

Report on the Workshop: "Clean Energy Innovations: Hydrogen Fuel Cells for a Sustainable Future" at CPRI, Bengaluru, May 30-31, 2024

Date: 30-31 May, 2024

Venue: CCAR Auditorium, CPRI, Bengaluru

Overview

The two-day workshop on "Clean Energy Innovations: Hydrogen Fuel Cells for a Sustainable Future" was organised by the Central Power Research Institute (CPRI), Bengaluru in association with Alva's Institute of Engineering and Technology (AIET), Mijar, Moodbidri and GITAM (Deemed to be University), Bengaluru Campus. The workshop aimed to bring together experts from academia, industry, and research institutions to discuss advancements in clean energy, with a focus on hydrogen fuel cells. The event featured a series of plenary talks, invited talks, panel discussions and interactive sessions designed to foster innovation and collaboration in the field of hydrogen energy technologies.

Day 1: May 30, 2024

Inauguration:

9:30 AM – 10:15 AM: Inaugural Session



Dr. Shashi Kumar K., Associate Professor, Department of Physics, AIET, welcomed the guests to the stage and acted as the master of ceremony. **Dr. B. A. Savale**, Director General, CPRI, presided over the ceremony and in his talk stressed the importance of green energy. He said, Government of India, through its Ministry of Power, has invested a lot in green energy technologies and urged researchers, academicians and industry to work in this area. He appreciated the efforts of convenors in organising this workshop and said it was very timely. **Dr. M. G. Ananda Kumar**, Joint Director, Business Development and Capacity Building, CPRI, Bengaluru welcomed the delegates and gave the overview of the workshop, stressed the importance of working in clean hydrogen energy technologies and the efforts of CPRI. **Dr. Richard Pinto**, Dean of Research, AIET, provided the background for the workshop and spoke about the importance of multidisciplinary collaboration to overcome the challenges in hydrogen fuel cells (HFCs) and photocatalytic hydrogen generation. He said that semiconductor technology was taken over by electrical engineers from physicists from late 1960s and changed the character of the entire technology by mid-80s with a mind-boggling advancement in VLSI technology in the 90s. He stressed that unlike semiconductor technology, photocatalytic hydrogen generation was first shown in Japan in 1972, and is still with the chemists, and engineers have not got in. He said it is the right time that we should take this seriously for decarbonisation of atmosphere. **Dr. Kishore Buddha**, Head, Department of Mechanical Engineering at GITAM (Deemed to be University), Bengaluru, spoke about research at GITAM and the importance of hydrogen energy. **Dr. M. G. Ananda Kumar** gave the vote of thanks and invited the attendees for a group photograph.

10:20 AM – 10:40 AM: Group Photograph and Tea Break



Morning Session:

The morning session on the first day of the workshop was chaired by **Dr. Shashi Kumar K.**, Associate Professor, Department of Physics, AIET.

10:40 AM – 11:20 AM: **Keynote Address** by **Dr. M. G. Ananda Kumar**, Joint Director, Business Development and Capacity Building, CPRI, Bengaluru on *“Advancements in Clean Energy and Hydrogen Fuel Cells”*.



Dr. Kumar spoke about the renewable energy situation in India, solar and wind power capacities, and said that India has achieved 174 GW of renewable energy capacity in 2023. He emphasized the importance of green hydrogen as a clean energy source, its production methods, and its potential to decarbonize various sectors. He highlighted broad research areas in clean energy technologies, including solar cells, fuel cells, and hydrogen storage. He also discussed the challenges in developing green hydrogen infrastructure and suggested strategies for economic sustainability and skill development.

11:20 AM – 12:00 PM: **Plenary Talk** by **Dr. Richard Pinto**, Dean of Research, AIET and Former Professor, TIFR Mumbai and IIT Bombay on *“Green Energy Solutions with Hydrogen Fuel Cells: A Research Perspective”*.



Dr. Pinto's presentation emphasised the urgent need to decarbonize the atmosphere and address climate change, highlighting hydrogen fuel cells as a promising green energy source which could be better than solar photovoltaics. He discussed the current

issues with HFCs, such as cost, reliability, and green hydrogen availability, and explored the status of photocatalytic hydrogen generation, its challenges and potential solutions. He showcased the work carried out at Alva's Institute of Engineering and Technology, in collaboration with IITB and TIFR, including novel proton exchange membranes and photocatalytic hydrogen generation. He outlined the need for multidisciplinary collaboration to advance HFC technology and suggested a way forward with photocatalytic green hydrogen and enhanced proton-conducting membranes.

12:00 PM – 12:40 PM: **Invited Talk** by **Dr. Arun Isloor**, Professor and Former Head, Department of Chemistry, NITK Surathkal on *"Advanced Membrane Technology for Hydrogen Fuel Cells"*.

Dr. Isloor's presentation discussed the role of advanced membrane technology in HFCs, highlighting the selective transport of protons and the conversion of chemical energy into electrical energy. He contrasted HFC membranes with water purification membranes, detailing their distinct functions, materials, and applications. He outlined key challenges in membrane technology, such as material stability and fouling prevention, alongside the desirable qualities of membrane materials like mechanical strength and thermal stability. He showcased novel synthesis methods for zwitterionic polymer nanoparticles and their application in dye removal, emphasizing the importance of efficient and economical membrane design.

12:40 PM – 1:00 PM: **Special Presentation** by **Dr. Kishore Buddha**, Head, Department of Mechanical Engineering, GITAM (Deemed to be University), Bengaluru on *"Presentation on GITAM University"*.

Dr. Buddha gave an overview of the University - A private deemed university with campuses in Visakhapatnam, Hyderabad, and Bengaluru, founded by Dr. M.V.V.S. Murthy in 1980. He said that the university promotes value-based education with principles like self-discipline, non-violence, and equality, and aims to be a knowledge-driven institution with a culture of honesty and compassion. He presented the organisational structure of the University led by President M. Bharat and Vice Chancellors for different campuses, with a focus on integrated research and holistic student development. He showcased the achievements of the University including accreditation with NAAC (A++), and facilities available - offers 112 programs, and has extensive teaching and research facilities, including smart classrooms and labs.

1:00 PM – 2:00 PM: **Lunch Break**

Afternoon Session:

The afternoon session on the first day of the workshop was chaired by **Dr. Jayarama A.**, Associate Professor, Department of Physics, AIET.

2:00 PM – 2:30 PM: **Invited Talk** by **Dr. S. Seetharamu**, Director, NDRF and Former Director, CPRI on *"Technology Readiness Levels to be achieved for GH2 Turbines: Hydrogen Generation and Hydrogen combustion"*.

Dr. Seetharamu revealed that he is leading effort on hydrogen-fuelled gas turbine project at NDRF which aims to design and develop a 9 MW hydrogen-fuelled industrial gas turbine. He emphasised that this technology is crucial for advancing clean energy and reducing reliance on fossil fuels. He said that turbine will have a twin shaft arrangement, with a compressor pressure ratio of 13.7 and a turbine inlet temperature of 1100°C, designed to be scalable and suitable for adjustments to 5 MW or up to 15 MW. He revealed that the turbine's expected cycle efficiency is 34%, with a generator power output of 9.38 MW and the high efficiency of 87% for both the turbine and compressor is notable. He stressed that collaboration with various institutions and industry partners is key for the success of this project.

2:30 PM – 3:00 PM: **Invited Talk** by **Dr. Rathindra N. Das**, Dense Power, Bengaluru and Former General Manager, BHEL on *"Innovative high-performance System Solution with Solid Oxide Electrolyser (SOE) & Solid Oxide Fuel cell (SOFC)"*.

Dr. Das discussed innovative Solid Oxide Electrolyser (SOE) and Solid Oxide Fuel Cell (SOFC) systems, highlighting their role in efficient energy transition from conventional power plants to hydrogen-fuelled systems with lower emissions. He emphasized breakthroughs in SOE cell performance, which has improved 2.5 times in 15 years, and the roadmap to achieving \$1/kg green hydrogen. The Triple Phase Boundaries (TPB) engineering was a notable advancement. He outlined the key system integration strategies for saving green electricity, such as shifting water vaporization outside the system and using external steam sources to enhance system efficiency by 15%. He presented the benefits of polygeneration with RSOEC, including optimum waste heat utilization, reduced energy losses, and optimizing multiple fuel use for enhanced electrolyser efficiency.

3:00 PM – 3:30 PM: **Invited Talk** by **Dr. Vaman Kulkarni**, Convenor, Turbine Power Group, NDRF, Bengaluru and Former General Manager, BHEL on *"Gas Turbine Engine with Hydrogen Fuel for Power Generation"*.



Dr. Kulkarni said that gas turbine engines operate on the Brayton cycle, drawing air from the atmosphere, compressing it, and mixing it with fuel for combustion. The resulting hot gases rotate the turbine, which drives the compressor, making the system self-sustaining at idle speed. He stressed the advantages of hydrogen as a fuel, favoured for its environmental benefits, producing no carbon dioxide when burned. He also outlined the challenges including managing high flame temperatures (2300 to 2500K) and NO_x emissions. To achieve lower exit temperatures (1200 to 1500K) and NO_x emissions (preferably below 10 ppm), his presentation discussed dilution design, homogeneous temperature profiles, and material selection to address hydrogen's reactivity and embrittlement effects. He showcased the collaborations involved in this project including IIT Madras, Misochain, and HAL, aiming to develop a 10 MW Gas Turbine Engine with hydrogen fuel. They have a goal to demonstrate TRL-5 with a focus on advanced combustion systems and fuel control technologies.

3:30 PM – 4:10 PM: **Invited Talk** by **Dr. Arnab Dutta**, Associate Professor, Department of Chemistry, IIT Bombay on "*Catalysts and Innovations in Photocatalytic Hydrogen Generation*".



Dr. Dutta discussed the energy and CO_2 nexus, highlighting the need to reduce greenhouse gas emissions. He outlined India's commitment to lowering CO_2 emissions by 45% by 2030 and achieving carbon neutrality by 2070 is emphasized. He gave an exploration of photocatalysts essential for hydrogen production, particularly focusing on Co-dimethylglyoxime complexes. His aim was to improve the catalytic rate of H_2 production, enhance water solubility, and probe the mechanistic details of catalysis. His study presented the design of ligands with variable outer coordination spheres to create multi-component proton channels, improving photocatalytic H_2 production and stability in acidic conditions. He outlined strategies for optimizing photocatalytic assemblies for industrial applications, including stabilizing catalysts with silica beads and scaling up the sample size for efficient hydrogen production.

4:10 PM – 4:30 PM: **Tea Break**

4:30 PM – 5:30 PM: **Panel Discussion** by **Dr. Richard Pinto**, **Dr. M. G. Ananda Kumar**, **Dr. Arnab Dutta**, **Dr. Rathindra N. Das** and **Dr. R. Venkata Nadh** on "*Accelerating Research and Investment in Green Hydrogen and Hydrogen Fuel Cell Technology*".



Moderated by Dr. Pinto and Dr. Kumar, the panellists included people from IITs, industry, AIET, GITAM and CPRI. Apart from moderators, it included Dr. Dutta from IIT Bombay, Dr. Das from Dense Power, and Dr. Nadh, Professor, Department of Chemistry from GITAM. The discussion revolved around the challenges and opportunities in the hydrogen energy sector, with a focus on integrating academic research with industry needs to foster innovation and sustainability. Dr. Nadh spoke about the efforts in biofuels area in clean energy and Indian railways blending biofuels with diesel and how it can help in renewable energy efforts. Dr. Pinto stressed the importance of green energy and decarbonisation of the atmosphere. In this regard, he said India has to make significant progress both in terms of R&D investment and industrial collaboration. He said currently, R&D in this area is meagre and efforts are scattered. In this sense, this workshop is very timely and relevant. Dr. Das said that industrial collaborations and bringing foreign investments in hydrogen energy sector in India is crucial. Dr. Dutta told that instead of Indian companies investing in R&D abroad, they could invest in India and help grow hydrogen energy sector. Dr. Kumar summarised the points mentioned in the discussion, highlighted the importance of having industry standards and regulations in hydrogen energy sector, role of government in recognising and funding R&D efforts in private institutions, and concluded the discussion.

Day 2: May 31, 2024

Morning Session:

The morning session on the second day of the workshop was chaired by **Dr. P. Sundararaman**, Assistant Professor, Department of Electrical, Electronics and Communication Engineering, GITAM (Deemed to be University), Bengaluru.

9:30 AM – 10:10 AM: **Plenary Talk** by **Dr. Prashanth S. Kulkarni**, Director, School of Energy Studies, Defence Institute of Advanced Technology (DIAT-DRDO) (Deemed to be University), Pune on *"Advances in Green Energy: Development of Safe Hydrogen"*.



Dr. Kulkarni spoke of hydrogen as clean energy carrier, highlighting its low combustion initiation energy, high energy density, and pollutant-free combustion. He also compared favourably to helium as an alternative for various applications. He discussed the challenges associated with hydrogen, such as its high flammability and potential for accidents, and outlined methods for safe production and storage. He revealed various approaches to reduce hydrogen's flammability, including the use of non-flammable diluents and chemical inhibitors to suppress active radicals during combustion. He gave details of experimental setups and

theoretical models used to study hydrogen combustion, including the effects of different diluents and inhibitors on flame speed and ignition delay.

10:10 AM – 10:50 AM: **Plenary Talk** by **Dr. C. D. Madhusoodhana**, General Manager, Corporate R&D, BHEL, Hyderabad on **"Clean Energy Innovations at BHEL"**.

Dr. Madhusoodhana outlined the active engagement of BHEL in the development of clean hydrogen energy technologies such as collaboration with Bhabha Atomic Research Centre (BARC) to develop a 50 kW alkaline electrolyser system for hydrogen production. He said that his company has invested on advancing hydrogen fuel cells and solid oxide fuel cells (SOFCs), aiming to improve their efficiency and capacity for sustainable energy applications. He said that BHEL is exploring photocatalytic processes for hydrogen generation, including developing reactors that utilize photocatalysts to efficiently produce hydrogen using solar energy. He revealed that research at BHEL also includes the development of 700 bar hydrogen storage cylinders based on carbon nanotube technology, enhancing the safety and efficiency of hydrogen storage solutions.

10:50 AM – 11:10 AM: **Tea Break**

11:10 AM – 11:40 AM: **Invited Talk** by **Dr. Shashi Kumar K.**, Associate Professor, Department of Physics, AIET on **"Progress in the World of Solid-state Nuclear Magnetic Resonance World and Density Functional Theory (DFT) Calculations of Catalysts and Proton Exchange Membranes (PEMs)"**.



Dr. Kumar introduced HFCs as the future of clean energy, highlighting their potential for renewable green energy. He covered the progress in solid-state Nuclear Magnetic Resonance (ssNMR) and Density Functional Theory (DFT) calculations for characterizing catalysts and Proton Exchange Membranes (PEMs). He discussed the characterization of PEMs and catalysts using ssNMR, including the fundamentals of NMR, the development of NMR during WWII, and its applications in various fields. He explored the modelling of PEMs and catalysts on the Gaussian platform, detailing molecular mechanics, empirical/statistical methods, and quantum mechanical approaches for chemical physics and physical chemistry.

11:40 AM – 12:10 PM: **Invited Talk** by **Dr. Arjun Sunil Rao**, Assistant Professor, Department of Electronics and Communication Engineering, Manipal Institute of Technology (MIT), Manipal on **"High-Efficiency Methanol Fuel Cells"**.



Dr. Rao began with a history of fuel cells, their types, and market size, focusing on Polymer Electrolyte Membrane Fuel Cells (PEMFCs), including HFCs and Direct Methanol Fuel Cells (DMFCs). He detailed the construction of DMFCs, explaining the roles of the anode, cathode, electrolyte, and catalyst. He also explained the electrochemical reactions occurring at the anode and cathode. He utilised the significant portion of his allotted time in addressing the methanol crossover in DMFCs, presenting solutions like UV irradiation, hydrophobic lamination, and hydrophilic coating of the electrolyte. He concluded with the advantages of DMFCs, such as ease of fuel storage and transportation, higher efficiency, and low noise pollution, along with their various applications.

12:10 PM – 12:40 PM: **Invited Talk** by **Dr. Jayarama A.**, Associate Professor, Department of Physics, AIET on *"Photocatalytic Hydrogen Generation for Hydrogen Energy"*.



Dr. Jayarama A. began by emphasizing the potential of hydrogen as a clean and sustainable fuel, capable of replacing fossil fuels in various sectors. He outlined the process of using photocatalysts to split water into hydrogen and oxygen using sunlight, highlighting its efficiency and environmental benefits. He discussed the current challenges in photocatalytic hydrogen generation, such as low efficiency and scalability, and presented recent research breakthroughs addressing these issues. He showcased the applications of photocatalytic hydrogen generation in energy storage and fuel cells and acknowledged recent significant research contributions to the field.

12:40 PM – 1:40 PM: **Lunch**

Afternoon Session:

The afternoon session on the second day of the workshop was chaired by **Dr. P. Sundararaman**, Assistant Professor, Department of Electrical, Electronics and Communication Engineering, GITAM (Deemed to be University), Bengaluru.

1:40 PM – 2:00 PM: **Special Presentation** by **Dr. M. Ajay Kumar**, Deputy Director (R&D), MURTI Research Centre & Associate Professor, Department of Electrical, Electronics and Communication Engineering, GITAM (Deemed to be University), Bengaluru on *"Presentation on MURTI Research Centre"*.

Dr. Kumar showcased the Multidisciplinary Unit of Research on Translational Initiatives (MURTI) of GITAM. He outlined MURTI's primary objective which is to create a cross-disciplinary think tank that brainstorms on issues of regional, national, and global relevance. These clusters test the workable hypotheses or measures proposed by the think tank within a dynamic research ecosystem. He said that these centres will be set up across all campuses of GITAM University. They will involve top-quality faculty from diverse disciplines, either from GITAM's talent pool or invited from established national/global institutions. He mentioned that by bringing together researchers from various fields onto a common platform, MURTI aims to create an intellectually stimulating research environment. He said that these hubs are collaborative platforms where researchers, experts, and stakeholders from various fields work together on complex problems to find innovative solutions.

2:00 PM – 2:30 PM: **Invited Talk** by **Dr. V. Ravindra**, Assistant Professor, Department of Mechanical Engineering, GITAM on *"Solar energy integrated systems for cold storages & Vacuum Technology for Sustainable future"*.

Dr. Ravindra discussed the significant loss of fruits and vegetables in India due to inadequate cold storage facilities and suggests solar energy-based tri-generation systems as a sustainable solution. He highlighted the role of vacuum technology in various applications, including solar thermal systems, and emphasised its importance in the International Thermonuclear Experimental Reactor (ITER) for achieving low-density conditions necessary for fusion reactions. He outlined challenges such as the development of high-pressure components and suitable control strategies for the proposed solar tri-generation system, along with possible improvements like multi-stage compression and use of evaporative cooling. He compared different working fluids for their toxicity, flammability, and temperature limits, and provides definitions and units for vacuum, illustrating its significance in industrial and scientific applications.

2:30 PM – 3:00 PM: **Invited Talk** by **Dr. Yuvaraj A. R.**, Associate Professor, Department of PG Studies in Chemistry, Alva's College, Moodbidri on *"Unlocking the Potential of Metal-Organic Frameworks for Hydrogen Storage"*.



Dr. Yuvaraj discussed the importance of hydrogen as a clean energy carrier and the challenges in safe and efficient storage methods, such as compressed gas, cryogenic liquid, and metal hydrides. He defined MOFs as crystalline materials with metal ions/clusters coordinated to organic ligands, highlighting their high porosity, tuneable structures, and large surface area for hydrogen storage. He emphasised MOFs' high surface area, tunability, and reversible adsorption for efficient storage/release cycles, along with synthesis methods like solvothermal, hydrothermal, and microwave-assisted techniques. He covered design strategies to enhance MOFs' stability and adsorption capacity, types of MOFs used in hydrogen storage, and the potential for large-scale applications, concluding with the need for further research on cost-effective synthesis and stability improvements.

3:00 PM – 3:30 PM: **Invited Talk** by **Dr. Satyanarayan**, Head, Department of Mechanical Engineering, AIET on *"Hydrogen Fuel Cells for Automotive Applications"*.



Dr. Satyanarayan began with an overview of global energy consumption, highlighting the dominance of fossil fuels and the significant share of the transportation industry in energy use. He discussed the types of HFCs, their advantages such as high energy efficiency and zero emissions, and their applications in various sectors including automotive and stationary power generation. He identified the challenges hindering the widespread adoption of HFCs in cars, such as cost, durability, infrastructure, and safety. He also provided a future outlook, emphasizing market growth, cost reduction, and increased infrastructure. He concluded with the need for joint efforts by academia, industry, and governments to overcome challenges and advance the commercialization of hydrogen fuel cell electric vehicles (HFCEVs).

3:30 PM – 4:00 PM: **Valedictory Programme**



The workshop concluded with a valedictory programme with Dr. M. G. Ananda Kumar, Dr. Seetharamu, Dr. Richard Pinto and Dr. Nageshwara Rao, Professor, Department of Mechanical Engineering, GITAM in the dais. The programme summarized key insights from the workshop, thanked the delegates and organisers and discussed future collaboration opportunities.

Key Highlights and Takeaways

- 1. Innovations in Hydrogen Technology:** The workshop highlighted cutting-edge research and development in hydrogen production, storage, and utilization technologies, emphasizing their potential to revolutionize the energy sector.
- 2. Collaborative Efforts:** Speakers from various prestigious institutions and industries shared their insights, fostering a collaborative environment for future projects and research initiatives.
- 3. Focus on Sustainability:** Emphasis was placed on sustainable practices, including the reduction of carbon footprints through the adoption of clean hydrogen energy technologies.
- 4. Industry-Academia Collaboration:** The workshop underscored the importance of collaboration between academia and industry to accelerate the deployment of hydrogen technologies.
- 5. Future Prospects:** Discussions highlighted the future prospects of hydrogen fuel cells in diverse applications, from automotive to industrial sectors, reinforcing the vision of a sustainable energy future, and organising similar workshops and conferences in the future.

The workshop successfully brought together a diverse group of experts and provided a platform for meaningful discussions on advancing clean energy technologies. The insights and collaborations formed during this event are expected to significantly contribute to the field of hydrogen fuel cells and sustainable energy solutions in India.