in a broader context. CO_2, largely generated from fossil fuel combustion, is a greenhouse gas driving climate change, glacier melting, ocean acidification, and other environmental impacts. While CO_2 capture technologies have matured, the conversion of CO_2 into renewable fuels and chemicals offers a dual benefit: reducing atmospheric CO_2 levels and lowering reliance on fossil fuels. Methanation of CO_2 produces synthetic natural gas (SNG), which can be readily transported through existing natural gas infrastructure. This provides a practical pathway to integrate renewable methane into industrial and domestic energy systems, supporting global energy transition goals.

3.3. 2025 TREND setter grant awardees

The following faculty members were selected under the TRENDsetter Program 2025 for their promising research contributions aligned with energy transition and decarbonization goals.

Track 1 – Pilot Demonstrators

Prof. Varunkumar S
– Department of Mechanical Engineering.

Track 2 – Early Career Faculty

Prof. T. Palaniselvam
– Department of Chemistry.

Prof. Sagar Sourav
– Department of Chemical Engineering.

Prof. Richa Karmakar
– Department of Biotechnology.

3.4 Early Career Chairs

Prof. Kothandaraman Ramanujam and Prof. Himanshu Goyal received Early Career Endowed Chair recognition for their contributions to research and innovation in energy and engineering domains. The recognition highlights their growing academic leadership and continued efforts towards developing impactful and future-focused technology solutions.

Advancing Global Energy Security through Indigenous Innovation: The Frontier of Sustainable Electrochemical Engineering

Interview with Prof. Kothandaraman Ramanujam, Annamalai & Santhi Rajendra Early Career Research Chair

Prof. Kothandaraman Ramanujam, Annamalai & Santhi Rajendra

In the global pursuit of a net-zero future, the transition from fossil fuels to renewable energy hinges on one critical bottleneck: energy storage. While laboratory breakthroughs are frequent, the path to commercial viability is often fraught with technical and supply-chain hurdles. Prof. Kothandaraman, recently recognized with the Annamalai & Santhi Rajendra Early Career Research Chair, is spearheading a paradigm shift in Indian energy research. His work focuses on translating fundamental electrochemistry into Minimum Viable Products (MVPs), prioritizing India's strategic independence and the practical needs of the industrial sector.

The Philosophy of the Minimum Viable Product (MVP)

For academia and industry to converge effectively, Prof. Kothandaraman advocates for a shift away from "beaker-scale" demonstrations toward pilot-scale evaluation. His chair professorship, a three-year tenure driven by performance reviews, is built on the objective of developing field-ready technologies.

A prime example is the development of a **10 kW - 50 kWh vanadium redox flow battery (VRFB)** with indigenous electrolyte and membrane, which has already moved from the laboratory to the field. Deployed at High Energy Batteries' premises, this unit is currently undergoing technoeconomic and durability evaluations. This field-first approach ensures that research is not merely a theoretical exercise but a commercially vibrant pursuit capable of solving real-world energy problems.

Strategic Indigenization and Energy Sovereignty

A recurring theme in Prof. Kothandaraman's research is the pursuit of India-centric solutions. While sodium-ion batteries are often touted as a "plentiful" alternative to lithium, he cautions that the host materials required—such as nickel, cobalt, and manganese—remain heavily dependent on imports.

To achieve true energy independence, his team is focusing on 80% indigenization in energy storage systems. In current megawatt-hour plant designs, the electrolyte, design, flow frame, and membranes are all developed and manufactured within India. By utilizing materials plentiful in the Indian subcontinent, such as Zinc, Iodine, and Bromine, his lab is creating a secure supply chain that circumvents the geopolitical risks of mineral scarcity at the same time offering energy storage capacities much higher than VRFB

Notably, the Zinc-Iodine battery offers a distinct advantage in the circular economy: iodine can be recovered through sublimation, transitioning directly from a solid to a gas, making the recycling process both economically viable and environmentally sustainable without requiring additional chemicals for recycling.

Breakthroughs in Hydrogen and Carbon Valorization

Beyond storage, the research extends to the "greening" of industrial processes through innovative electrochemical reactors.

Decoupled Hydrogen Generation: Traditional water electrolysis carries the risk of hydrogen being contaminated by oxygen, necessitating complex and difficult-to-maintain system designs. Prof. Kothandaraman has pioneered a decoupled electrolysis system using a three-electrode setup. By producing hydrogen and oxygen in a staggered manner, the system enhances gas purity and simplifies maintenance, offering a more robust prototype for industrial-scale hydrogen generation.

Carbon Dioxide Conversion: To address climate change, his team in collaboration with Prof Ramanathan S has developed reactors that convert CO2 into formic acid and carbon monoxide with a remarkable 90-95% efficiency. Carbon monoxide, as a component of syngas, is a highly sought-after industrial raw material, turning a greenhouse gas into a value-added reagent for the chemical sector. Since this reactor also produces hydrogen as byproduct, a gross margin model considering value of formic acid, CO and H2 indicates it as a profitable process.

Solving Practical Engineering Challenges: The Flow Battery Test Rig

In the burgeoning field of flow batteries, standardization has been a significant hurdle. Researchers often face electrolyte shifting due to osmotic pressure differences, which leads to capacity imbalance.

Prof. Kothandaraman's team has developed a specialized flow battery test rig that balances pressure drops countering electrolyte shifting. This allows the battery to maintain capacity balance over hundreds of cycles, performing as efficiently in the field as it does in its first cycle. By providing this standardized rig to the broader research community in India, he allows other scientists to focus on redox molecule innovation rather than mechanical troubleshooting.

A Global Academic and Industrial Network

The impact of this research is amplified through robust international and domestic partnerships. A flagship collaboration is the Australia-India Strategic Research Fund (AISRF) project with the University of Southern Queensland, focused on the eco-friendly recycling and repurposing of battery materials.

Further expanding his global footprint, Prof. Kothandaraman has established research ties with institutions in Taiwan, Singapore, and Malaysia. Domestically, he has completed NPTEL courses on electrochemistry and battery technologies, specifically designed for industry professionals, ensuring that the next generation of engineers is equipped with the knowledge to manage these emerging technologies. For past several years he is active in organizing several international conferences at IIT Madras, with the support of

Energy Consortium and Global Engagement Office at IITM, expanding the research network and internationalization at IIT Madras. The upcoming 3rd edition of IECS conference is in July between 13 to 17th at IITM (iecsconf.net; International conference on energy conversion and storage)

Repurposing Legacy Resources: The Coal Transition

As India pivots toward renewables, legacy industries like coal face obsolescence. Prof. Kothandaraman is working with Coal India to convert coal into value-added products like graphite and hard carbon. These materials serve as essential anodes for batteries or bipolar plates for fuel cells, offering a pathway to transition traditional coal resources into the clean energy supply chain.

The Future of Energy Research: A Vision for Academia

The Annamalai & Santhi Rajendra Early Career Research Chair serves as a vital endorsement of application-oriented research. For Prof. Kothandaraman, the award signals to the global community that solving tangible energy problems is as prestigious as fundamental discovery.

His "piece of wisdom" for the academic community and future chair professors is clear: prioritize field demonstration. The most effective research portfolios balance fundamental science with demonstrated pilot-scale projects. In a world where many claim to work on sustainability, the true measure of success is the ability to translate a laboratory concept into a commercially viable product that can be showcased in the field.

Through indigenization, innovative engineering, and a commitment to the circular economy, Prof. Kothandaraman is not just researching the future of energy—he is building it, one MVP at a time. This holistic approach ensures that India remains at the forefront of the global energy transition, transforming environmental challenges into indigenous economic opportunities.

Bridging the Innovation Gap: Scaling Core Engineering through Industrial Computing and Physics Based Models

Prof. Himanshu Goyal

Prof. Himanshu Goyal is a faculty in the Department of Chemical Engineering at IIT Madras and an affiliated faculty of The Energy Consortium. Recently he was recognized with the Radha and PK Narayanan Early Career Chair Professorship. His research group develops modeling and simulation tools to explore the interplay between transport processes (heat, mass and momentum) and chemical reactions that are at the heart of clean energy and process intensification technologies. The Energy Consortium's communications team sat down with Prof Himanshu to learn about his research focus and its applications.

Today, the journey of a new material from a lab-scale breakthrough to commercial implementation can take between 10 to 20 years and require an immense investment of capital and human resources. In a world demanding rapid decarbonization, this timeline is no longer acceptable. The objective of Prof Himanshu Goyal's research group is to utilize computational resources to compress this innovation cycle, aiming to reduce the transition timeline from decades to a span of 5 to 10 years.

Over the past few decades, core engineering innovation within academia has experienced a noticeable decline. The primary focus of research has shifted significantly toward materials development—a necessary endeavor, but one that is incomplete without a corresponding evolution in process engineering. The central challenge of our era, specifically regarding climate change and the energy transition, is not merely the discovery of a new catalyst or a more efficient electrolyzer; it is the implementation of these technologies at scale.

A New Paradigm: From Art to Science

Historically, the design, optimization, and troubleshooting of large-scale industrial reactors have been treated more as an art than a science. Engineers have traditionally relied on previous experience, empirical heuristics, and "thumb rules" to navigate the complexities of industrial systems. While effective for incremental improvements, these methods are insufficient for the radical technological shifts required for Net Zero targets.

Prof Himanshu's work aims to replace these experience-based techniques with science-based fast tools. He intends to provide industry leaders with a deeper understanding of the internal dynamics of their systems, allowing for designs based on fundamental scientific principles rather than trial-and-error.

The Methodology: Physics-Based Models and Digital Twins

The cornerstone of his approach is the development of digital twins—virtual representations of physical systems that allow for real-time simulation and optimization. His methodology relies on a dual-track strategy:

1. **First-Principles Physics:** He develops high-fidelity models grounded in the core

principles of chemical engineering to understand what is happening inside complex systems.

2. AI and Machine Learning: He leverages AI and ML to build fast surrogate models. While high-fidelity simulations are accurate, they are often too computationally expensive for real-time industrial use. ML allows us to create leaner models that can deliver rapid insights without sacrificing scientific rigor.

A critical emerging trend in this field is the unification of AI with domain knowledge. Prof Himanshu believes that ML and AI tools are only truly effective when combined with a strong background in core engineering principles. Bridging these two worlds—the latest computational tools and fundamental chemical engineering—is essential for solving the industry's most pressing problems.

Addressing the Industrial Scale-Up Gap

One of the most significant hurdles in industrial computing is the "Gap" between laboratory simulations and real-world application. While commercial simulation software is widely available, its utility is often limited to simple, lab-scale systems operating under ideal conditions.

Actual industrial commercial-scale systems are massive and involve complexities that are typically ignored in a laboratory setting. Prof Himanshu's research focuses on bridging this gap by taking accurate, high-fidelity simulations from the lab and translating them into simple, fast models that remain robust when applied to real-world, commercial-scale reactors. These tools are designed for three primary industrial needs:

* **Scale-up:** Taking new technology from the lab to the field efficiently.
* **Optimization:** Designing systems to be more energy-efficient and carbon-neutral.
* **Troubleshooting:** Using scientific models to identify and solve challenges in existing processes.

Impact Across Key Industrial Sectors

The versatility of core engineering principles allows his computational tools to have a broad impact across various sectors. We have successfully collaborated with industry leaders to address diverse challenges:

* **Petrochemicals, Oil, and Gas:** Working with partners like Shell, he has applied these models to traditional refinery problems while also looking toward the future of energy.
* **Fast-Moving Consumer Goods (FMCG):** Collaborating with Unilever to apply chemical engineering fundamentals to the production and optimization of consumer products.
* **Pharmaceuticals:** Partnering with companies like Pfizer to develop models that enhance the precision of drug manufacturing and system design.

In each of these sectors, the goal remains the same: to provide tools that allow for more efficient design and the reduction of energy-intensive trial-and-error techniques.

The Path Toward a Sustainable Future

The transition to a sustainable economy requires a fundamental change in technology. Whether the focus is on green hydrogen based on electrolyzers or Carbon Capture, Utilization, and Storage (CCUS), the engineering scale remains the "missing link". There are very few researchers globally working at the intersection of material science and engineering scale-up, and Prof Himanshu's group at IIT Madras is dedicated to filling this vacuum.

By building computational tools that facilitate faster transitions, he is not just conducting a textbook exercise; he is engaging in work that has a real chance of making a significant global impact. The interest he has captured from industry partners validates the huge demand for these tools and motivates his team to continue pushing the boundaries of what is possible.

A Call to Collaboration

Receiving the Radha and PK Narayanan Early Career Chair has provided Prof Himanshu's research group with increased visibility and the encouragement to pursue these ambitious goals. However, the journey from scientific theory to industrial reality requires a deep, ongoing partnership between academia and industry leaders.

The future of engineering lies in his ability to synthesize the "art" of industrial experience with the "science" of advanced computation. As he looks forward, his focus remains clear: leveraging AI, ML, and fundamental physics to ensure that the innovations of today become the industrial standards of a cleaner, more efficient tomorrow.

3.5 Insights from Rajnish Kumar on low carbon future

Compiled based on his appointment as a member to the National CCUS R&D Roadmap committee constituted by DST and launched to Advance India's Net Zero Goals

Rajnish Kumar

India's Strategic Roadmap to Net Zero: Navigating the CCUS Landscape

The Department of Science and Technology (DST) in India has recently unveiled the Carbon Capture, Utilization, and Sequestration (CCUS) roadmap, a critical strategic document designed to guide the nation toward its ambitious carbon emission intensity reduction goals that are part of the nationally determined contributions. This high level task force, chaired by Dr. Ashish Lele, Director, CSIR-NCL, Pune and featuring subject matter experts from across the country including affiliated faculty of The Energy Consortium, Professor Rajnish Kumar, was tasked with identifying the necessary research and development trajectory for the next five to ten years. In conversation with the Energy Consortium communications team Prof Rajnish shared details about the thinking behind the CCUS roadmap document.

The primary focus of this roadmap is to foster a robust CCUS community in India that can effectively contribute to the national goal of achieving net-zero emissions by 2070. While the destination is clear, the roadmap acknowledges that achieving this target requires a series of intermediate milestones focused on reducing fossil fuel dependence and curbing CO_2 emissions.

The Scale of the Challenge

The motivation behind this roadmap is rooted in the sheer scale of India's current carbon footprint. As of 2026, India emits approximately 3 billion tons of CO2 annually, making it the third-largest emitter globally, trailing only China and the United States. Although India's per capita emissions remain low, the total volume is significant and is currently increasing at a rate of roughly 5% every year. If left unaddressed, these emissions could double to 6 billion tons in the near future.

Professor Rajnish compares the 2070 net-zero target to a "missile which shoots beyond visual range," noting that because the destination is two generations away, it is difficult to visualize the exact path without rigorous modeling and planning. To reach net zero, India must aim to reduce at least 50% of its current emissions, which equates to roughly 1.5 billion tons per year. The roadmap serves as a vital tool to assess the cost implications, infrastructure needs, and technological interventions required to achieve such a massive reduction.

Industrial Implementation and Economic Reality

The Ministry of Environment, Forest and Climate Change (MOEFCC) has already begun implementing phased emission intensity targets for over 700 companies across diverse sectors, including cement, steel, aluminum, and petrochemicals. While initial targets—such as a 7% to 15% reduction in emissions—are deemed

achievable through better heat integration and waste reduction, deeper cuts represent a significant challenge.

Prof Rajnish highlights a "double whammy" facing energy-intensive industries: the lack of affordable high-end technology and the high cost of energy transitions. In India, coal remains a dominant and inexpensive energy source, sold at approximately 1 rupee per kg. Moving away from this cheap energy or retrofitting existing units with CCUS technology could double production costs, potentially making Indian products uncompetitive in the global market. Consequently, the roadmap emphasizes that achieving optimized costs and environmental protection simultaneously will require a combination of advanced research, government subsidies, and the development of voluntary carbon markets to help bridge the funding gap.

Technological Frontiers at IIT Madras

At the forefront of the technical research described in the roadmap are the efforts at IIT Madras, where researchers are developing several promising CO_2 capture technologies. These include:

Direct Air Capture (DAC): In collaboration with L&T, researchers have delivered DAC solutions that are already being implemented in hundreds of units across the country. This technology is particularly challenging because it must capture CO2 from the atmosphere where concentrations are as low as 400-500 ppm, requiring highly robust and efficient processes.

Point Source Capture: The team is operating a 250 kg per day pilot scale unit exploring two main approaches: amine-based solvents and solid adsorbents like zeolites.

Advanced Materials: Ongoing research involves testing a mixture of amines and ionic liquids, as well as proprietary technologies currently undergoing pilot-scale testing.

Despite these developments, the sources maintain a realistic outlook, noting that current research is still focused on reducing the "energy penalty" associated with capture materials. The goal is to move beyond simply matching existing market materials and instead optimize conditions to make the technology truly cost-effective.

The Academia-Industry Divide

A critical aspect of the roadmap is defining the transition of technology from academic labs to industrial application. There is often a mismatch in expectations; while industry seeks "finished products," academia is primarily a training ground for PhD students focused on fundamental science. **Professor Rajnish argues that academic institutions should generally not attempt to move beyond Technology Readiness Level (TRL) 5 or 6.**

The higher TRL levels (7, 8, and 9) require specialized safety cells, massive human resources for 24/7 operation, and industrial-scale management that universities are not equipped to handle. Instead, the roadmap envisions a collaborative model where academia solves technical challenges and develops prototypes, while industry takes the lead on large-scale implementation.

This requires sustained efforts, often spanning two to three years, supported by experienced postdoctoral researchers who possess the specific skill sets needed for process development at scale.

The Role of Nature-Based Solutions

The roadmap also considers nature-based sequestration, such as projects involving the Tamil Nadu Pollution Control Board. While these solutions are viewed positively, the Professor cautions that they cannot be the sole remedy. With global emissions at 40 billion tons per year and the average person emitting 5,000 kg of CO_2 annually, the rate of human emission far outpaces the natural sequestration rate. Nature-based solutions must therefore be implemented alongside human-engineered interventions, such as new materials, improved heat integration, and increased industrial efficiency.

A Bridging Solution for a Renewable Future

Ultimately, the sources characterize CCUS not as a permanent fixture, but as a "bridging solution". The long-term outlook for India involves a complete transition away from fossil fuels toward renewable energy, a process estimated to take at least 30 to 40 years. During this transition period, India cannot afford to sit idle while emissions continue to rise.

CCUS provides a necessary pathway to reduce the national carbon footprint in the immediate three-to-five-year horizon while the infrastructure for a 100% renewable grid is established. By integrating research, policy, and industrial collaboration, the 2026 roadmap aims to ensure that India remains on a viable path toward its 2070 net-zero destination, utilizing CCUS to manage the environmental impact of its growth in the intervening decades.

4

PARTNERSHIPS

During the year, The Energy Consortium, IIT Madras continued to strengthen its industry and global collaboration network through strategic partnerships focused on energy transition, industrial decarbonization, grid modernization, and clean energy innovation.

These collaborations brought together industry leaders, research organizations, and international partners to accelerate translational research and support the development of scalable low-carbon technologies.

A. Energy Consortium and Eni Establish Multi-Year Research Collaboration

The Energy Consortium, IIT Madras, has entered into a multi-year master framework agreement with Eni, marking a significant step in strengthening industry–academia collaboration to support the energy transition. The partnership will shepherd multiple research and technology engagements in coordination with IIT Madras faculty, focused on advancing solutions for a sustainable, low-carbon future.

Under the agreement, Eni and IIT Madras will undertake joint research activities with a strong emphasis on Technology Readiness Level (TRL) advancement. Key focus areas include water and wastewater treatment, biofuels processing and testing, and AI and digital technologies, alongside broader themes of energy, decarbonisation, environment, and sustainability. The national labs and state-of-the-art research infrastructure at IIT Madras will play a critical role in enabling these efforts.

Eni, a leading Italian multinational integrated energy technology company, is transitioning toward carbon neutrality by 2050 by decarbonising its products and processes and investing in renewables, biorefining, circular economy solutions, and advanced technologies such as fusion. This collaboration reflects The Energy Consortium's mission to catalyse impactful partnerships that accelerate innovation across the energy value chain.

B. bp & Caterpillar Join the Energy Consortium, IIT Madras as Core Members

The Energy Consortium, IIT Madras is pleased to welcome bp as a core industry member for a three-year engagement, working closely with IIT Madras faculty and consortium partners to guide research, technology development, and innovation in support of the energy transition. The collaboration was formalised during a brief ceremony at the IIT Madras campus, where senior leaders from bp exchanged agreements with Institute representatives, marking the start of deeper engagement across fuels, low-carbon technologies, and shared research priorities.

Caterpillar Inc. has also joined The Energy Consortium, IIT Madras as a core industry member for a three-year term, partnering with faculty and industry members to accelerate research and innovation toward net-zero and sustainable energy systems. The collaboration was formalised at IIT Madras through an agreement exchange with senior Caterpillar leadership and Consortium representatives, laying the foundation for joint work across electrification, energy systems, and industrial decarbonisation technologies.

Together, these partnerships strengthen The Energy Consortium's role as a platform for sustained industry–academia collaboration, accelerating the development and deployment of scalable technologies for a low-carbon and resilient energy future.

C. KSEB – For Future Grid Augmenting and Grid Enhancing Technologies

The Energy Consortium – IIT Madras signed a definitive MoU with the Kerala State Electricity Board (KSEB), an integrated electricity utility of the Government of Kerala responsible for generation, transmission, and distribution of electricity across Kerala, supplies electricity to about 99% of consumers in Kerala, to around 1.42 crore consumers as on December 2025. KSEB's journey has seen significant changes in energy generation, cost structures, and consumer patterns. It places a strong emphasis on renewable energy adoption, Solar power, in particular, has seen exponential growth. To address the intermittency of renewable energy, KSEB is exploring the feasibility of Pumped Storage Plants and Battery Energy Storage Systems. The surge in peak demand and off-peak availability has necessitated investment in the power infrastructure and in balancing peak and off-peak requirements.

Jointly with The Energy Consortium, KSEB will be exploring opportunities of engagement in research areas of interest that include Grid stability and integration of renewable energy, particularly rooftop solar, and Electric Vehicle (EV) related charging load management, dynamic line rating solutions, grid analytics, grid edge solutions, analytics solutions using smart meters and other areas.

The Energy Consortium will conduct technology verification and validation of its advanced models and AI based stacks for helping better anticipate and therefore cater to the enhanced management of volatile and intermittent renewable sources. The engagement will also include support on policy and regulatory matters through collaboration on white papers, scientific inputs to policy makers, and reports on impact assessments.

D. E.ON - Trilateral Partnership to Drive Innovation in Resilient Grid Technologies

Indian Institute of Technology, Madras has, via The Energy Consortium – IIT Madras and School of Innovation & Entrepreneurship, entered into a collaborative framework agreement with E.ON Group Innovation (EGI) and Infosys in the field of energy and digital innovation. The objective is to jointly explore, structure, and advance innovation opportunities by aligning business challenges identified by E.ON with solutions emerging from startup ecosystems and student-led ventures in India, including both IIT Madras–affiliated and non-affiliated participants.

Stay tuned for more details coming in very shortly!

EGI is the E.ON Group's incubator for technologies and business models in the new energy world. As part of one of Europe's largest energy providers, EGI drives the development of new solutions for the E.ON Group and promotes collaboration with start-ups, universities, and innovative companies.

Infosys is a global leader in next-generation digital services and consulting. As a digital energy orchestrator, Infosys partners with leading energy companies to modernize grids, integrate renewables, and enable low carbon solutions leveraging cutting-edge digital innovation—advanced analytics, AI-powered optimization, IoT, and digital twins.

E. The Energy Consortium-IIT Madras Partners with UK's Energy Systems Catapult to Drive Net-Zero Innovation

The Energy Consortium-IIT Madras has entered into a strategic partnership with Energy Systems Catapult (ESC), a UK government-backed innovation centre focused on accelerating the transition to a net-zero energy future. This collaboration signifies a major step for cross-border knowledge exchange and the commercialization of clean energy technologies.

The Memorandum of Understanding (MoU) was officially announced today with key representatives from both EC (Dean Manu Santhanam, Dean Raghunathan Rengasamy, Prof. Satyanarayanan Seshadri, and CEO Nikhil Tambe) and ESC (Brendan O'Neill and Lowri Williams), alongside the British High Commission (Babita Sharma and Tabinda Bashir).

This partnership will enable joint research and development initiatives in critical areas, including renewable energy, smart grids, green hydrogen, electric mobility, and green ports. It also aims to foster innovation in energy policy and regulation through bilateral workshops and collaborative studies relevant to both India and the UK. This collaboration further strengthens IIT Madras' long-standing ties with the UK in the energy sector, underscoring a shared commitment to advancing clean energy innovation and international partnerships.

F. NLC India and The Energy Consortium - IIT Madras Join Forces to Advance Carbon Capture Technologies

The Energy Consortium-IIT Madras has signed a new strategic partnership agreement with NLC India Limited. This collaboration marks a significant step towards advancing India's decarbonization goals, with a specific focus on economical Carbon Capture technologies and the future utilization of captured carbon dioxide.

Through this partnership, NLC India Limited aims to leverage IIT Madras's robust academic and innovation ecosystem. The goal is to pilot, refine, and ultimately scale practical Carbon Capture, Utilization, and Storage (CCUS) solutions that are suitable for large-scale deployment in industrial settings.

The partnership reflects a shared, time-bound commitment to supporting India's decarbonization goals through scientifically robust and commercially viable technologies.

The Energy Consortium will serve as the collaborative platform, facilitating co-development of solutions, student engagement, and long-term knowledge exchange tailored to NLCIL's operational context.

G. A Big Leap Towards the Future of Clean Energy: IIT Madras Partners with Triveni Turbine Limited

In a significant step towards advancing next-generation clean energy solutions, Triveni Turbine Limited has entered into a partnership with the Indian Institute of Technology Madras to jointly develop capabilities in supercritical carbon dioxide (sCO_2) technologies. This collaboration will focus on building cutting-edge infrastructure, fostering human capital, and accelerating innovation in sCO_2-based power systems — a frontier area with transformative potential for the energy sector.

Key areas of collaboration include leveraging IIT Madras' existing transcritical sCO_2 test loop and high-pressure testing infrastructure to accelerate research and validation. The partnership will also focus on developing a new high-temperature sCO_2 test loop to explore advanced applications and establishing a dedicated Triveni Test Lab for Integrated sCO_2 Circuits—creating a robust platform for experimentation, capability development, and industrial-scale innovation.

This collaboration marks a powerful step forward in aligning research, industry, and innovation for a cleaner, more resilient energy future.

H. The Energy Consortium - IIT Madras Faculty Drives Green Hydrogen Innovation in Key Indo-Danish Project

Prof. Shanti Swarup has been selected for a pivotal Green Hydrogen Research Project under the 2024 Indo-Danish bilateral research call. This initiative, part of the strategic Green Strategic Partnership between India and Denmark, aims to accelerate the deployment of cutting-edge hydrogen technologies.

Out of 15 joint proposals, Prof. Swarup, in collaboration with Prof. Kaushik Das of DTU – Technical University of Denmark, will be a core part of the "Strategic Green Hydrogen Integration Towards Energy Transition and Localisation Demand to Deployment (SHIELD)" project. This significant effort is focused on converting renewable electricity into green fuels for clean transport and a decarbonized industry.

This selection highlights our commitment to leading advanced energy research and our crucial role in fostering international collaboration for a sustainable future.

5

GLOBAL PERSPECTIVES

5.1 Special Sessions

A. Munib Amin: Challenges in Energy Transition in Europe (Expert talk)

The Energy Consortium – IIT Madras, jointly with the School of Innovation and Entrepreneurship, organized a talk delivered by Munib Amin, MD – E.ON Group Innovation. The talk explored Europe's shift from a centralized, 19th-century electromechanical model to a distributed, digitized energy system — focusing on complexity, resilience, renewables integration, workforce constraints, and the role of digitalisation and automation.

Munib Amin

It covered some key challenges such as:

System Complexity & Stability: The move toward millions of decentralized assets (like solar PV) makes the grid less predictable and harder to stabilize compared to traditional centralized power plants.

Infrastructure Mismatch: Existing distribution grids were designed for consumption, not for collecting and redistributing massive amounts of renewable energy, requiring expensive and massive upgrades.

Resilience & Security: The system faces increasing vulnerabilities from technical instabilities (oscillations), physical sabotage, and cyber risks, all while needing to maintain 100% reliability.

Workforce Constraints: An aging population in Europe has created a severe shortage of qualified craftspeople and engineers needed to physically implement the energy transition.

Legacy & Regulation: Mature economies often struggle with "over-engineered" solutions and heavy regulatory burdens that slow down innovation and increase costs.

And also discussed possible pathways including

Massive Digitization: Implementing real-time grid observability, AI-driven forecasting, and automation to manage the complex, fluctuating intake of renewables.

Frugal Innovation (Indo-European Collaboration): Leveraging India's expertise in "frugal innovation" to develop simple, low-cost, and scalable solutions that can be proven in India and then transferred to the European market.

Paradigm Shift in Design: Instead of just emulating the old system digitally, there is an opportunity to build an entirely new, decoupled, digital-first system that is more resilient and sustainable.

Resilience Framework: Moving toward a "Prevention, Detection, and Mitigation" strategy where the ability to rapidly recover from a disruption is prioritized alongside system robustness.

In the context of the India–EU FTA, the talk highlights opportunities to scale India's presence in Europe's high-value markets, with long-term, predictable access fueling partnerships.

B. Colloquium by Dr. Cathy Tway (British Petroleum): Rethinking Catalysis for a Sustainable Future

The Energy Consortium, IIT Madras was delighted to host a delegation from bp (British Petroleum), including Dr. Cathy Tway, Chief Chemist and Vice President for University Partnerships; Dushyant Sharma, Technology Head; and Dr. Mandar Thakare, Associate Director, bp International Centre for Advanced Materials (ICAM).

As part of the visit, the Department of Chemical Engineering organised a colloquium by Dr. Cathy Tway on "Is Catalysis Reaching Its Transition State?" Her thought-provoking insights reminded us that sustainable catalysis is not solely about greener raw materials but demands system-level thinking, responsible innovation, and long-term environmental accountability.

At The Energy Consortium, IIT Madras, we continue to create platforms for such conversations that shape the future of energy, chemistry, and materials science.

C. Green Energy Academy: Advancing the Green Transition Through Indo-Danish Collaboration

With support from the Danish Energy Agency, The Energy Consortium, IIT Madras is leading the Danish–Indian Green Energy Academy, in collaboration with Energy Cluster Denmark, Aprendio, and the Energy and Climate Academy, under Denmark's Energy Export Initiatives programme. The initiative strengthens public–private collaboration to accelerate clean energy adoption and market readiness in India.

The Green Energy Academy is designed to bridge critical gaps in innovation, capacity building, and deployment, making renewable energy solutions more accessible, scalable, and impactful. By connecting research, industry expertise, and skills development, the project aims to support India's green transition while enabling knowledge exchange between Danish and Indian energy ecosystems.

The initiative directly contributes to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), while reinforcing SDG 17 (Partnerships for the Goals) through international collaboration. It also highlights the growing strategic partnership between Denmark and India in accelerating renewable energy deployment, decarbonisation, and long-term sustainable development.

D EU Horizon Funding to Vinu

Prof. Vinu received support through the EU Horizon framework, further strengthening international collaboration and research engagement in sustainable energy and industrial decarbonisation themes.

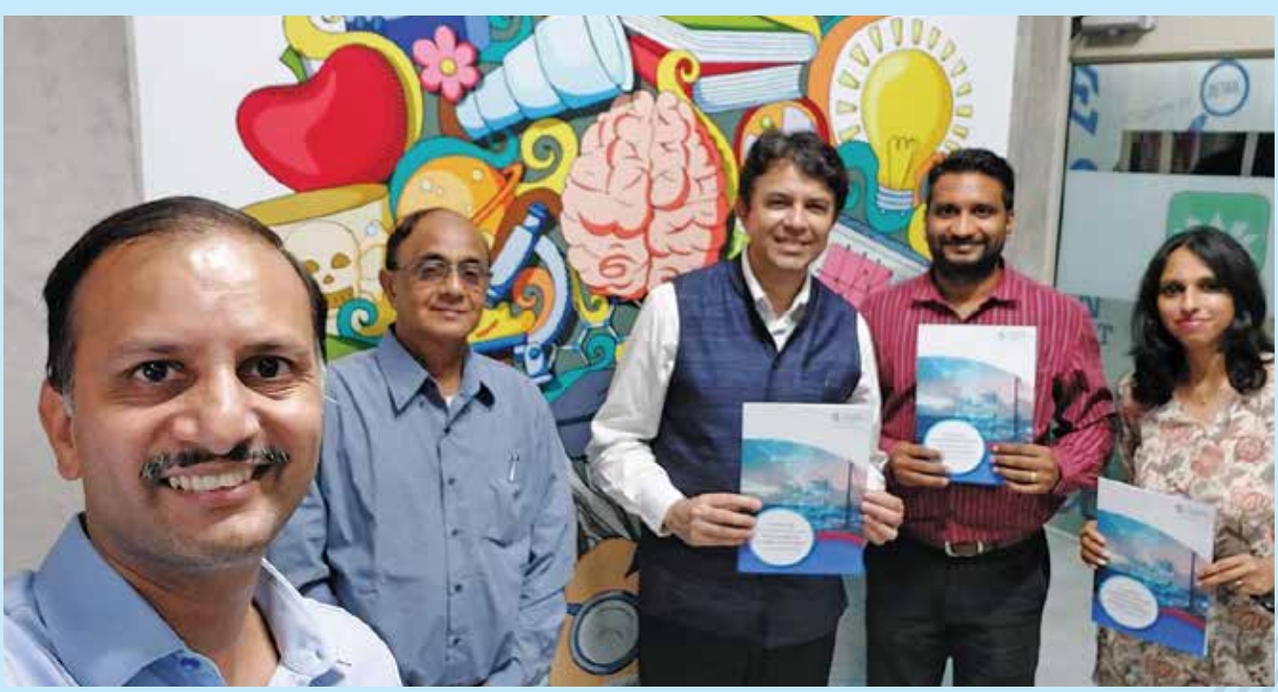
E. Strengthening Indo-Danish Energy Ties: IIT Madras Hosts Indian Ambassador to Denmark

The Energy Consortium, IIT Madras was honoured to host Shri Manish Prabhat, Ambassador of India to Denmark, for a special campus engagement celebrating the Indo-Danish energy partnership.

The visit highlighted The Energy Consortium, IIT Madras' active collaborations with Danish academia, industry, and government bodies, including joint research under the Indo-Denmark Energy Partnership. Prof. Shanti Swarup, a recent award recipient, represented these efforts.

Key focus areas include marine spatial planning, offshore wind, and green ports, with ongoing work in collaboration with the Danish Energy Agency and Energy Cluster Denmark. As an advisory member of Innovation Centre Denmark, Bangalore, The Energy Consortium, IIT Madras plays a strategic role in shaping bilateral energy transition agendas.

The Ambassador was introduced to select research pilots, student-led innovations, and the legacy of IIT Madras, reinforcing the institution's commitment to global energy innovation.



5.2 Engagement with academia: Mobility program highlights

i. Ranjit Bauri

Prof. Ranjit Bauri, Department of Metallurgical and Materials Engineering, IIT Madras, is collaborating with the Norwegian University of Science and Technology (NTNU) on the project "Synergistic Recovery of $FePO_4$ from Bauxite Residue and Steel Making Slag for Making Cathodes of Lithium-Ion Batteries." The research focuses on recovering materials from industrial waste streams—specifically bauxite residue and steelmaking slag—and converting them into value-added cathode materials for lithium-ion batteries, advancing sustainable resource utilisation and supporting circular economy practices in energy materials.

ii. Raghuram Chetty

Prof. Raghuram Chetty, Department of Chemical Engineering, IIT Madras, has been awarded the project "Feasibility Study for Enhanced Local Grid Stabilisation Using a 100 MWh Vanadium Redox Flow Battery (VRFB) System to Support Critical Infrastructure" under the Jointly Funded Bilateral Mobility Program (JFBMP) 2025. In collaboration with the University of Hull, the project explores the deployment of large-scale VRFB systems to enhance grid stability, facilitate long-duration energy storage, and bolster critical infrastructure resilience, thereby contributing to India's clean energy transition and global innovation in electrochemical energy systems.

iii. Somnath C. Roy

Prof. Somnath C. Roy, Department of Physics, IIT Madras, has worked on the project "MoS_2–TiO_2 Heterojunction Photocatalyst for Photoreduction of CO_2" under the Jointly Funded Bilateral Mobility Program (JFBMP) 2024. In collaboration with Tel Aviv University, the project focuses on developing advanced heterojunction photocatalysts that enable efficient CO_2 reduction under solar irradiation, offering promising pathways for sustainable fuel generation and renewable-driven carbon solutions.

6

POWERING CONVERSATIONS

6.1 News Highlights

1. Chairman of the IIT Madras Board of Governors, Dr Pawan Goenka, reviewed our ongoing work on Industrial Decarbonisation

The Energy Consortium, IIT Madras, had the pleasure of hosting Dr. Pawan Goenka, Chair of the Board of Governors, and Prof. Kamakoti Veezhinathan, Director, IIT Madras, at the Cooling and Heating Innovation Lab (CHIL), led by Prof. Satya Seshadri.

The visit highlighted The Energy Consortium's focus on guiding deep-tech startups in translational research on energy-transition technologies. Discussions centred on opportunities to decarbonise industrial process heating using high-temperature heat pumps developed by TRIGeN Decarbonisation, an IndusDC portfolio company.

The team also showcased upcoming product innovations aimed at increasing heat pump delivery temperatures beyond 160 °C, with the potential to address up to 40% of industrial heating requirements. The engagement underscored the role of The Energy Consortium, IIT Madras, in translating cutting-edge research into scalable solutions for industrial decarbonisation.

2. Continuing Founding Members Shell and Baker Hughes appoint respective nominees, Dr. Vikrant Urade and Rahul Wagh to The Energy Consortium, IIT Madras Advisory Board

Continuing their long-standing engagement as founding members of The Energy Consortium, IIT Madras, Shell and Baker Hughes have appointed Dr. Vikrant Urade and Rahul Wagh, respectively, to The Energy Consortium's Industry Advisory Board—further strengthening industry leadership in shaping the Consortium's research and innovation agenda.

Dr. Vikrant Urade, Principal Researcher – Energy Systems and Pathfinding at Shell, brings deep expertise in energy systems modaelling, technology pathfinding, and decarbonisation strategies. His work at Shell focuses on enabling the global energy transition through integrated system design, clean technology pathways, and strategic foresight, supporting the Consortium's mission to bridge academia and industry for real-world energy transformation.

Rahul Wagh, Senior Engineering Manager – Innovation, Research & Technology at Baker Hughes, contributes over two decades of experience across engineering, R&D, and techno-commercial leadership. His expertise spans energy transition technologies, gas turbine systems, digital transformation, advanced manufacturing, and Lean Six Sigma, reinforcing the Consortium's focus on innovation-driven, scalable energy solutions.

Together, these appointments reflect the continued commitment of Shell and Baker Hughes to collaborative leadership and the advancement of impactful, industry-aligned research at The Energy Consortium – IIT

3. Core Members Caterpillar and bp appoint respective nominees, Prashanth Ravi & Dr. Kartick Mondal to The Energy Consortium, IIT Madras Advisory Board

The Energy Consortium, IIT Madras is pleased to welcome Dr. Kartick Mondal (bp) and Prashanth Ravi (Caterpillar Inc.) to its Industry Advisory Board, reflecting the deepening engagement of core members in shaping collaborative research and innovation for the energy transition.

Dr. Kartick Mondal, Eastern Hemisphere Strategic University Relationship Manager at bp, brings over two decades of R&D experience across catalyst innovation, process optimisation, and sustainable energy solutions spanning Oil & Gas, Petrochemicals, and Advanced Materials. An accomplished researcher, he has authored 30+ high-impact publications, holds multiple patents, and has led large-scale projects advancing catalyst engineering, polymer circularity, methane mitigation, and AI-driven process optimisation.

Prashanth Ravi, , Senior Engineering Manager – Electrification at Caterpillar Inc., contributes more than 20 years of expertise in engine development, emissions, regulations, electrification technologies, batteries, hybrid systems, and power generation. His work in energy storage, control systems, optimisation, and simulation-based design supports the development of next-generation, low-carbon power solutions.

Together, their leadership strengthens The Energy Consortium's mission to bridge academia and industry, accelerate translational research, and drive impactful, scalable solutions for a resilient and sustainable energy future.

4. Founding Member and Industry Partner Visits During the Year

During the year, The Energy Consortium, IIT Madras hosted engagements and visits involving several founding members and industry partners including Caterpillar, Shell, Baker Hughes, bp, Xynteo, and Danish energy ecosystem representatives. These interactions brought together industry leaders, faculty members, researchers, and students for discussions around industrial decarbonisation, sustainable mobility, green hydrogen, energy systems, and translational clean energy technologies.

The visits enabled collaborative dialogue on research priorities and future partnership opportunities, further strengthening industry-academia engagement across the consortium's energy transition initiatives.

6.2 Faculty in Spotlight

1. People (affiliated faculty) on the move

Prof. Satyanarayanan Seshadri was appointed the new Head of the School of Innovation & Entrepreneurship (SIE), IIT Madras. A faculty member in the Department of Applied Mechanics, Prof. Satya leads The Energy Consortium - IIT Madras and has been instrumental in driving several deep-tech innovation initiatives on campus — including a venture studio model to accelerate deep-tech commercialization. He has also co-founded and mentored multiple startups, and was the first faculty mentor of NIRMAAN IITM, IITM's pioneering pre-incubator for student entrepreneurship.

Prof. Preeti Aghalayam, Dept. of Chemical Engineering, was appointed as Dean of Global Engagement, IIT Madras

Prof. Satyanarayanan Seshadri, Department of Applied Mechanics & Biomedical Engineering and Prof. Rajnish Kumar, Department of Chemical Engineering as Faculty In- charge of the Auroville-IITM Sustainability Campus, Tamil Nadu

2. Editorial Debuts – Kothandaraman Ramanujam

Prof. Kothandaraman Ramanujam marked his editorial debut during the year, contributing to the consortium's growing thought leadership in sustainable energy research. His research focuses on advanced energy storage and conversion technologies, including redox flow batteries, solar cells, supercapacitors, and fuel cells. His work has led to several research publications in electrochemical energy systems and clean energy materials.

3. Fellow of National Academy of Sciences, India

Professor Jitendra Shital Sangwai, Department of Chemical Engineering, Indian Institute of Technology Madras, Chennai was elected as a full Fellow of The National Academy of Sciences, India. Prof. Jitendra Sangwai has made outstanding contributions to petroleum engineering, advancing gas hydrate science, carbon sequestration, and enhanced oil recovery. His innovations in reservoir modelling, nanotechnology, and sustainable energy processes have significantly influenced both fundamental understanding and real-field applications.

APPENDIX 7


also joined The
nergy Consortium,
osted at IIT Madras,
s a core member.
CONSORTIU
IIT MADRAS

7.1 Journal Publications

Consolidated Grand Theme	Combined Total Entries
Advanced Catalysis & Reaction Engineering	44
Heterogeneous Catalysis & Reaction Mechanisms Focus: Dry reforming of methane, active site configurations, inverse metal oxides, and coking resistance. Electrocatalysis & Fuel Cell Design Focus: Bimetallic anodes, oxygen evolution/ reduction reactions, and membrane electrode assemblies. Reaction Engineering & Operando Spectroscopy Focus: Automated modulation excitation spectroscopy, transient experiments, and spectro-kinetics. Photocatalysis & Solar Water Splitting Focus: Solar-driven chemical conversion and catalyst stability under irradiation.	
Advanced Functional Materials & Nanotechnology	61
Porous Frameworks (MOFs, ZIFs & Gas Hydrates) Focus: ZIF-67 and ZIF-90 frameworks, methane oxidation, gas mixture diffusion, and gas hydrate crystallization. Nanostructured Materials & 2D Sheets Focus: MXene synthesis, MoO3 nanostructures, phonon engineering, and thermoelectric performance enhancements. Optoelectronics & Perovskite Materials Focus: Perovskite indoor solar cells, organic light-emitting diodes (OLEDs), and interface defect mitigation.	
Applied Fluid Dynamics & Aerodynamics	23
Aerospace Engineering & Advanced Propulsion Systems Focus: Field Emission Electric Propulsion (FEEP) thrusters, Taylor cones, electrospray propulsion, and supersonic crossflows. Multiphase Flows & Reactor Hydrodynamics Focus: Silt erosion and wear testing, fluidized bed modeling, and multiphase transport in porous media. Turbomachinery & High-Speed Internal Flows Focus: Transonic axial turbine guide vanes, blade tip purge flows, and endwall aerodynamics.	
Industrial Decarbonization & Policy	15
CCUS & Manufacturing Sustainability Focus: Mineral carbonation of steel slag, Corporate Social Responsibility (CSR) impact on energy efficiency in Indian steel/manufacturing industries, and thickener design for enhanced oil recovery.	

Consolidated Grand Theme	Combined Total Entries
Thermal Sciences & Phase Change Storage	13
Convective Transport & Latent Heat Storage Focus: Magnetohydrodynamic (MHD) free convection flow, melting/solidification tracking, and single vs. multi-phase change materials.	
Smart Computational Systems & Industrial AI	15
Physics-Informed Machine Learning & Digital Twins Focus: Adaptive physics-informed neural networks (PINNs) combined with Ensemble Kalman Filters for system diagnostics. Industrial Cyber-Security & Operational Performance Focus: Deep learning frameworks for cyberattack detection in Industrial Control Systems (ICS), and field operator tracking via eye gaze.	
Advanced Electrochemical Energy Storage	9
Lithium-Metal & Composite Electrolytes Focus: Ultra-robust single-ion conducting composite electrolytes and solid-state stability	
Power Electronics & Grid Integration	12
Power Electronics & Motor Drives Focus: Four-level shared switch converters, buck-boost energy recovery stages, and harmonics mitigation in polluted grids. Smart Grids & Distribution Power Systems Planning Focus: Dynamic line rating (DLR), sequential conic relaxation-based optimal power flow (OPF), and analytical reliability.	
Biotechnology, Biomaterials & Biofluidics	12
Biomass Valorization & Circular Bioeconomy Focus: Plastic waste upcycling to liquid fuel, lignin valorization, and biochemical production. Microfluidics & Biofluid Dynamics Focus: Antimicrobial susceptibility testing via screen-printed electrodes and hydrodynamic modulation of bacterial biofilm formation.	
Specialized Industrial Operations & Logistics	56
Focus: split-delivery mathematical programming for LNG procurement coalitions, and specialized high-pressure physical chemistry transitions.	
Grand Total	**260**

7.2 White Paper

1. Accelerating Net Zero

The Energy Consortium, IIT Madras published the white paper Accelerating Net Zero in February 2025, presenting perspectives from academia, industry, and policy stakeholders on India's energy transition priorities. The publication featured themes including carbon capture and utilization, energy-efficient industrial heating and cooling, digital energy transition in electricity markets, and computing-driven clean energy technologies, highlighting the role of interdisciplinary innovation in advancing decarbonization pathways.

2. INNOWIND Report

The Energy Consortium, IIT Madras published the INNOWIND Report in January 2025, highlighting pathways for advancing renewable energy collaboration and offshore wind development between India and Denmark. The report covered themes including policy frameworks, infrastructure readiness, grid integration, technological innovation, and industry-academia collaboration, while also featuring perspectives on navigating the Indian offshore wind market from a Danish industry viewpoint and recommendations for accelerating clean energy growth.

3. Marine Spatial Planning

The Energy Consortium, IIT Madras published a two-part Marine Spatial Planning report focused on fishing activities and environmental protection in the Gulf of Mannar and Palk Bay regions of Tamil Nadu. The report examined offshore wind development in the context of existing legal and policy frameworks, including marine fishing regulations, coastal zone notifications, and deep-sea fishing policies.

Drawing from legislative analysis, stakeholder consultations, and case studies on subsea cables and port infrastructure, the report identified implementation challenges, research gaps, and conflict mitigation strategies. The publication emphasized the importance of stakeholder participation and science-based planning

approaches for balancing biodiversity conservation, offshore development, and livelihood protection in ecologically sensitive coastal regions.

4. Green Hydrogen and Green Ammonia

The Energy Consortium, IIT Madras published a white paper on Green Hydrogen and Green Ammonia highlighting India's emerging green hydrogen ecosystem under the National Green Hydrogen Mission. The publication reviewed developments under the SIGHT initiative, including allocation of 412,000 metric tons of green hydrogen production capacity and 1.5 GW of electrolyser manufacturing capacity.

The report also documented early-stage adoption and demonstration projects led by organizations such as GAIL, NTPC, Indian Oil, and Oil India Limited, while outlining the role of policy incentives, pilot deployments, and industrial participation in accelerating green hydrogen production and commercialization in India.

5. Compendium on ESG

The Energy Consortium, IIT Madras published the Compendium on ESG in November 2025, examining ESG adoption and reporting challenges within India's MSME ecosystem. The publication explored themes including Scope 3 emissions, ESG benchmarking, sustainability reporting frameworks, and alignment of business practices with Sustainable Development Goals (SDGs).

The report emphasized ESG as a strategic business imperative supporting India's long-term industrial growth, decarbonization, and net-zero ambitions, while also highlighting the need for context-sensitive ESG approaches for MSMEs.

6. EC Researchers Chart a Roadmap for Scaling Green Hydrogen in India

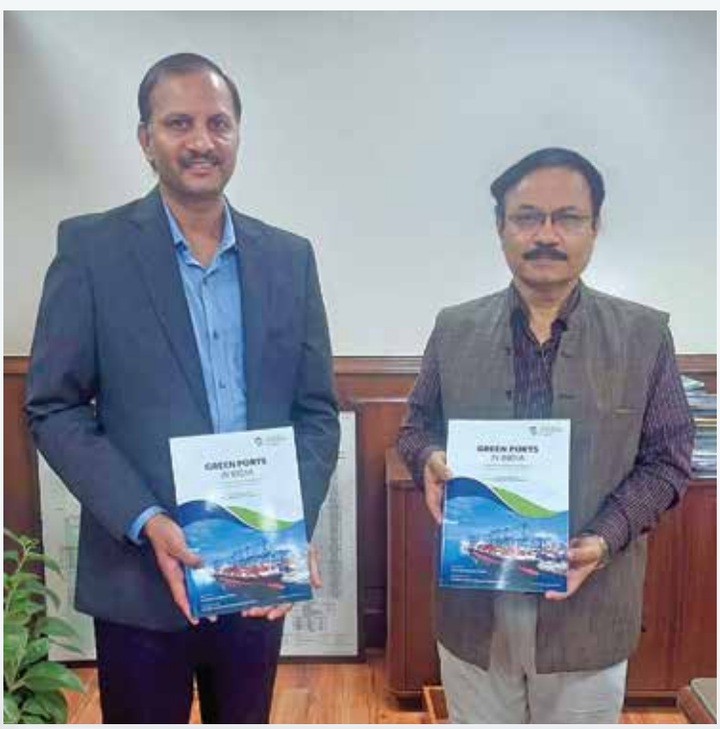
The Energy Consortium, IIT Madras affiliated researchers, in collaboration with CSTEP, published a peer-reviewed study in Energy & Fuels focused on scaling green hydrogen production in India. Led by Prof. Satyanarayanan Seshadri, the research assessed lifecycle and material implications of Proton Exchange Membrane (PEM) electrolysers and proposed a tiered framework for green hydrogen classification.

The study provides policy and technology insights supporting India's target of achieving 5 million tonnes of green hydrogen production annually by 2030.

7.3. Workshops Conducted

7.3 A. Internal Workshops Conducted

A. Green Ports in India



A stakeholder roundtable on Green Ports and sustainable maritime infrastructure was conducted during Industry Day 2025 with participation from government, industry, academia, and international stakeholders. The discussions focused on key challenges and enabling factors for green port development, while identifying opportunities for collaboration across stakeholders in sustainable maritime infrastructure.

The engagement also proposed continued dialogue and development of an outcome document capturing key insights and action points for relevant ministries and port authorities.

B. Accelerating Green Hydrogen Workshop

The Energy Consortium – IIT Madras and Xynteo's Energy Leap jointly organized a workshop titled "Accelerating Green Hydrogen: Unlocking India's Technological Prowess" during Industry Day 2025. The discussions focused on electrolyser manufacturing, domestic supply chains, commercialization challenges, policy support, funding requirements, and pathways for scaling green hydrogen adoption in India.

The workshop also strengthened ongoing collaborative engagement with Xynteo and Technip Energies towards advancing innovation and coordinated action in the green hydrogen sector.

C. ESG Masterclass Empowers Industry Professionals to Lead with Purpose

The School of Sustainability, IIT Madras, together with The Energy Consortium, IIT Madras, organized the 3rd cohort of the ESG masterclass centered on strengthening sustainability-led business practices and ESG integration within organizations. The programme addressed evolving ESG reporting expectations, governance frameworks, responsible business strategy, and long-term value creation in the Indian industry context.

The sessions were facilitated by experts including Anuradda Ganesh, Rahul Muralidharan, Nikhil Tambe, Ajay Patil, and teams from The Energy Consortium and CODE IIT Madras, providing participants with practical approaches for ESG reporting, risk management, transparency, and identifying sustainable business opportunities.

D. Topical Workshop Explores Prospects and Challenges of Compressed Biogas

IIT Madras hosted a workshop on Compressed Biogas (CBG): Prospects & Challenges on 16 December 2025, organized by the School of Sustainability, IIT Madras, together with The Energy Consortium, IIT Madras and Srinivas Waste Management Services Private Limited (SWMS). The programme focused on CBG technologies, policy support, implementation challenges, and opportunities for scaling bioenergy solutions in India.

Participants also visited the SWMS CBG facility at Chetpet, Chennai, gaining practical insights into biogas production and operational processes.

E. ESG: Driving Strategic Sustainability for Indian MSMEs

The Energy Consortium, IIT Madras, together with the School of Sustainability, IIT Madras, released the compendium ESG: How Should MSMEs Be Prepared under the guidance of SEBI. Developed over 18 months, the publication focused on ESG reporting challenges faced by MSMEs, including data collection, benchmarking, reporting frameworks, and sustainability awareness.

Guided by Ms. Yogita Jadhav, CGM at NISM, the initiative also outlined practical approaches for integrating accessible sustainability technologies and ESG practices within MSME operations. The compendium was inaugurated by Shyam Sunder P, Director at the Bureau of Energy Efficiency, during the Accelerating Net Zero workshop.

F. Joint Technical Workshops on Transportation Decarbonization

A joint technical workshop on Transportation Decarbonization was conducted during Industry Day 2025 by The Energy Consortium, IIT Madras, the Centre of Excellence for Zero Emission Trucking, and The Mint Collaborative. The programme brought together participants from industry, government agencies, and startups to discuss sustainable mobility pathways and net-zero transition strategies in the transportation sector.

Representatives from organizations including Aramco, Ashok Leyland, Sun Mobility, Infosys, ARAI, the Ministry of Housing & Urban Affairs, and Chennai Unified Metropolitan Authority shared perspectives on decarbonization initiatives, technology pathways, and sector-wide implementation challenges. The workshop also helped identify areas for future collaborative engagement and research.

7.3 B. External Workshops Conducted

F. India Exchange (Xynteo): Industrial Decarbonization for Metals and Mining Sector

The Energy Consortium, IIT Madras participated in the Industrial Decarbonization Studio for Metals and Mining at the UK–India Exchange 2026, conducted in partnership with Xynteo. The discussions focused on enabling large-scale decarbonization in heavy industries through trade partnerships, green metals corridors, financing frameworks, and coordinated industry action across India, the EU, and the UK.

The session brought together leaders from industry, finance, policy, and technology organizations including Tata Steel, Hindalco, Shell, Technip Energies, Siemens Infrastructure, JSW Steel, ONGC, and GIZ India. Representing The Energy Consortium, IIT Madras, Nikhil Tambe contributed perspectives on industrial decarbonisation pathways, collaborative ecosystems, and future green trade opportunities.

G. CII SR Energy Transition Summit

The Confederation of Indian Industry (CII) – Southern Region, jointly with The Energy Consortium, IIT Madras, conducted the 2nd edition of the CII-SR Energy Transition Summit 2026 focused on accelerating energy transition through innovation, infrastructure, and investment. The two-day summit brought together policymakers, industry leaders, investors, utilities, and technology stakeholders to discuss pathways for building a secure and sustainable energy future.

Key discussions covered the energy–water nexus, green hydrogen and emerging fuels, digital energy infrastructure, solar and wind hybrid systems, energy storage solutions, financing mechanisms, and the role of regulators in accelerating low-carbon transition. The summit highlighted the importance of coordinated policy, technology, investment, and industry collaboration in advancing India's energy transition goals.

H. MNRE – From Vision to Action: India Accelerates Green Hydrogen R&D

The Energy Consortium, IIT Madras participated in the 1st Annual Green Hydrogen R&D Conference held in New Delhi under India's National Green Hydrogen Mission (NGHM). The conference brought together representatives from government, industry, academia, startups, and research organizations, while also announcing a Rs. 100 crore Call for Proposals supporting hydrogen startups across production, storage, transport, and utilization technologies.

Nikhil Tambe represented The Energy Consortium, IIT Madras in a roundtable discussion on testing infrastructure for green hydrogen R&D in India. The discussions emphasized the need for shared plug-and-play testing infrastructure, industry-supported TRL 5–7 facilities, duty cycle testing capabilities, and digital twin-based approaches to accelerate collaborative hydrogen research and technology validation.

7.4 Invited Talks and Lectures

S.No	Faculty Name	Title	University/Forum/ Invitee Name	Date of Lecture/Talks
1	Pravendra Kumar	Enabling Advanced Combustion Technologies for Blended Bio - and Alternative Fuels	IIT Bombay	22-26 Sep 2025
2	Pravendra Kumar of Technology	Fundamentals of Electrical Propulsion	SJC Institute	24-28 Feb 2025
3	Jithin John Varghese	Structure-activity-selectivity-stability correlations in CO2 cycloaddition with epoxides with ZIF catalysts	International Conference on Carbon Capture and Utilization 2025, JNCASR	Dec 2025
4	Jithin John Varghese	Oxygen Vacancy Driven Performance of Supported In_2O_3 Catalyst: Insights from DFT Microkinetic Analysis	Carbon Discussions, CO_2 India Network	Oct 2025
5	Jithin John Varghese	Inverse and supported metal oxide catalyst for methanol synthesis: Learnings from DFT-Microkinetic Analysis	10th Asia-Pacific Congress on Catalysis (APCAT 10) 2025, Singapore	Aug 2025
6	Jithin John Varghese	CO_2 Reduction to Methanol: What We Have Learnt from Multiscale Modelling	Sustain X- ACE 2025 and 4th CO2 India Meet, IITM	Jun 2025
7	Jithin John Varghese	CO_2 Reduction to Methanol: DFT Microkinetic Insights into Catalytic Structure-Activity Relations	Aapali Psi-K International Conference on Density Functional Theory Simulations and Applications, IISER Pune	May 2025
8	Jithin John Varghese	Structure activity relation in methanol synthesis from CO_2	24th National Symposium on Catalysis, Catalysis for Sustainable Chemicals Materials and Energy CSCME25, Thapar University	Feb 2025

S.No	Faculty Name	Title	University/Forum/ Invitee Name	Date of Lecture/Talks
9	Himanshu Goyal	First-principles models for quick design of CO2 capture and utilization reactors	International Conference on Carbon Capture and Utilization 2025, JNCASR	Dec 2025
10	Himanshu Goyal	Challenges in doing chemistry at large scales	Sustain X- ACE 2025 and 4th CO_2 India Meet, IITM	Jun 2025
11	Himanshu Goyal	Role of supercomputers and machine learning in chemical engineering	Engineer's day celebration at Technip	Sep 2025
12	Himanshu Goyal	Applications of ML/AI in high-fidelity simulations of biomass utilization	BTN Chennai Chapter Knowledge Series, Infosys	Dec 2025
13	Himanshu Goyal	Using supercomputers and machine learning in core chemical engineering	IIT Tirupati	Feb 2025
14	Himanshu Goyal	Challenges in doing chemistry at large scales	SMARTCHEM 2026: CHAINS, St Joseph, Bengaluru	Jan 2026
15	Himanshu Goyal	Modeling of Joule heated reactors: Applications in H2 production and CO_2 capture	International Conference Hydrogen Energy and Sustainability, IIT BHU	Oct 2025
16	Nitin Muralidharan	Development of Critical Material Free Lithium-ion Batteries	CHEMSCAPE 2025, Saintgits College of Engineering, Kottayam	Oct 2025
17	Nitin Muralidharan	Critical Material-Free Batteries - From Lab Scale to Pilot Scale and Beyond	RAICGC (Indian Ceramic Society), 2025, Mumbai	Nov 2025
18	Nitin Muralidharan	Critical Material-Free Batteries - From Lab Scale to Pilot Scale and Beyond	MBRS (Battery IResearch Society) 2025, Bangalore	Dec 2025

S.No	Faculty Name	Title	University/Forum/ Invitee Name	Date of Lecture/Talks
19	Nitin Muralidharan	Battery Material Manufacturing & Recycling – From Lab Scale to Pilot Scale and Beyond	Polymera 2026, Mahathma Gandhi University, Kottayam	Jan 2026
20	Guhan Jayaraman	Bioprocessing India 2025	IIT (BHU) Varanasi	Dec 2025
21	Guhan Jayaraman	SYNBIO'26: New Frontiers in Synthetic Biology.	IIT Bombay	Feb 2026
22	Sagar Sourav	Molecularly Engineered Catalytic Materials for CO_2 Utilization	Carbon Discussions, CO_2 India Network	25 Oct
23	Sagar Sourav	Thermo-catalytic CO_2 Activation and Utilization	Sustain X- ACE 2025 and 4t^h CO_2 India Meet, IITM	25 Jun
24	Abdus Samad	Tidal Energy, Recent Advancements in Pico Hydro Technologies	RAPHT-2025, National Institute of Technology Silchar, Assam, India	Feb 3 - 5, 2025
25	Abdus Samad	Research methodology	All India Research Scholars' Summit, Chennai,IITM	23-Mar-25
26	Abdus Samad	Tidal energy	Newcastle University, UK	May 8, 2025
27	Abdus Samad	Turbo Machinery	Strathclyde University, UK	9 May, 2025
28	Abdus Samad	Turbo Machinery	Otto von Guericke University Magdeburg, Germany	20 May, 2025
29	Abdus Samad	Turbo Machinery	Université de Technologie d Belfort-Montbéliard, France	27 May, 2025
30	Swapna Singha Rabha	CO_2 capture	4th edition of Shell.ai Scientific Conference Bangalore	May 2025

S.No	Faculty Name	Title	University/Forum/ Invitee Name	Date of Lecture/Talks
31	Swapna Singha Rabha	CO_2 Capture: Challenges, Advances and Future opportunity	International Conference Hydrogen Energy and Sustainability 2025, IITBHU	Oct 2025
32	Swapna Singha Rabha	CO_2 Capture: Challenges, Advances and Future opportunity	International Conference on Carbon Capture and Utilization, JNCSR, Bangalore	Dec 2025
33	Swapna Singha Rabha	CCUS: Present state of the art in India	SPARC workshop on digital Analysis of Flow process in porous Material for geoenergy applications	26 Jan

7.5 Patents

Title	Principal Inventor	Department	Application No	Status
Architecture and Fabrication of High-Performance and Long-Durable Tri-Layer Gas Diffusion Electrode For Scalable Metal-Air Batteries	Aravind Kumar Chandiran	Chemical Engineering	202541134243	Application - Awaiting Examination
Battery Performance, Lifetime and Safety Testing Device	Aravind Kumar Chandiran	Chemical Engineering	202241059308	Granted
Electro-Deposition Bath for Recharging the Anode of Mechanically Rechargeable Metal-Air Batteries	Aravind Kumar Chandiran	Chemical Engineering	202341051043	Granted
System For The Measurement of Polarization-Induced Charge Transfer In Optoelectronic and Photoelectrochemical Devices	Aravind Kumar Chandiran	Chemical Engineering	202441067075	Granted
Closed-Loop Energy Storage and Retrieval System of Mechanically Refuellable High Energy Density Aqueous Metal-Air Batteries	Aravind Kumar Chandiran	Chemical Engineering	202441061771	Granted
System For The Measurement of Polarization-Induced Charge Transfer In Optoelectronic and Photoelectrochemical Devices	Aravind Kumar Chandiran	Chemical Engineering	PCT/IN2025/051421	Application - Complete
Biradial Multiple Entry Mesochannel Heat Sink with Dielectric Organic Coolant and Method Thereof	Dhiman Chatterjee	Mechanical Engineering	PCT/IN2025/050484	Application - Published
System and Method for Co_2 Capture Through Hybrid Sorption	Jitendra S Sangwai	Chemical Engineering	202541017310	Application - Awaiting Examination
Electrolyte For Zinc-Polyiodide Redox Flow Batteries	Kothandaraman Ramanujam	Chemistry	202541022785	Application - Awaiting Examination

Title	Principal Inventor	Department	Application No	Status
Electrolyte Additive for Improved Performance in Zinc-Bromine Flow Batteries	Kothandaraman Ramanujam	Chemistry	202541039153	Application - Provisional
Membrane for Redox Flow Battery and Method of Preparation Thereof	Kothandaraman Ramanujam	Chemistry	202541094369	Application - Provisional
Anacardic Acid Impregnated Eco-Friendly Solid-State Electrolytes for Sustainable Lithium-Ion Battery Applications	Kothandaraman Ramanujam	Chemistry	202541044517	Application - Provisional
A Smart Metallic Self-Healing Composite Coating and a Method of Preparation Thereof	Kothandaraman Ramanujam	Chemistry	202541070953	Application Examined (Fer Issued)
Gamma Radiation Based Charging In Zinc Polyiodide Flow Battery	Kothandaraman Ramanujam	Chemistry	202541076918	Application - Provisional
An Electrode Material for Soluble Lead Redox Flow Batteries and Preparation Thereof	Kothandaraman Ramanujam	Chemistry	202541114780	Application - Waiting Examination
Nafion-Free Hydrocarbon-Based Porous Membrane for Vanadium Redox Flow Battery Application	Kothandaraman Ramanujam	Chemistry	202341088792	Granted
A Battery Cell	Kothandaraman Ramanujam	Chemistry	202441048319	Granted
Low-Cost Zinc-Polyiodide Redox Flow Battery	Kothandaraman Ramanujam	Chemistry	Pct/In2025/050873	Application - Complete
A Device For Extraction and Accumulation of One or More Metal Ions and Method Thereof	Nitin Muralidharan	Chemical Engineering	202541131513	Application - Awaiting Examination

Title	Principal Inventor	Department	Application No	Status
A Method For Extracting High Pure Lignin from Biomass	Raghuram Chetty	Chemical Engineering	202441077134	Granted
A Method For Extracting High Pure Lignin From Biomass	Raghuram Chetty	Chemical Engineering	PCT/IN2025/051605	Application - Complete
An Organometallic Catalyst Anchored on a Polymeric Support and Method of Preparation Thereof	Rajnish Kumar	Chemical Engineering	202541059793	Application - Provisional
Energy Optimization in Refrigeration Systems	Satyanarayanan Seshadri	Applied Mechanics & Biomedical Engineering	202541122880	Application - Awaiting Examination
A System and Method for Electrical Load Management	Satyanarayanan Seshadri	Applied Mechanics	202441099525	Granted
A System and Method for Electrical Load Management	Satyanarayanan Seshadri	Applied Mechanics	PCT/IN2025/052008	Application - Complete
Smart Meter Based Energy Hubs Performing Energy Interoperability to Improve Consumer Friendly Energy Sector	Shanthi Swarup K	Electrical Engineering	202441002589	Granted
Medasolv-12515: A High-Performance Blended Amine Solvent for Efficient Co_2 Capture with Reduced Energy Demand	Swapna Singha Rabha	Chemical Engineering	202541053858	Application Examined (Fer Issued)
A Method of Converting Waste Plastic Feedstock nto Fuels and Chemicals	Vinu R	Chemical Engineering	202441091002	Granted

8

STARTUPS

8.1 Faculty Startups

S.No	Start up Name	Start up Technology Area	Faculty Name
1	TrigenDC	Heat Pumps	Satya Seshadri
2	Wankel Energy Systems	Steam Power Recovery	Satya Seshadri
3	EnergyETA	Energy IOT	Satya Seshadri
4	Sthyr Energy Private Limited	Zinc-air batteries	Aravind Chandiran
5	Arantree Consulting Services Pvt Ltd	Sustainability consulting	Santosh Kumar Sahu
6	Susstains Engineering Solutions LLP	Engineering consultancy on biomass	Varunkumar S
7	X2Fuels and Energy Pvt Ltd	Waste to fuels and energy conversion	Vinu R
8	Celdzyne	Biotechnolgy	Guhan Jayaraman
9	Vamanie Paramita Energy Pvt. Ltd.	Renewable energy	Abdus Samad

Highlights

i. Sthyr – Raising Funding from Special Invest

Sthyr Energy Private Limited, an IIT Madras–origin startup, has raised $1 million in funding to advance its grid-scale energy storage solution. Founded by IIT Madras PhDs Gunjan Kapadia, Akhil Kongara, and Muhammed Hamdan, the company is developing modular zinc-air battery systems designed for long-duration renewable energy storage. Its technology converts excess renewable energy into high-density metallic zinc, enabling reliable power supply across seasonal demand cycles.

The funding will support scaling of its 200 kWh modules and accelerate its path toward commercial deployment.

ii. Wankel Energy Systems (WES) – Winning Funding

Wankel Energy Systems (WES), founded by IIT Madras alumni, develops Dynamic Volumetric Control Expanders for efficient industrial steam energy recovery, improving performance beyond conventional systems.

Through GDC's I-NCUBATE program, the startup refined its market focus by identifying high-potential sectors such as paper, textiles, and breweries and strengthening its customer engagement strategy. This shift enabled stronger commercial alignment and investor readiness. The company secured a $1 million pre-seed funding round led by Shastra VC in 2025, supporting further product scaling and deployment.

iii. Indus DC raising in 100 cr

IndusDC, founded in 2023 and closely linked to the IIT Madras ecosystem, is a deeptech venture studio focused on building clean technology startups at scale. It is driven by serial entrepreneur Kushant Uppal, Prof. Satyanarayanan Seshadri of Indian Institute of Technology Madras and founder of the Energy Consortium, along with Kaustubh Hanmantgad, an expert in behavioural analytics and team building.

The platform has announced a Rs. 100 crore commitment to co-build deep tech startups targeting large-scale carbon reduction in clean energy.

This initiative strengthens IIT Madras–linked innovation pathways by bridging research, venture creation, and industrial deployment.

8. 2 Events and Engagement

A. CLIMAFIX 2025

The Energy Consortium, IIT Madras, jointly with Energy Alternatives India (EAI) and TiE Chennai, hosted CLIMAFIX 2025 at the IIT Madras Research Park, Chennai. The summit brought together more than 400 climate startups, 150 investors, and 250 corporate leaders, creating a platform for collaboration across India's climate innovation ecosystem.

The two-day programme covered themes including bio-solutions, energy efficiency, AI, deep-tech innovation, and translational research. Through startup pitches, founder interactions, expert sessions, and investor discussions, the summit strengthened engagement between startups, industry, and investors working on sustainability and climate-focused technologies.

B. Indo-Nordic Forum on Green Transition: Energy Consortium, IIT Madras Showcases India's Green Transition at TechBBQ

The Energy Consortium, IIT Madras participated in the Indo-Nordic Forum on Green Transition at the TechBBQ summit. The forum brought together investors, innovators, industry representatives, and ecosystem leaders from India and the Nordic region to discuss collaborative opportunities in clean energy transition and sustainable technology development.

The session featured speakers including Gunjan Kapadia (Sthyr Energy), Nikhil Tambe (The Energy Consortium, IIT Madras), Anders Thorsen (NIFO), Peter Jannik Sjontoft (Copenhagen Infrastructure Partners), and Tejs Laustsen Jensen (Hydrogen Denmark). The engagement reinforced the role of IIT Madras in enabling global clean energy innovation and strengthening Indo-Nordic energy partnerships.

C. The Energy Consortium – IIT Madras Mentored Startups Win HDFC Parivartan Grant for Clean Tech Innovation

The Energy Consortium – IIT Madras celebrated the recognition of several consortium-mentored startups under the HDFC Parivartan Startup Grants 2025–2026, an initiative supporting impactful innovations in clean technology, climate resilience, and the circular economy. The selected startups included Wankel Energy Systems, EarthFokus, Inventive Scientific Minds LLP, TRIGeN Decarbonisation, Satiq Concrete Manufacturer Pvt. Ltd., JSP Enviro Private Limited, CeraTattva InnoTech, and XYMA Analytics. The achievement highlights the consortium's role in nurturing sustainability-focused entrepreneurship and enabling scalable solutions for pressing environmental challenges.

9

STUDENTS

9.1 Joint Programs: Deakin and UoB

The Indian Institute of Technology, Madras, and the University of Birmingham are offering the Joint MSc in Sustainable Energy Systems (AY 2025-2026), designed to equip students with cutting-edge expertise in clean energy transition. The program offers flexibility in choosing study locations, industry placements for hands-on experience, and a year-long research project co-mentored by faculty from both institutions. With a dual-track option after the second semester, students can tailor their learning path to suit their career aspirations.

Beyond technical knowledge, the program fosters a global perspective, cross-cultural learning, and industry collaborations, creating a strong professional network.

9.2 Summer Internship 2025

The Energy Consortium, IIT Madras conducted the Summer Internship Program 2025, providing students with hands-on exposure to emerging energy research and sustainability-focused projects under faculty and expert mentorship. The programme enabled interns to work on goal-oriented mini-projects across different areas of the energy value chain.

Key themes explored during the internship included recycling strategies for end-of-life lithium-ion batteries, resilient and smart grid systems, and sector-specific sustainability challenges, helping students build practical understanding of clean energy and industrial transition domains.

9.3 Watt's Next! – Awards for Emerging Scholars

The Energy Consortium, IIT Madras hosted Watt's Next! during Industry Day 2025 as a platform for showcasing emerging PhD research in energy and sustainability. Selected scholars presented research spanning circular economy, biomass and waste conversion, sustainable construction materials, and solar-driven CO_2 conversion technologies.

Finalists included Mansi Thakur, Mahendra Tiwari, Uma R, and Ragulkrishnan V, who presented research on reclaimed coal ash utilization, biomass and plastic waste processing, microbial manufacturing for circular economy applications, and catalyst engineering for solar-driven CO_2 conversion. The programme recognized outstanding student research through jury and peer awards, with evaluations conducted by industry representatives from Baker Hughes, Shell, and Aditya Birla Group.

The initiative strengthened interaction between young researchers, academia, and industry stakeholders working on clean energy and sustainability challenges.

Mansi Thakur

Mahendra Tiwari


Uma R


Ragulkrishnan V

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