ACBHPE 2022

Awareness and Capacity Building in
Hydrogen Production and Energy uses: Towards a Net-Zero strategy

Dates & Venue

8th - 10th June, 2022
India International Centre,
New Delhi, India

Workshop Theme

Chemistry of Hydrogen Production and Energy uses

PROCEEDINGS & RECOMMENDATIONS

#ONLY ONE EARTH

Climate Change Research Institute

India International Centre







Awareness and Capacity Building Workshop
Hydrogen Production and Energy uses: Towards a Net-Zero strategy

ACBHPE-2022

Venue

India International Centre Annexe, Lecture Hall 1
June 8 – 10, 2022

PROCEEDINGS & RECOMMENDATIONS

Workshop Sessions

Hydrogen Production Technologies

Green Hydrogen Production: Hybrid approach

Thermal (coal, oil & gas) Conversion with CCS

Sustainable Hydrogen Storage & Risk Management

Hydrogen Production from Biomass and Startups Ecosystem

Climate Change Research Institute
Science & Technology Solutions for Sustainable Energy Future

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Preface

The workshop on 'Hydrogen Production and Energy Uses: Towards a Net-zero Strategy' organized by the Climate Change Research Institute (CCRI) from 8th to 10th June 2022 in association with the India International Center (IIC) turns out to be fantastic awareness and capacity building workshop for addressing climate change concerns. Hydrogen is emerging as an important source of energy, which has zero carbon content and is an emission free source, in contrast to fossil fuels, which are majorly responsible for global warming. According to the 6th IPCC report hydrogen is expected to play a decisive role in our future energy systems. The workshop initially proposed to be held off-line was conducted in Hybrid mode to facilitate participation of outstation delegates in the World Environment Day 2022 (falling on 5th June) event amidst the celebration of 75th year of Azadi ka Amrit Mahotsava.

I express deep gratitude to Shri R.V. Shahi, Former Secretary, Ministry of Power, who delivered the Presidential address and highlighted the policy challenges in introducing hydrogen as a step towards clean energy transition in India. Special thanks are due to *Padamshree* Prof G.D. Yadav, National Science Chair, SERB and Prof P.C. Ghosh, IIT Mumbai for the Keynote Addresses on hydrogen production technologies. I thank distinguished speakers for the workshop; Dr V.A. Mendhe and Dr Prakash D. Chavan, Sr Principal Scientists, CMFIR Dhanbad; Prof S.K. Singh, IIT Indore; Sh Gautam Sen, ONGC; Ms Gauri Jauhar, IHS Markit; Dr S. Nand, Add. DG, Fertilizers Association of India; Prof G. D. Sharma, Ex Secretary UGC; Dr Rakesh Kumar, Ex-Director NEERI; Dr Bipin Gupta, Principal Scientist NPL; Prof S. Ahmad Ex-VC Jamia; Shri V. S. Verma Ex-Member CERC, and Sh R. Varshney, DGM NTPC who shared their wisdom and experience in research & development, an eye opener to many delegates.

We are thankful to Shri A.K. Jain, former Commissioner DDA for the evening lecture on 'Climate Resilient and Low Carbon India'. Shri K.N. Shrivastava, Director IIC Presided over the Session. We thank Prof. D. P. Agrawal, Chairman National Advisory Board and the members for their kind support and encouragement and convey special thanks to Shri Gautam Sen and Sh R. Varshney, members from the Organizing Committee. The CCRI acknowledges the partial support from Science & Engineering Research Board (SERB) and excellent facilities at the India International Center.

Dr (Mrs) Malti Goel
Organizing Secretary, ACBHPE-2022

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Climate change Research Institute

Workshop on Awareness and Capacity Building in Hydrogen Production and Energy uses: Towards a Net-Zero strategy (ACBHPE-2022)

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Awareness and Capacity Building in Hydrogen Production and Energy uses: Towards a Net-Zero strategy, (ACBHPE- 2022)

(ACBHPE- 2022)

India International Centre Annexe, Lecture Hall-1, New Delhi

8th – 10th June, 2022

Day 1

INAUGURAL SESSION

Welcome and Introductory Remarks: Dr (Mrs) Malti Goel, President, Climate Change Research Institute

The event began with the lighting of lamp.

1. Dr Malti Goel, President Climate Change Research Institute (CCRI) and Organizing Secretary extended warm welcome to all distinguished dignitaries, esteemed guests and delegates. She said the workshop on Hydrogen Production and Energy Uses is an initiative of the CCRI. Our Institute has been making noteworthy contribution towards the emerging social challenges due to climate change impacts and unearthing S&T solutions by interactions with the students, with the teachers, with the professionals and with the scientists in novel ways. The awareness of climate change and its impacts through communications, workshops and education is crucial for generating support for climate change action.

2. Post COVID-19, this was Institute's first physical event after three years on the world environment day through participation from the experts and youth. In the 2020 and 2021 major effort has gone into holding virtual events, environment education and dissemination of information. The present workshop was planned in collaboration with IIC, New Delhi and a proposal was submitted the SERB, DST. But there were many hurdles and at the last minute we decided to go into hybrid mode.

3. The 'World Environment Day' campaign began in 1974. The CCRI has been holding science campaigns and awareness workshops every year, since 2014. Dr Malti Goel gave an

introduction to World Environment Day 2022. She said in the First Stockholm Conference on Environment and Development (UNCED) held in Sweden 50 years back. The theme was ‘Only One Earth’ adopted from Barbara Ward and Rene Dubos book ‘*Only One Earth: The Care and Maintenance of a Small Planet*’. The book published in 1972 drew attention to the limited earth resources. Every year UN assigns a host country and a theme. Sweden is the host this year and the theme is chosen to be ‘Only one Earth’ with a focus on *Living Sustainably in Harmony with Nature*.

4. Hydrogen is emerging as an important source of energy and has zero carbon content and is an emission free source in contrast to fossil fuels, which are majorly responsible for CO_2 emissions and global warming. Hydrogen can be a ‘healing balm’ to planet earth from climate change disasters. It is expected to play a decisive role in future energy systems, according to the IPCC.

5. The ACBHPE-2022 is a three day awareness and capacity building workshop on ‘Hydrogen Production and Energy uses: Towards a Net-Zero strategy’ with following technical sessions

- Hydrogen Production Technologies
- Green Hydrogen Production: Hybrid approach
- Thermal (coal, oil & gas) Conversion with CCS
- Sustainable Hydrogen Storage, Energy Uses & Risk Management
- Hydrogen Production from Biomass & Startups Ecosystem

6. She said three day national level workshop will provide a platform for young researchers to learn about the scientific & technological challenges faced in hydrogen production and energy uses. We earnestly desire that workshop deliberations would be serving the goal of implementing Hydrogen Mission Programme of the Government of India and contributing to progress towards Climate Action.

7. Dr Malti Goel welcomed distinguished Chief Guest Shri R. V. Shahi, Former Secretary Ministry of Power, who connected from Ahmedabad online in the hybrid mode and delivered the Presidential Address.

Presidential Address: Shri R. V. Shahi, Former Secretary, Ministry of Power

1. Shri R. V. Shahi, former Secretary, Ministry of Power is an illustrious leader in the Power Sector of India, known for his pioneering policies, having many feathers on his cap. Shri Shahi at the outset complimented Dr Malti Goel for the good work being done by the Climate Change Research Institute (CCRI) in bringing awareness and capacity building in energy and climate change.

2. He said climate change due to increased greenhouse gas emissions is a key global concern. South Asia and China are among the major contributors to carbon emissions to the atmosphere. China is having the highest level followed by India in South Asia. However, per capita emission of India continues to be much lower than the global average. India has been taking a position of 'Common but Differentiated Responsibility (CBDR)'. Developmental needs of India will continue for many years. He said in 1980s India and China were at par yet China has gone far-ahead much earlier and their per capita carbon emission is 5 to 6 times that of India at present. India is facing issues like how to have negative carbon emission, reduce the cost of energy and get more energy output by increasing efficiency. The challenge for policy makers in India is that we should still try to minimize the carbon emissions and possibly get into net-zero at the earliest.

3. We are seeing very radical changes in the energy sector, not only in coal based generation but all fossil fuel are now been put into discussion globally. India is coal dominant and the question is how fast we should reduce coal. We have 85% import dependence on petroleum products and how it would reduce as automobiles are transitioning to be electric vehicles. Agriculture sector is another area where our fossil fuel use is being replaced by solar pumps.

4. India has set ambitious targets for renewable energy and we are going big way in developing solar, wind, and hybrid energy systems. It is creating another challenge that we are not having full backup and a shortfall is created as solar radiance is not available 24 hrs and therefore we have to find solutions through battery storage or hydrogen storage. The vital question is; we would achieve five hundred thousand megawatt Renewable Energy by 2030 or say by 2032-33 but how can we replace all our energy by solar? Battery storage has a significant role. Pump storage can play a role in providing a supplement.

6. In various options being mentioned today hydrogen is one of them. Hydrogen has been known for decades in transport applications and fuel cell research. With a new thrust given by our Prime Minister Shri Modi ji, Green Hydrogen would provide the solution for clean energy transition. Ministry of Power, Government of India has announced green hydrogen policy in Feb 2022. A large number of industrial groups viz. NTPC, TATA, Reliance industry, Adani and others have come forward to make major financial investment commitments.

7. There are debates whether hydrogen is to be produced from coal, or biomass or water. There are many methods of producing hydrogen and handling hydrogen. We have programmes on coal-to-hydrogen and biomass-to-hydrogen. Electrolysers are under development. Green hydrogen production requires high capital investment, but has good potential of becoming economically acceptable on a large-scale. India enjoys the advantage of providing a large consumer base, so one of the ways in making the particular technology development affordable is to create big demands.

8. **Shri R V Shahi concluded by saying that challenges are there, options are also there and India needs to develop suitable strategies for achieving success. He observed that it is a matter of satisfaction that the workshop will disseminate vast information on various ways of producing hydrogen and energy uses by eminent scientists and engineers. He wished the deliberations a success.**

Special Address: Ms. Gauri Jauhar Executive Director, IHS Markit on "Mega Trends in the Energy Transition"

1. Ms Gauri Jauhar, ED IHS Markit gave an overview of climate change and described hydrogen as a solution to manage it. Hydrogen is becoming integral to the global 2050 net-zero vision. We need to understand the mega trends in energy transitions taking place globally. The energy transitions are governed by policy, technology, finance and company strategies. In reality it is the ecosystem comprising of academia, industry, technology players, and innovators in supply chain that make it happen.

2. Since 1789 energy is transitioning, started when the first change from mechanical power to steam engine and coal use, then from coal to oil, oil to gas, fuels, renewables and now hydrogen. The triggers in past energy transitions have been efficiency of different fuels used but trigger this time is heating of the atmosphere. The aim is to limit the growth and limit the rise in temperature to 1.5^{o}C rise from pre-industry levels. Pressure is from climate change and finding solution to deliver better and more sustainable energy. Financial sector is coming in the forefront to address all the policy making challenges and giving a push to these developments. Green Bond market is emerging.

She summarized eight trends in energy transitions to meet the climate goals as below:

1. Climate: Pressure for climate-related financial risk disclosure increases

   – Focus on climate-related financial risk reporting has reached record levels in 2021; SEC proposal seeks standardization in firms' mandated emissions reporting.

2. Net-zero: Leap forward in net-zero emissions targets by countries

   - *Top 3 emitters – China, the US and India have announced net zero targets in 2021; Approximately 90% of global greenhouse gas (GHG) emissions covered by net-zero pledges, but with different strength and timing.*

3. Carbon prices: Article 6 agreement is the most significant outcome of COP26 which will govern global carbon markets.

   - *Voluntary carbon markets are set to grow dramatically with investment expected to exceed $100 bn by 2050.*

4. Increased Capex for renewables, storage, green hydrogen: ~$440 bn p.a. investments globally, 20% point increase in proportion of total power generation.

   - *Total renewable power, storage, green hydrogen investment is expected to become $12.8 trillion between 2022-50.*

5. Hydrogen is becoming integral to the global 2050 vision

   - *Multiple Hydrogen-related policy documents exist to explain governments' strategic intentions and specific measures to support projects.*

6. Carbon Capture: While material to meeting net-zero targets, >60% of global CCUS large-scale projects are still in early development

- *CCU projects are key contributor to current operating capture capacity; CCS projects account for 15% of the current capacity.*

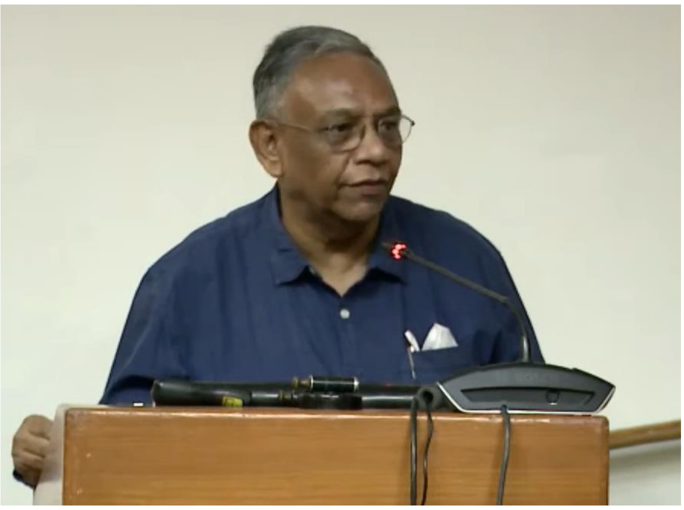
7. Low-carbon Capex by companies reflect net-zero strategies: Varying strategies in low carbon spending by IOCs.

   - *While the proportion of hydrogen spending to renewable investments remains modest, new commitments are expected.*

8. Green bonds: Energy firms took on growing role as energy related corporate green bond issuers in 2021.

   - *Across the globe US utilities like Dominion, Canadian fossil fuel leaders like Enbridge, Indian conglomerates like Adani and European IOCs like Repsol and Eni all issued green bonds during 2021.*

Vote of Thanks by Shri Gautam Sen, Ex-Sr. VP, Reliance and ED, ONGC



1. Shri Gautam Sen Ex-Sr. VP, Reliance and ED, ONGC presented vote of thanks. He said we have had two excellent sessions on Hydrogen energy challenges. In the Presidential Address Sh. R.V. Shahi discussed the things that are happening today around the world, India has its biggest challenges as our per capita emission still very low, our development still has long way to go but the world already gone to define net-zero. He thanked him profusely for his inspiring address.

2. Ms Gauri from IHS has described eight mega trends in energy transition. She touched upon the importance of carbon markets. The question arises why carbon markets could not be successful in India. How geopolitics will change with the mega transitions happening in the energy sector? He thanked her for a very insightful lecture.

3. He complimented Dr Malti Goel for conceptualizing the workshop so well and going ahead with the planning of three day workshop on Hydrogen. He said that he admired her initiatives and wished her success for taking up this challenge on behalf of CCRI.

Day 1

TECHNICAL SESSION – I: Hydrogen Production Technologies

Chairman: Prof. G.D. Sharma, Former Secretary, UGC – Opening Remarks

1. Prof G.D Sharma, Former Secretary UGC and Professor NEIPA in his opening remarks said solar energy is vital the for energy future. He talked about the model of development on the planet, which we started with animal energy, then mechanical energy, and then came the steam engine and use of fossil fuel grew. We have moved from use of fossil fuel to use of biomass and other renewables as carbon free sources. Hydrogen has added a new dimension and we are discussing it today.

2. He quoted that solar energy in 2041 is seen as developing into zero marginal cost energy. Methods of energy production and storage are going to change dramatically. Two factors will remain, renewable and non-renewables. Model of development will be integrated with Artificial Intelligence applications and satellite communication systems. Solar will emerge as least carbon footprint technology. Quantum computing, block chain technology and cloud computing are going to affect the future energy systems tremendously.

3. With these remarks he introduced the distinguished speakers and invited Prof G. D. Yadav, from Institute of Chemical Technology, Mumbai to deliver his Keynote Address.

Keynote Address: Prof. Ganapati D. Yadav, Emeritus Professor of Eminence, ICT Mumbai on Adoption of Green Hydrogen Technologies, CO_2 Refineries and Biomass Valorization

1. Prof. Ganpati Yadav, Emeritus Professor of Eminence, ICT Mumbai in his address quoted that Paris Agreement 2015 was evoked in 21st Conference of the Parties (COP 21) of United Nations Framework Convention on Climate Change's (UNFCCC). A consensus on the accord comprised of commitments by 195 nations to combat climate change and adapt national determined commitments. He said 'Leaders Summit on Climate' took place on April 22-23, 2021 and discussed accelerated actions needed to address the climate crisis, including emissions reduction, finance, innovation, job creation, resilience and adaptation etc.

2. Prof Yadav highlighted the importance of materials recycling, sustainability and zero waste society. He discussed the need for circular energy storage, battery recycling and the issues in waste management. More than 1.6 billion tons of CO_2 equivalent GHG emissions were generated from solid waste treatment and disposal in 2016, or 5% of global emissions. Disposing of waste in open dumps and landfills without landfill gas collection systems is a huge issue. Solid waste–related emissions are anticipated to increase to 2.38 billion tons of CO_2-equivalent per year by 2050 if no improvements are made in the sector.

3. He said energy and environment are intimately connected. More energy means more environmental damage. The energy needs of the world are increasing day by day and use of carbon-based fuels will continue to rise. Whether the carbon is coming from fossil fuels or biofuels, there would be a need to convert CO_2 into fuels, chemicals and materials. Hydrogen is the cleanest fuel which can be produced from hydrocarbons or from water and can be used to convert CO_2 into useful products. Treatment of biomass waste into hydrocarbons with the help of novel catalysts can be reformed into hydrogen, but CO_2 generated in the process needs to be utilized. Hydrogen will be the SAVIOUR for the planet EARTH.

4. For the hydrogen economy to become a reality, hydrogen must be produced cheaply and in an ecofriendly manner, and it should serve as the commercial fuel that would provide a substantial portion of the country's energy demand and services. In a net-zero economy, green hydrogen will have to play a dominant role. He also described Blue, Grey and other shades of Hydrogen. Solar, Wind and Hydrogen are new trinity.

5. Prof. Yadav explained Hydrogen uses in an oil refinery and a bio-refinery. Hydrogen use is expected to grow from 2% of the global energy mix in 2018 to 13-24% by 2050 with the investment of 150 billion by 2030. Methane pyrolysis produces hydrogen and graphene with no greenhouse gas pollution or CO_2 emission. He explained the ICT-OEC Ca –CI Thermochemical process for green hydrogen production. The technology was developed at the Institute of Chemical Technology in Mumbai in 2007. The cost of hydrogen production by the ICT-OEC Process for Hydrogen is 0.95 USD per kg.

6. Prof. Yadav recommended conversion of biomass into chemicals and not into energy fuels. He explained waste plastic chemical recycling techniques perspective of H_2 economy. In the long-term single use plastics can be recycled using chemical processes. By their nature, all fuels have some degree of danger associated with them. The safe use of any fuel focuses on preventing situations where the three combustion factors – ignition source (spark or heat), oxidant (air), and fuel – all are present. A number of hydrogen's properties make it safer to handle and use than the fuels commonly used today. Hydrogen is much lighter than air, it dissipates rapidly when it is released, allowing for relatively rapid dispersal of the fuel in case of a leak. Testing of hydrogen systems-tank leak tests, garage leak simulations, and hydrogen tank drop tests – shows that hydrogen can be produced, stored, and dispensed safely.

7. **In conclusion, Prof Yadav said hydrogen economy can be elegantly intertwined to make many chemicals from waste carbon sources including biomass and C1 off-gases. Green Hydrogen will be the savior of the world. Carbon dioxide should not be a liability but an asset to convert into products. Agricultural waste as bio-refineries and blue hydrogen sources must be explored. He suggested that Govt. of India should adopt hydrogen economy to meet the demands of the Paris Agreement. He opined that ICT-OEC Hydrogen production technology is very promising at <USD~1.00 per kg and it can be achieved**.

Keynote Address : Prof. Prakash C. Ghosh, Department of Energy Science & Engineering, IIT Bombay on Green Hydrogen Economy: Challenges and Opportunities

1. Prof. Prakash C. Ghosh, IIT Mumbai is having vast experience in working with hydrogen in Germany and India. He said that he is currently working on a project on 'Hybridization and Integration of Renewable Systems' in an off-grid location in North Sikkim to cater the partial energy requirements of an Indian army base. It comprises of AC-DC hybrid micro-grid supported by a 50 kWp PV system. Evaluation of uninterrupted performance is being done in extreme cold conditions at a height of 17000 it. He quoted, "A hydrogen economy will mean a world where our pollution problems are solved and where our need for abundant and affordable energy is secure and the concerns about dwindling resources are a thing of the past."

2. He gave an introduction to hydrogen as fuel and compared properties of hydrogen with other fuels. Every fuel produces energy if it reacts completely with oxygen. This energy is quantified in terms of Heating Value. Depending on the state (gaseous or liquid) of product it is categorized as higher heating value and lower heating value. Higher heating value refers to the fact that the product is in liquid form. Lower value refers to the fact that the product is in gaseous form. Auto ignition temperature range of Hydrogen is higher in comparison to other fuels.

3. Hydrogen leakage is dangerous but keeping in view properties of other fuels, leaking gasoline or diesel spreads laterally and evaporates slowly resulting in a widespread, lingering fire hazard. Propane gas is denser than air so it accumulates in low spots and disperses slowly, resulting in a protracted fire or explosion hazard. Heavy vapors can also form vapor clouds or plumes that travel as they are pushed by breezes. In case of hydrogen the molecules are smaller than all other gases, and during leaking it can diffuse through many materials considered airtight or impermeable to other gases. This property makes hydrogen more difficult to contain than other gases. A comparison of conventional and H_2 value chain suggests that hydrogen fuel performance is much better in terms of emission reduction and efficiency but has higher investment cost and is in R&D stage.

4. He described hydrogen production pathways using fossil fuels, nuclear energy and renewables. The storage options were also discussed. Hydrogen can be classified into

different colors and the processes how these can be produced. Seasonal variation of solar energy played significant role in PV cell output and using hydrogen as a complementary to battery output proved highly efficient to get 100% output. This was done in Germany in late 1990s. He described the composition of Proton Exchange Membrane (PEM) fuel cell and applications. PEM fuel cells have several advantages in terms of high current density and high efficiency, but they are only partially established and cost of components is high. A comparison of different technologies was presented as in Figure 1.

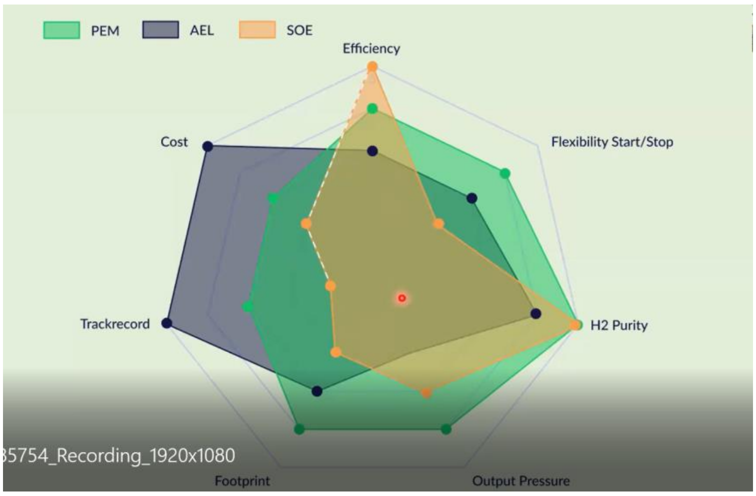


Fig. 1 Comparison of different fuel cell technologies

5. Electrolysis proves efficient but cost is high. Hydrogen production cost comparison was presented. Green Hydrogen production requires complementarity of sources and battery to support an electrolyzer. The system level analysis suggests lite cycle electrolyzer cost - INR 224/ Kg of H_2. Using total solar energy cost per kg of H_2 as INR 15 and battery storage cost per kg of H_2 as INR 720, the total hydrogen product cost per kg comes to INR 959. This has to reduce.

6. **Prof. Ghosh concluded that Green hydrogen is considered as a sustainable solution. Alkaline electrolyser is considered as a cost-effective solution. However, energy storage should also be cost-effective. PEM fuel cell would be cost-effective only if the catalyst used can be recycled.**

SPECIAL ENVIRONMENT DAY LECTURE by Sh. A.K. Jain, Former Commissioner, DDA on "Climate Resilient and Low Carbon Urban India"

Chairman: Sh. K. N. Shrivastava, Director IIC

Opening Remarks: Shri K.N. Shrivastava, Director IIC in his address pointed out that climate change has become a reality and we are now seeing the vital signs of climate change in our ecosystem. On one hand water table is going down in the plains, on the other, we witnessed devastating Kedarnath Temple tragedy caused by flash floods in 2013 in Uttrakhand hills. He recalled that as then Secretary, Ministry of Civil Aviation it was of matter of great consequence in managing this calamity. He said at the IIC we have taken several steps towards sustainability and also have installed a solar plant. He then introduced Shri A K Jain and invited him to deliver his lecture.

Guest Lecture: Shri A.K. Jain former Commissioner, DDA in the Special Evening Lecture on World Environment Day on **"Climate Resilient and Low Carbon Urban India"** covered a wide range of topics relating to urban development, and energy uses with converge into a pathway towards mainstreaming sustainability in the built environment. He said, according to the Intergovernmental Panel on Climate Change (IPCC), urban areas account for 67 to 76% of global energy use and 71 to 76% CO_2 emissions. Buildings in India account for 40% use of energy, 30% of raw material, 20% of water and 20% of land. They generate 30% and 20% of the solid waste and liquid effluents, and about 1/ 4th of the CO_2 emissions. The built environment with circular metabolism can give as much to the nature as it takes out, thus reducing its ecological impact and carbon emissions. This needs relooking at the processes of urban development which should shift from fossil fuel era to the circular concepts for conservation of natural resources and by passive design with the sun, wind, water earth and space. This means that the cities and buildings, including their energy, water sanitation, and transport have to be sustainable, climate resilient and low carbon, with net zero energy and water.

Vote of Thanks: Dr Malti Goel, President CCRI presented vote of thanks. She thanked the Chairman Shri K N Shrivastava for his opening remarks and appreciated his leadership role in taking a number of sustainability initiatives at IIC. She thanked Shri A K. Jain for an excellent lecture and bringing out insights into integrating not one but many SDGs with the urban planning strategies. She thanked distinguished participants for their time and India International Center for hosting the lecture.

Day 2

TECHNICAL SESSION - II: Green Hydrogen Production - Hybrid Approach

Chairperson: Dr. (Mrs.) Malti Goel, President and Chief Executive, CCRI Address: Hydrogen Production Technologies and Energy Uses

1. Dr. Malti Goel President, Climate Change Research Institute in her theme address quoted "*If the world is to reach net-zero emissions, hydrogen will play a vital role"*- from the 6th Assessment Report of Intergovernmental Panel on Climate Change (IPCC) released on 5th April 2022.

2. Since the 1950s, the measurement of atmospheric CO_2 concentration has shown an increase and from 310 ppm in 1970s, it has increased to 421 ppm in 2021. China, India, the US and EU have added to around 70% of the global increase in CO_2, in the last 50 years. Climate Change context is the driving force for revival of hydrogen as a fuel with no carbon content. She said Hindenburg airship accident of 1937 had raised vital issues about safety from use of hydrogen as fuel and had put airship use on the back burner. Though, road transport advancements since then have made it safer.

3. Advocating both for hydrogen and carbon capture, storage and utilization the IPCC assessment highlights following key challenges for hydrogen economy: (a) cost-effective low/zero carbon production, (b) delivery infrastructure cost, (c) land area (ie, 'footprint') requirements of hydrogen pipelines, compressor stations, and other infrastructure, (d) challenges in using existing pipeline infrastructure, (e) maintaining hydrogen purity, (e) minimizing hydrogen leakage, and (f) the cost and performance of end-uses.

4. The hydrogen production technology can be grouped into four main categories based on production methods as: Electrical, Thermal, Hybrid, Biological processes. Each of the processes is explained with examples. Electrical method involves Water splitting by Electrolysis and Plasma Arc Electrolysis. Thermal processes are based on conversion of fossil fuels like coal, oil and natural gas. Biological processes can be grouped into Fermentation and Photosynthesis. A byproduct of solar chemical energy or 'artificial photosynthesis', it can lead to clean energy transitions. Hybrid processes are combination of these like thermo-electrochemical, biocatalytic-photolysis and others.

5. The CSIR-National Chemical Laboratory Pune, India, has developed an ultra-thin artificial leaf device consisting of semiconductors stacked in a manner to simulate the natural leaf system. In the presence of solar light, electric current flows through the semiconductors and results in water splitting. The results are promising and suggest that it could become the basis of ‘solar factories’ in which solar collectors’ arrays are used to split water into hydrogen.

6. She explained the ladder of hydrogen colors, current global consumption of hydrogen in industry and gave an example of DOE, USA project on scaling up hydrogen use. Global investments in hydrogen are increasing and almost 40 countries have identified hydrogen roadmaps. Possible Green Hydrogen pathways viz., water electrolysis among electrical methods, biomass gasification as being CO_2 neutral among thermal methods, photo-electrochemical and photo-fermentation production among hybrid methods and bio-photolysis among biological methods make hydrogen production “green”.

7. India has been giving attention to hydrogen as fuel and took several initiatives from time to time. In 2003 National Hydrogen Energy Board was formed. In 2006 the Ministry of New and Renewable Energy laid out the National Hydrogen Energy Road Map identifying transport and power generation as two major green energy initiatives. The R&D programme on ‘Hydrogen Energy and Fuel’ was launched to address challenges in production of hydrogen from renewable energy sources, its safe and efficient storage, and its utilization for energy and transport applications through combustion or fuel cells.

8. In 2015 India participated in Mission Innovation Challenge for clean hydrogen and shared the objective to accelerate the development of a global hydrogen market by identifying and overcoming key technology barriers to the production, distribution, storage and use of hydrogen at gigawatt scale. In 2018 the India Country Status Report on ‘Hydrogen and Fuel Cells’ by Mission Innovation, and Department of Science & Technology was published. Under Mission Innovation programme the R&D has been intensified across the hydrogen value chain, focusing on improving the efficiency of water-splitting reaction, and finding newer materials, catalysts and electrodes to accelerate the reaction.

9. In 2020 Indian Institute of Science (IISc) and the Research and Development Centre of Indian Oil Corporation Limited have signed a MoU to develop and demonstrate biomass gasification-based hydrogen generation technology for producing fuel cell-grade hydrogen at an affordable price. The MoP&NG has launched a “Hydrogen Corpus Fund” (HCF) for funding R&D (Research and Development) and is planning pilot projects on Green Hydrogen. Maharashtra Institute of Technology-World Peace University plans a Hydrogen Research Centre at Pune for carbon neutrality. Other Indian success stories were presented.

10. On 17th February 2022 Ministry of Power has announced Green Hydrogen Policy aimed to aid the government in meeting its climate targets and making India an export hub for green hydrogen. It sets a target of production of 5 million tonnes per annum for Green hydrogen by 2030, aiming to reduce dependence on fossil fuel and also reduce crude oil imports. It envisages Hydrogen and Ammonia to be the future fuels and Identifies facilitating mechanisms for transmission of renewable energy and Regulations for environmentally sustainable energy security of the nation.

11. **In conclusion, Dr Malti Goel raised five questions to ponder upon**

- **Can Hydrogen be widely viewed as an important fuel for a future energy transition?**
- **How Green is Green Hydrogen?**

- **How Green is Blue Hydrogen?**
- **Why there is IPCC urgency to scale up Hydrogen technology worldwide?**
- **Which processes for hydrogen production should be considered leading to Green Hydrogen?**

She introduced the distinguished speakers and invited Dr Sanjay K. Singh Professor, Department of Chemistry, IIT Indore to deliver his lecture.

Keynote lecture: Dr. Sanjay K. Singh Professor, Department of Chemistry, IIT Indore on Hydrogen Production from Liquid Hydrogen Carriers

1. Prof. Sanjay Singh, IIT Indore, said climate crisis is looming large. He stated India's commitment towards Net-Zero Emissions by 2070 and said that Prime Minister Narendra Modi has announced in COP-26 that India will draw 50% of its consumed energy from renewable sources by 2030, and cut its carbon emissions by a billion tonnes more in the same year.

2. Global CO_2 emissions are on rise. Transport sector contributed 138 TMT of CO_2 in 2007-08 and the contribution could rise to 346 TMT in 2022 in a business-as-usual case, an increase of about 150%. Current policy of 10% ethanol (E10) and 3 % methanol (M3) blends by 2025, and 20% ethanol (E20) blended gasoline by 2030 could make specific vehicles compatible with 3.045 million NGVs (India stands 3rd). 10,000 CNG filling stations will be required by 2030 for 20 million CNG vehicles.

3. Giving examples of India's potential in sustainable energy, he said that use of alternative fuels can make electrical vehicles (EVs) environmentally friendly. The storage battery however, would increase dependence on lithium battery. Hydrogen is the fuel of the future, it is well balanced with high energy content for CO_2 free transportation to cater to the global energy demand, reduce oil dependency, greenhouse gas emissions and air pollution.

4. Energy content of H_2 (130 MJ/kg) is much greater than the energy content of fossil fuels (~46 MJ/kg) and for electricity production 33.6 kWh/kg (H_2) >> 12-14 kWh/kg (diesel). Water is the only byproduct during utilization of H_2 as fuel. Hydrogen and Fuel Cell technologies could achieve a 33-35 % reduction in greenhouse gases by 2030 of its 2005 level, apart from co-benefits in terms of lower levels of air pollution, affordability, sustainable transportation etc. Agriculture sector is the second largest user of hydrogen (as nitrogenous fertilizer), with 49% of hydrogen being used for ammonia production.

5. He described challenges before a hydrogen-based society and explained Indian initiatives. Trains can run on Hydrogen Fuel Cell-Based hybrid systems. Council of Scientific and Industrial Research and KPIT has indigenously developed fuel cell technology. Big hydrogen-fuelled bus project is in operation in Leh; with Ladakh to be 1^{st} UT to run completely on renewable energy. Advantages and limitations of hydrogen fuel cell vehicles and the

infrastructure requirement in their operation were described. Global and Indian initiatives toward hydrogen fuel cell vehicles use were also discussed.

6. Liquid organic hydrogen (LDH) carriers are organic compounds, and can absorb and release hydrogen though chemical reactions usually with the intervention of a catalyst. They have the advantage that existing infrastructure of petroleum can be used. A number of chemicals can be liquid hydrogen carriers such as Ammonia, Hydrazine and Methanol etc. Ammonia is a promising zero-carbon liquid hydrogen storage carrier. But it has adverse physical and chemical properties, high coefficient of thermal expansion, high vapor pressure at ambient conditions, propensity for reacting with water, reactivity with container materials and high toxicity of the vapor if released into the air, which need to overcome. Research carried out in developing Hydrazine as carriers, the use of catalysts and plausible pathways were described. Hydrogen production from methanol is a hydrogenation of CO and CO_2 and reversed water-gas shift reaction were explained. Methanol is a liquid at room temperature and has a high H_2 content (12.6 wt%). Various catalysts and catalytic routes for onboard hydrogen production from LOH were presented.

7. **Dr. Singh concluded that by saying that development of efficient technology by chemical intervention has created enormous opportunity to fulfill the global energy demand in a most efficient and cleaner way. In this regard, H_2 based economy is the ultimate solution at this point of time**.

Special Lecture: Dr. S. Ahmad, Ex- VC, Jamia Hamdard, New Delhi, Ex-Director, CEERI, Pilani on 2D-NMs Photocatalyst Hydrogen Evolution

1. Dr S. Ahmad Ex- VC, Jamia Hamdard delivered the special lecture on the use of photocatalysts for producing hydrogen. He observed that for last 15-20 years he has been trying to understand little bit about intelligent materials that has been his passion. Being an electronic engineer with specialization in semiconductor technology, working there for more than 40 years he tried to switch over to the life sciences and start looking at the relevance of nano-materials in biomedical applications. In this context, he came across different forms of materials starting from nanoparticles. This lecture describes two dimensional nanomaterial photocatalysts for production of hydrogen.

2. CLIMATE CHANGE mitigation is addressed by reducing CO_2 emissions and use of renewable sources. Producing H_2 from photocatalytic conversion requires efficient & affordable photocatalyst. The question arises why hydrogen fuel? The following Table gives a summary of energy content of different fuels.

S. No.	Fuel	MJ/Kg
1.	Liquid Hydrogen	130
2.	Aviation Gasoline	46.8
3.	Premium Gasoline/Petrol	46
4.	Regular Gasoline/Petrol	47
5.	Jet Fuel (Kerosene)	47
6.	Jet Fuel (Naphtha)	46.6
7.	Diesel	48
8.	Biodiesel	39.9
9.	Liquefied Natural Gas	55
10.	E85 (85:15:: ethanol : gasoline)	~33

11.	**Ethanol**	**31.1**
12.	**Methanol**	**19.9**
13.	**Vegetable Oil**	**37.7**
14.	**Gasohol (10:90:: ethanol : gasoline)**	**~45**
15.	**Liquid Petroleum Gas (LPG)**	**~51**

3. Hydrogen is a convenient energy carrier. Appropriate band-gap semiconductor can be an optical photocatalyst satisfying REDOX potential for spitting water into hydrogen and oxygen for production of hydrogen. 2D-Nanomaterials can be explored as semiconductor photocatalysts as they have adjustable bandwidth and charge carrier transport lifetime.

4. He said with the discovery of Graphene from graphite, exploration of 2D-NMs has Intensified as possible photocatalysts. Various combinations and structures have been studied.

G-C3N4 Graphic Carbide Nitride forms a hetero-structure suitable for REDOX reaction. The various designs of other hetero-structures include;

Cu2O/g-C3N4,
Graphene / g-C3N4,
CdS / gC3N4,
TiO2 / g-C3N4.
Untreated g-C3N4 / Sulfidized g-C3N4.

5. Their experimental characteristics have been studied. A list of opportunities exists. Hydrogen can power the automobiles using a PEM fuel cell.

6. **Prof Ahmad summarized the challenges to materials development in achieving hydrogen revolution are summarized as**

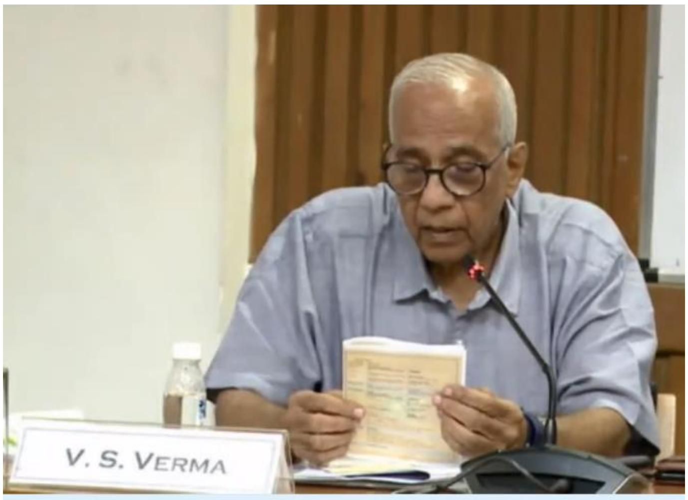
- **i)** **durability/stability & efficient recycling,**
- **ii)** **better precursors – Critical Decision,**
- iii) **newer heterojunction & homojunction**,

7. Carbonaceous semiconductors can also be investigated. He said opportunities are immense and this area needs to be explored further.

Day 2

TECHNICAL SESSION – III: Thermal (coal, oil & gas) Conversion with CCS

Chairman: Shri V.S.Verma, Former Member, CERC and Member Planning, CEA



1. Shri V S Verma, Former Member CERC and Chairman extended warm welcome to all participants and observed that in the Indian Power Sector coal quality has been an issue. How mining can help improving the coal quality so that imports can reduce is another issue? This session is on conversion of fossil fuel into Hydrogen. Two lectures are; Conversion of CBM to hydrogen and coal gasification route for hydrogen production.

2. He said today one kg of H_2 is produced at 10-15 $ per kg and till it because 1 $/ Kg, then only it can because viable. In electrification of transportation, country is going slow in case of four wheelers and what is future for hydrogen is to be seen. Depending on the nature of uses, Electric Vehicles (EVs) & Hydrogen (H_2) fuel vehicles both will have a market.

3. He introduced the speakers Dr. V.A. Mendhe and Dr Prakash D. Chavan from CMFRI Dhanbad. He said Dr Rakesh Kumar, Former Director NEERI would be shortly joining online from Mumbai. He then invited Dr V A Mendhe to deliver his address.

Special Lecture: Dr. V. A. Mendhe, Sr. Principal Scientist, Head, Shale Gas & Non-Conventional Gases, CSIR-CIMFR, Dhanbad on Scope and Potential of Coalbed Methane to Hydrogen Production in India

1. Dr. V.A. Mendhe, Sr. Principal Scientist, CMFIR Dhanbad said that his group is working on scope of converting coalbed methane to hydrogen. His team included Ms. Priyanka Shukla, Mr Shashanka Pandey, Mr Vinal Vinod Mendhe, Ms. Akanksha Pandey, Dr. Mollika Banerjee, and Prof. Chavan who have come to attend the workshop. He began with the current status of coal bed methane (CBM) in India. Presently seven blocks are commercially producing (aprox. 3.0 MMSCMD). With the recent completion of the national gas pipeline grid under "Urja Ganga Project" the 3376 km Jagdishpur-Haldia-Bokaro-Dhamra (JHBD) gas pipe is passing through CBM shale gas blocks in India in the eastern part of the country. There is extreme pressure on CBM operators to increase methane production from their respective blocks, though gas pressure is low.

2. With the continuous inclination towards the development of clean alternative energies by world countries looking for better use of energy resources, methanol, ethanol, H_2, fuel cells, etc. are the emerging options for clean energy. Clean hydrogen is hyped as the future fuel, likely to deliver an excess of carbon-neutral energy by 2030. However, hydrogen production from different sources is in the nascent stage in India. Conversion of CBM to hydrogen is a very lucrative, technically, and economically feasible option, because the average calorific value of CBM is aprox. 8500 kcal/kg and hydrogen is aprox. 30,000 kcal/kg. The high calorific value of hydrogen and source material for fuel cells offers excellent economics to the operators. In addition, CH_4 to H_2 conversion through CO_2 capture and its injection in reservoirs provides an added opportunity for enhanced coal bed/shale gas recovery.

3. He said the National Hydrogen Mission targets to aid the government in achieving its climate targets and creating India green hydrogen action toward net-zero emissions. The current green hydrogen production cost ranges between INR300 and INR 350 per kilogram in India. The operators like Larsen & Toubro, Reliance Industries (RIL), NTPC, Indian Oil Corp, BPCL, JSW Steel, Jindal Steel and others, have announced ambitious plans to install green hydrogen production projects in India.

4. He described CBM potential blocks in India, resources and recoverable CBM. The produced CBM gas composition contains >97% CH_4, about 2% C_2H_6 and 1-2% water. The mass ratio of carbon to H_2 in CH_4 is 3:1. In terms of mass, CH_4 is (4.032/16.04) x 100 = 25.13% H_2 and (12.01/16.04) x 100 = 74.87% carbon. Therefore, CBM thermal dissociation through

the steam reforming process is a good option for obtaining hydrogen. Also, the estimates of hydrogen production from CBM gas appear to be an excellent alternative and have a great scope of development in India. Global hydrogen demand and global fuel cell market are growing rapidly. Different hydrogen levels are well known as Green, Blue, Grey and Brown Hydrogen.

5. He explained four main sources for the commercial production of hydrogen as; natural gas (48%), oil (30%), coal (18%), and electrolysis (4%). The thermal catalytic conversion of methane to hydrogen is a well-known technology. The cracking of CH_4 through thermal dissociation involves molecular components of CH_4, H_2 and carbon being separated at about 750°C deprived of harmful emissions. About, 95% of the H_2 in the world is produced using the steam methane reforming process. Here, 100% of the carbon in the received CH_4 is eventually converted to CO_2. In order of generating 1 molecule of CO_2, 4 molecules of H_2 are formed, with the steam causative of the extra hydrogen. Hence, about 250,000 scf of CO_2 may be produced per 1 million scf of H_2 production from CH_4 dissociation. Likewise, 1 million scf of H_2 may produce 13 metric tons of CO_2, i.e. 19,253 scf of CO_2 in one metric ton.

6. CIMFR work on CO_2 permeability studies was described. In an integrated approach for CBM to hydrogen production, CO_2 utilization by carbon dioxide capturing and reinjection will be desirable. Steam CBM reforming has been attempted for appropriate CBM reservoir characteristics.

7. **Dr Mendhe concluded by saying that it is proposed to have a pilot-scale demonstration plant for hydrogen conversion at the CBM production block for confidence building and subsequently large-scale commercial implementation**.

Special Address: Dr. Rakesh Kumar, Former Director NEERI & OSD, CSIR Headquarters, New Delhi on Demand Side Measures Across the Economy – Implications to Climate Change

1. Dr. Rakesh Kumar, OSD, CSIR Headquarters and Director NEERI in his virtual lecture addressed the concerns of climate change and pollution control conflict. International climate change indicators are climate forcing and climate change agents. In the international actions there is a debate that country's economic plan should be obligated to climate change mitigation.

2. Climate forcing can be defined as an imposed perturbation of Earth's energy balance. This forcing can be imposed, natural, or anthropogenic. The other factor responsible for changing of earth's climate conditions is climate forcing agents. The agents can be differentiated in two categories: Short-lived Climate forcing agents or Long-lived Climate forcing agents.

3. The aggregate investment support required by India to achieve its 2070 net-zero target will be $1.4 trillion [Rs 105 lakh crore'. The government approved an investment of Rs 1,500 crore ($200 million) in the Indian Renewable Energy Development Agency budget, which provides project financing to the renewable energy sector. The allocation to the Climate Change Action Plan under the MoEFCC was reduced from Rs 40 crore in 2020-21 to Rs 30 crore in 2021-22. At the same time, the rising levels of Air Pollution have impacted several aspects of life. I Economic loss due to air pollution is high.ndia is estimated to bear 10.7 lakh crores (USD 150 billion), or 5.4 per cent of India's GDP annually, the third highest costs from fossil fuel air pollution worldwide. Global Economic loss incurred because of air pollution amounts to 2.9 trillion $.

4. Industries are major pointers and the actions to reduce industry sector emissions may lead to change in location of GHG intensive industries and have high implications. Such re-location will have global and national level distributional effects on employment and economic structure. He quoted from IPCC summary for policy makers that policy packages must therefore include, among other things, "*socially inclusive phase-out plans of emissions intensive facilities within the context of just transitions*".

5. The potential and sequencing of mitigation strategies in urban planning will vary depending on a city's land use, spatial form, development level, and state of urbanization. For older cities efficiency improving, repurposing or retrofitting building stock with low cost materials reduce energy footprint. Supporting non-motorized and public transport and

walking, providing financial and legal reforms will require high effort in changing existing patterns.

6. New and emerging cities will need energy efficient infrastructures and services and people-centered urban design to achieve high quality of life. In 2019, global direct and indirect emissions (*offsite generation of electricity and heat and emissions from cement and steel used in construction and renovation)* consumption indicated - Non-residential buildings: ~55% increase wrt 1990 and Residential buildings: ~50% increase wrt 1990. Low renovation rates and low ambition of retrofitted buildings have hindered the decrease of emissions. Developing countries have largest share of the mitigation potential for new buildings. Developed countries have highest mitigation potential within the retrofit of existing buildings.

7. Demand-side options and low-GHG emissions technologies can reduce transport sector emissions in developed countries. In both categories of scenarios, transport sector is not likely to reach zero CO_2 emissions by 2100-negative emissions needed to counterbalance. Electric Vehicles have large potential, costs are decreasing, but continued investments in supporting infrastructure would increase in case of deployment. Growing concerns are about critical minerals needed for batteries. Biofuels, if sustainably sourced, can provide mitigation benefits in the short and medium-term. Technology transfer and financing can support developing countries leapfrogging or transitioning to low emissions transport systems.

8. The Agriculture, Forestry and Land Use (AFOLU) sector can deliver large- scale greenhouse gas emission reduction by enhanced removal but cannot fully compensate for delayed action. Several barriers exist. Mitigation options and costs for technologies in 2030 timeframe have been developed for each sector.

9. It shows "net lifetime costs of avoided GHG emissions calculated relative to a reference technology". Mitigation potential is the quantity of net GHG reductions that can be achieved by a given option relative to a specified emission baseline. Large uncertainties exist including assumptions on the rate of technological advancement, regional differences, and economies of scale among others. Options for mitigation have been identified and these should be pursued. Carbon Capture and Utilization has high potential in AFOLU but low in industry where fuel switching has high potential. Because of high cost involved, technology transfer would be critical. Green Future Index 2022 has been identified for countries, using MIT Technology Review insights.

10. Over-use and high emission of developed countries can be reduced through "transformational policies". Industry and transport are hard to abate. AFOLU has high potential but has many social and economic barriers with varying degree across countries and regions. Equity and climate justice, both within and between the countries are important while implementing mitigation policies.

11. **Dr Rakesh Kumar said that lot of work has been carried out in CSIR Laboratories along these lines. Specific to India as developing country, it is important to lead from the front, as largely seen in RE energy sector. The R&D and studies for global practices must address the changing landscape. He concluded that Pollution and Climate Change debate is an angle which should be simultaneously addressed for sustainable growth of the country. He appreciated this initiative of CCRI and said more such discussions should be held to create awareness about it.**

Keynote Lecture: Dr. Prakash D. Chavan, Sr. Principal Scientist, Head Gasification & Catalysis Research Group, CSIR-CIMFR, Dhanbad on Indian Coal Gasification Strategy: Current Status and Way Forward

1. Dr. Prakash D. Chavan Sr. Principal Scientist, CIMFR from Dhanbad presented Indian coal scenario and coal gasification requirement. Understanding of solid fuels characteristics of variety of feedback can be used by knowing these requirements. The study on 'Gasification Potential Mapping of Indian Coal' has been carried out and the report has been submitted to Niti Aayog in 2019. He explained three main gasification processes as Fixed bed, Fluidized bed and Entrained bed, and described coal gasification option suitability for Indian coal resources.

2. Presently, the Govt. of India is emphasizing on the coal-based methanol economy, to reduce import dependence of crude and petroleum products vis-à-vis to shield the country from the global volatility in the oil and gas market. India has a huge potential in the form of abundant coal reserves to produce alternate products such as methanol, fertilizers, SNG, chemicals, DRI, etc. through gasification route. Methanol Economy program of NITI Aayog mainly includes adoption of commercially proven suitable gasification technologies for the Indian coal followed by syngas to methanol conversion.

3. For venturing in the area of coal gasification at commercial level, availability of the suitable gasification technology along with successful operational philosophy is a crucial aspect. As coal choice may be the least flexible factor due to economic, geographical and political reasons, so it is necessary to adapt the gasification technology according to the available coal only. CSIR-CIMFR has developed gasifier selection criteria suitable for Indian coal resource and suggested *Matching gasification technology* vis-à-vis *Utilization pattern* & *gasification strategy* for gainful utilization of Indian coal resource.

4. In the integrated approach Methanol Economy Task Force under the aegis of NITI Aayog has identified two options for coal gasification program in India for utilization of Indian coal resource.

Option-I: Gasification with Commercially Proven Entrained Flow Gasifier (EFG)

Use of low ash containing coal resource available in India, specifically in ECL area has been identified as suitable. A demo project using low ash coal from ECL area is proposed to be installed at Dankuni Coal Complex (DCC) with membrane wall based high temperature Dry Fed Shell (Air-Products) EFG Technology. Further, high ash coal resource from neighboring subsidiaries like CCL and MCL can be tested in the EFG at Dankuni Project for gasification performance.

Option-II: Development of Indigenous Pressurized Fluidized Bed Gasifier (PFBG)

CSIR-CIMFR has developed and installed oxy-blown PFBG Pilot Plant and established gasification of high ash Indian coal. The pilot scale development is providing engineering data to the Engineering Houses for its up-scaling. In view of the pros and cons of the installation options, indigenously developed demo scale gasification facility can be installed as a stand-alone facility or can be installed at existing/planned projects.

5. Performance of the indigenously developed gasifier has been compared with commercially proven technologies identified under Option-I specifically Shell EFG in view of gasification efficiency, operational performance and finally to evaluate their suitability towards Indian coal resource.

6. He described achievements in 1.5 TPD oxy blown PFBG pilot plant. A 250kg per day coal syngas to methanol programme is on-going in mission mode. He said both the routes, dry feed membrane walled entrained flow gasifier based commercially proven technology adoption and Indigenous demo scale fluidized bed gasification technology development need to be executed in parallel. With CCU integration it could perform as blue hydrogen.

7. **Dr Chavan concluded that for fast and successful development of demo units, programs need to be executed with joint ventures between R&D institutions; Engineering Houses and Industries instead of independent parallel programs, as all individual stakeholders have specific strengths at different levels of technology development and implementation.**

Day 3

TECHNICAL SESSION – IV: Sustainable Hydrogen Storage and Risk Management

Chairman: Shri Gautam Sen, Ex-Sr. VP Reliance and ED, ONGC
Address: Hydrogen as Energy Source of the Future

1. Sh. Gautam Sen welcomed all and began his presentation by saying that our world is going through a major transition period in energy sourcing. Consequently, energy driven geopolitics is also changing. Carbon dioxide concentration in air has increased from 280 ppm to around 420 ppm. Average global temperatures are higher than 1 degree above the pre-industrial level and all trends indicate that unless we achieve negative emission of carbon dioxide in the near future it is unlikely, that we will be able to maintain average global temperatures within 1.5 degree of the pre-industry level. This calls for a major shift in the type of energy we are accustomed to.

2. He said Electric Vehicles (EV) driven by renewable energy have proved to be more energy efficient and cheaper as compared to hydrogen fuel cell (FCV). Depending on the model, the battery-powered e-car thus achieves an efficiency of between 70 to 80 percent. The hydrogen fuel cell requires 2-3 times more energy to drive the same distance as a battery powered vehicle, as the overall Well-to-Wheel efficiency is only 25-35%. However, renewable driven batteries cannot be used for transportation of heavy vehicles. They will need continuous charging and for longer charging time. Hydrogen fuel cells are preferred which can be simply replaced at the charging stations.

3. Hydrogen can be produced either from fossil fuels, which leaves carbon footprints or through electrolysis of water using renewables generated electricity and has therefore zero carbon footprint. He explained the colours of Hydrogen based on the means of production as Grey Hydrogen, Blue Hydrogen and Green Hydrogen.

4. Hydrogen driven fuel cells can be used in refineries, steel and fertilizer industries. It can also be used in power sector for power generation, in heating residential and commercial complexes and in transportation of heavy vehicles, trains, in aviation and shipping industry. Hydrogen therefore, is considered as the source of energy of the future. Fuel cells supply hydrogen which when burnt using oxygen from air, yields energy for the reaction is

exothermic and the product is water with no carbon emission. Cheaper and more efficient methods of electrolysis have to be developed before green hydrogen can match the costs of generating blue and then grey hydrogen.

5. About hydrogen STORAGE he said it can be stored in gaseous state at high pressure or in liquid state at cryogenic temperatures and relatively lower pressure. These are cost exorbitant and losses from the inevitable boiling-off of liquid are an area of concern. While the energy per unit mass of hydrogen is substantially greater than most other fuels, its energy by volume is much less than liquid fuels like gasoline. A fuel cell vehicle will need about 5 kg of hydrogen for a 300-mile driving range. At 700 bar (~10,000 psi), 5 kg of hydrogen will occupy a volume of about 200 liters which is 3-4 times the volume of gasoline tanks typically found in cars. A key challenge, therefore, is to store sufficient quantities of hydrogen onboard, without sacrificing passenger and cargo space. He described the hydrogen storage techniques in solid state through Chemisorption or Physio-adsorption at relatively normal pressure and temperature, which are under active research.

6. Chemisorption: Two types of metal hydrides are already in use as Intermetallic (or interstitial) hydrides where hydrogen occupies interstitial spaces within metal alloys (e.g., $LaNi_5H_6$) and Complex hydrides where hydrogen covalently bonds to a metal to form multi-element anion that combines with other metal(s) through ionic interactions (e.g., Na (AlH_4)) Hydrogen is released from chemical hydrogen storage materials through non-equilibrium processes depleting the adsorbate. The depleted materials have to be removed and chemically processed to regenerate the original hydrogen containing material.

7. Physio-adsorption: Molecular hydrogen can absorb onto the surface of porous solids, providing the potential for higher storage densities at significantly lower pressures in a process known as physio-adsorption. Such sorbents are high-surface area, micro-porous solids (e.g., activated carbons or metal-organic frameworks (MOFs)) where the diatomic hydrogen molecule adsorbs onto the surface through Van der Waals interactions. MOFs can also store liquid hydrogen and are cost competitive. However, MOFs are still in R and D phase mainly being researched at Berkley.

8. The challenge for all hydrogen storage methods exist. The effort is to develop cost-effective materials with high hydrogen density by volume and mass, capable of fast charge/discharge rates within the temperature and pressure ranges of fuel cell operation and able to undergo sufficient charge/ discharge cycles to last the lifetime of the FCEV (Hydrogen Fuel Cell Electric Vehicle). Another area of contemporary research is in Mg hydrides. In this case hydrogen can be released using light.

9. He said a breakthrough in hydrogen storage materials is awaited so that carbon footprints can be diminished. Global investment in hydrogen projects, current hydrogen consumption in various countries, and data on possible year by which green hydrogen can become at par with blue hydrogen was presented.

10. A recent report by IRENA (International renewable energy agency) suggested that by 2050 China could deliver green hydrogen at just over $0.65 per kg by 2050. China is endowed with rare earth metals and is emerging as the front runner in this race. He said geopolitics will accordingly swing away from fossil fuel rich states to these countries.

11**. Shri Sen concluded that apart from restricting the devastations from climate change, thrust on new source of energy is likely to create millions of new jobs globally, and younger population needs to be skilled accordingly.**

Keynote Lecture: Dr. Bipin Kumar Gupta, Principal Scientist, CSIR-NPL, New Delhi on 'Hydrogen Energy a Freedom Fuel for India: Emphasis on Hydrogen Storage Technology and Applications

1. Dr Bipin Gupta, Principal Scientist NPL observed that energy is directly related to the currency of any nation. No doubt, energy is always in huge demand, but unfortunately always in short supply and insufficient to match the unparalleled population explosion and our changing life style. Undeniably, we are facing an energy crises, energy has become the most important commodity and deciding factor not only for national but also for international policies and politics.

2. The depleting and polluting fossil fuel makes it imperative to find renewable and clean fuel. In the search for alternative fuels, decades of dedicated R&D efforts have revealed that Hydrogen is indeed such a fuel. Hydrogen is an ideal candidate as a clean energy carrier for both transportation and stationary applications. It is a promising medium for both energy transmission and storage. It is non-polluting, the major by-product of combustion being H_2O and it can be generated through readily available water and a variety of sources, e.g. using solar energy (photovoltaic, photoelectrochemical and photocatalytic routes) and nuclear energy, conventional grid and hydroelectricity. Hydrogen has the highest energy density per unit weight of any chemical fuel and has a diversified number of uses, ranging from fuel for internal combustion engines to produce motive power and for generation of electricity and also for motor driven transport through fuel cells. The striking properties of hydrogen and its comparison with other fuels are listed in Table 1.

3. Dr Gupta said he had the opportunity to work on hydrogen under late Prof. O.N. Srivastava from BHU, Varanasi. One of the key issues surrounding the exploitation of hydrogen as a fuel, however, is the difficulty in storing it efficiently, economically and its transportation. Unlike fossil fuels such as coal or petroleum which are self-storable, hydrogen will have to be effectively stored before its deployment in energy systems. Hydrogen use at an appropriate site requires "storage" which is a crucial aspect of the total "Hydrogen Energy" concept. Both high pressure gaseous (bulky and risky mode) and liquid (expensive cryogenics, thermal and ortho-para conversion losses) forms are rather impractical modes of storage.

Table 1: The striking properties of hydrogen

Properties	Units	H_2	CH_4	Gasoline
Lower heating value	kWh/kg	33.33	13.9	12.4
Self ignition temperature	ºC	585	540	228-501
Flame temperature	ºC	2045	1875	2200
Min ignition energy	mWs	0.02	0.29	0.24
Ignition limits in air	Vol%	4-75	5.3-15	1-7.6
Flame propagation(air)	m/s	2.65	0.4	0.4
Explosion energy	Kg TNT/m^3	2.02	7.03	44.22
Diffusion coeff in air	Cm^2/s	0.61	0.16	0.05
Chemical energy	kWh/kg	39.4	13.1	13.1

4. He said chemical storage of hydrogen in the form of metal hydrides represents an attractive alternative, which are the subject matter of intensive R&D efforts being carried out worldwide. The advantages of storing hydrogen in the form of metal hydrides include high volume efficiencies, relative ease of recovery, indefinite storage capabilities without loss of hydrogen and a high degree of safety and portability. However, the stored weight of hydrogen per unit weight of solid metal hydride i.e. the gravimetric hydrogen density is rather low and efforts to increase this capacity forms the challenges of current research. A lot of new lightweight materials are projected till date such as carbon nano tubes/fibers, $NaAlH_4$, $Na_XLi_{1-X}H_4$ $NaBH_4$ and many more but none could qualify the required storage capacity target set by DOE Department of Energy, USA in year 2010. (10wt% Volumetric efficiency and 45 kg/m^3 gravimetric efficiency). Some of these projected materials displayed good volumetric efficiency but have poor gravimetric efficiency. Similarly a number of them have high gravimetric efficiency but have low volumetric efficiency, thus none could qualify to possess the acceptable levels of volumetric efficiency as well as gravimetric efficiency and are found to be unsuitable as storage material.

5. In India considerable progress has been made in the field of harnessing hydrogen as fuel. India's hydrogen energy programme is part of the Ministry of New and Renewable Energy sources (MNRE) calls its New Technologies. The strategy has been to help these laboratories to acquire expertise in production, storage, and utilization of hydrogen as an alternative fuel. There are a number of major hydrogen energy programmes running in India by various institutes. Some of the major programme locations are listed in Figure 1.

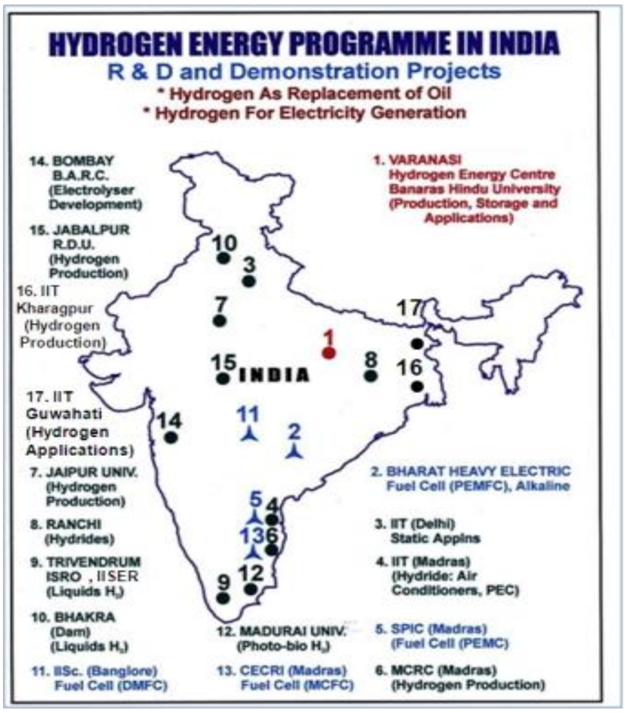


Figure 1. The major hydrogen energy R&D activities in India

6. Dr. Gupta described many challenges in H_2 storage and presented a comparison with gasoline. Characteristics of metal hydrides and alloys have been investigated in detail. Investigation on synthesis, structural and macro-structural characteristics of graphite nanostructures have been carried out.

7. Dr Gupta concluded that to establish hydrogen as fuel in India, special efforts have to put forth to work out the new storage materials which should be reversible, economic and easy to produce in large-scale.

Special Address: Dr. S. Nand, Additional Director General, Fertilizers Association of India on Ammonia Storage Challenges in Fertilizers Industry

1. Dr. S. Nand, Additional Director General, Fertilizers Association of India (FSI) delivered the special address. He observed that fertilizers are an important segment where green hydrogen and green ammonia have a big role and storage is required. Ammonia is used for making fertilizers and one of the four important elements required for increasing agriculture produce. Nitrogen is most prime and ammonia is the vehicle for fixing nitrogen in a product.

2. Dr. Nand said that synthesis of ammonia began in 1913. It could be industrially synthesized at high pressure of 600 atmosphere and high temperature 452^{o}C. Today we are synthesizing it at 150 atmosphere pressure at around 450^{o}C temperature and this application led to Noble Prize to the scientist who did it. The importance of green revolution leading to 50% increase in the yield of wheat or rice or any other crop is attributed to application of mineral fertilizers. In fertilizer production we are probably the second largest after China.

3. Fertilizers are vital for food and agriculture but only 40 % of Nitrogen is actually absorbed. The remaining 60 % active N2 escapes in the atmosphere. UN 2019 held in Nairobi evolved Sustainable Nitrogen Resolution to minimize N2 escape and steps to increase uses up to 60-70%. India was initiator of the regulation.

4. Fertilizers Association of India has networking with other similar entities around the world. Green Hydrogen policy in formulation Identifies facilitating mechanisms for transmission of renewable energy to achieve the target of 5MT production. The incentives for putting up a green hydrogen plant and PLIs are aimed at making it cheaper. Electrolyser is an established technology but needs large capital.

5. Giving a long-term policy vision he said second part of the policy would be how to make low cost electrolyser so as to develop larger capacity. There is a need to bridge viability gap in hydrogen and ammonia manufacturing capacity. The third segment would be to fill viability gap in hydrogen and ammonia manufacturing costs. A policy to regulate green hydrogen use in refineries and fertilizers manufacture would be needed to create the demand. Other upstream uses for green ammonia include as a carrier for hydrogen and the technology for injecting ammonia for firing in power plants is being tried. He said according to International Energy Agency the calorific value of ammonia is 3 times that of H_2.

6. Ammonia storage or Ammonia terminals exist at 30 coastal locations and our safety record is excellent. Storage in smaller capacities is maintained at 8 bar pressure. For large-scale storage >5000 tons and technology is different, the tank structure needs to build accordingly. Ammonia can be transported at atmospheric pressure and -33 ^{o}C. Transfer infrastructure is required to be built. The efforts are to replace the imports by green ammonia.

7. The government has identified fertilizers as one of the major hydrogen consumer sectors and other is refineries. We have 22 million tonnes of annual ammonia consumption, which include import of 4 million tonnes. The policy has already notified that for hydrogen producers there will not be any transmission charges. However, there are challenges to be met and it is required to bridge the viability gap for fertilizer industry to take off.

8. **Dr Nand concluded that challenges in adoption of green ammonia would have to be resolved, such as ammonia technology suppliers would need to ensure operation in fluctuating load. In the absence of CO_2 generation from green ammonia manufacture, the urea production will be affected and a strategy would be needed for farmers to wean away from farming with urea and shift to others, like ammonium phosphate.**

TECHNICAL SESSION – V: Hydrogen Production from Biomass and Startups Ecosystem

Keynote Lecture: Shri Rajan Varshney, DGM, NTPC Ltd. on Waste to Hydrogen

1. Mr Rajan Varshney, DGM NTPC said India has some of the world's most polluted cities and there is on urgent requirement of decarbonisation. India also has lot of waste generation round the year that can be used for producing Hydrogen. Hydrogen is versatile energy carrier interconnecting various sectors. Green Hydrogen can make India self-reliant and facilitate its journey towards carbon neutrality by 2070. Hydrogen from waste promises beneficence for PPP viz., People, Planet and Profits and putting India on a high growth trajectory.

2. Hydrogen can be made from various feedstock. When it is made from fossil fuels like Coal, Natural Gas etc. using SMR (Steam Methane Reforming) or Gasification without carbon Capture, it is called Grey or Brown Hydrogen and emits lot of CO2. Green Hydrogen can be produced from renewable feedstock like water, Organic waste, Sewage sludge etc. using RE through various methods like Thermochemical Processes, Electrolysis, Gasification of waste, Direct Solar Water Splitting Processes, etc. Analysis indicated that hydrogen from biomass/waste can be produced not only at least cost but also can reduce air, water and soil contamination. Further, green hydrogen can facilitate faster and sustainable energy transition cutting energy imports even energy export. Moreover waste is available everywhere and needs to be tackled in a sustainable manner to avoid soil, water, air pollution and also avoiding release of Methane can help in combatting climate change.

3. He cited global examples of use of H_2 in Tokyo Olympics 2020, in Paralympics and in China Winter Olympics. Several global companies are now producing hydrogen from waste. The Government of Ontario released its first Low-Carbon Hydrogen Strategy on April 7, 2022, outlining the province's vision and expectations for the developing hydrogen sector. Babcock & Wilcox and Kiewit Industrial have teamed up to build a biomass power plant in the Port of Greater Baton Rouge in Louisiana. The 200-megawatt Project Cyclus power facility will be the largest of its kind.

4. He cited many other examples like Thermochem Recovery International Gasification of Waste to Syngas from which H_2 and Biodiesel are produced, Standard Hydrogen (Waste+Sulphur: H_2S to H_2 and recirculating S) process. Ergostech converts sewer-waste into bio-H_2. Shell IH_2 integrated hydrophyrolysis and hydroconversion, process and CAC-H_2 is also

utilising its carbon-negative biomass-gasification technology to produce H_2 and Biochar. Another company Mote uses proprietary integration of proven equipment in a novel process. The biomass is heated in a limited-oxygen environment to above 815^{o}C converting it to a mixture of gases which produce hydrogen & CO_2 and the resultant Ash is used as additive for Fertilisers.

5. He gave many examples. H2 Industries two big projects on waste to H_2 are coming up in Egypt and Oman using integrated thermolysis process. The waste heat from the process can be used to generate power. Levidian is currently scaling up LOOP technology to deploy LOOP1000+ using a patented low temperature, low pressure process to crack methane into its constituent atoms, hydrogen and carbon, without the need for catalysts or additives. The carbon is locked into high-quality graphene and the hydrogen can either be used as a hydrogen-rich blend or separated and stored for use in its pure form. A single LOOP50 device utilising Bio-CH4 reduces CO_2 equivalent (CO_2e) by 100 tonnes per year.

6. He described methods of hydrogen production from waste as; anaerobic digestion gasification, plasma gasification, pyrolysis and microbial electrochemical cell. Financial analysis of a waste to hydrogen plant suggests that cost of H_2 production can be as low as INR 30 per kg of H_2. In India Institute of Plasma Research has developed plasma gasification from waste. It uses waste to produce biochar and H_2.

7. Microbial electrochemical cell (MECC) can convert plastic waste to hydrogen and produces no harmful gases as in case of incineration or pyrolysis. Techno economics of the process has been worked out. The MECC has control over the experimental conditions such as current density, potential, pH, partial pressure of oxygen to control formation of Ethylene glycol and terephthalic acid. It inhibits the absorption of ethylene glycol and TPA by the outer membrane and stops further metabolism by bacteria via electrical impulses on the electrode. It takes hours to days to degrade the tones of plastic waste generated every day. H2 converstion is environmental friendly, no harmful pollutants, complete conversion of plastics to value added products.

8. He said co-firing coal with hydrogen or ammonia reduces pollution drastically and this is being attempted in Japan and at other places. The SWOT analysis of Biomass to H_2 has been carried out. Decentralized Green Hydrogen production at optimum price can boost proliferation of microgrids for electricity, heating, cooling and transport in a big manner.

9. **He made policy recommendations as below**.

- **Carbon intensity should be measured instead of colours.**
- **If pilot/ demo plants are set up by govt/ PSU, the success will create change and more and more entrepreneurs will come in.**
- **Derisked and Long term finance by Banks / Institutions/ Agencies.**
- **Carbon mkt regulator/ regulations/ trading established ASAP. Carbon credits will help financing green economy.**
- **Policies supporting decentralised waste to H_2 : reducing transportation of waste/H_2 and the waste accumulation.**
- **Just like RE: Banking and Different Points of Injection and withdrawal should be permitted for Bio-H_2 and for Bio-CH4.**
- **Certified Carbon Intensity for H2 and bio-CH4.**

Hydrogen Start-ups Ecosystem

Coordinator: Shri Rajan Varshney, DGM, NTPC

The Following Start-up Companies made Presentations

1. **Mr. Gerald Hollins, CEO, HYDROLOOP Inc. U.S.A.**

2. **Ms. Florian von Hofen RG H2 Sustainable H_2, CO_2, No**

3. **Mr. Sidharth R Mayur, Founder & CEO, H2E Power Systems Pvt. Ltd**. – 9890297575, sid@h2epower.net

4. **Mr. Prateek Vyas, Bloom Energy Overview** – prateek.vyas@bloomenergy.com – 7203040225

5. **Mr. Guy Downie, LEVIDIAN**

   Smart Innovation Science led Collaboration

6. **Mr. Chandrashekhar Chincholkar, Strategic Advisor, KPIT Technologies Ltd Pune**
   Technology to support Hydrogen Usage, Generation and Net Zero transition
   H_2 Generation by Gasification of Biomass using thermochemical process, a plant exists

in Baroda

7. **Mr. Mahesh Pagnis, Paganism Innovation Pvt. Ltd. (PIPL)**

8. **Ms. Amy McCrae Kessler, Chief Commercialisation officer PENNSACO Technologies, USA**

9. **Mr. Parimal Shah, CEO, Sunsys Renewable HYDrone**

   Plasma Gasification- Fuel cells

10. **Mr. Rajesh Ayyappasur, Director - GPS Renewables**

    Coll – xebec – Low Carbon Economy through Green H_2

11. **Dr. D.C. Patra, IESD -Indian Energy Skill Development Pvt. Ltd** – 90 days Certification Programme

12. **Dr. Sarit K. Das, Director, SMISAR Green Agro Solutions Pvt. Ltd**. – environ_sarit@yahoo.co.in and

    Dr. Ambika S., Assistant Professor, Dept. of Civil Engineering, IIT Hyderabad

    ambika@iith.ac.in, ambikame@gmail.com

Feedbacks from the Participants

- *'I got to know in details about all latest developments regarding H_2 fuel – Future of India from renowned scientists and dignitaries'*, said Ms. Ipsita Dutta, Chemistry PGT from Universal Public School.

- '*The workshop was very good & interesting, the best thing was the knowledge I gained and experienced*' said Dr. Mollika Banerji, Research scholar, CSIR-CIMFR, Dhanbad

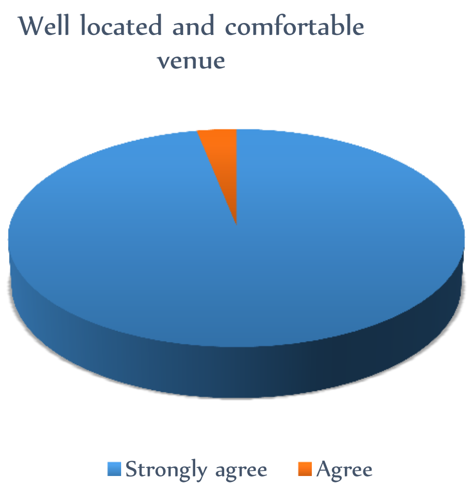
- *'The workshop was immensely well organized & properly timed, I would like to know more about policy roadmap for hydrogen energy along with feasible financial mechanisms, it covered most important topics related to hydrogen energy*', said Dr Vandana Maurya, Assistant Professor, Motilal Nehru College, University of Delhi

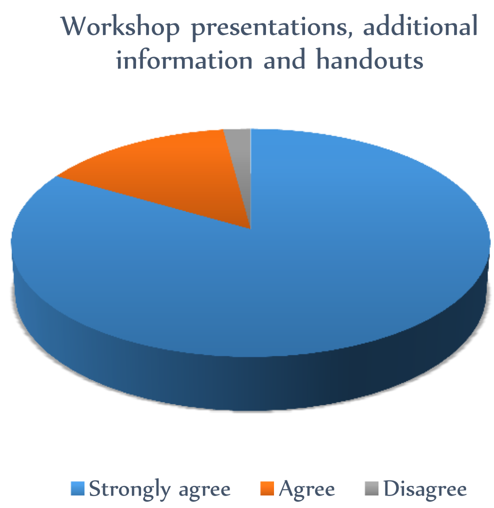
- *'I am very thankful to Dr Malti Goel for giving us this opportunity to attend this workshop, everything was best'*, said Ms. Akanksha Pandey, Research scholar, CSIR-CIMFR, Dhanbad

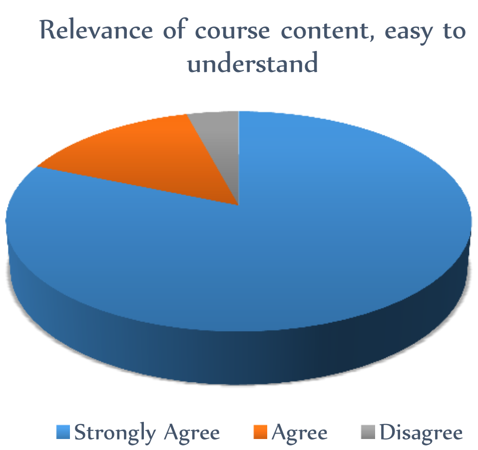
- '*To be honest for the first time I attended a workshop like this, I can say this was great, I like best the opportunity to interact with great speakers*', said Md. Javed Ullah, Indian Energy Skill Development (IESD) Pvt. Ltd., Noida

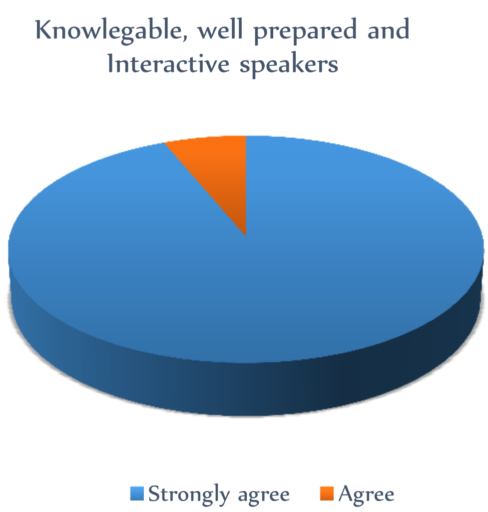
- *'Excellent venue, well organized sessions and excellent views shared on hydrogen technology by well prepared & knowledgeable speakers'*, said Dr V A Mendhe, Principal Scientist, CSIR-CIMFR, Dhanbad

Survey Result from the Delegates of Workshop









Awareness and Capacity Building in Hydrogen Production and Energy uses: Towards a Net-Zero strategy

(ACBHPE- 2022)

India International Centre Annexe, Lecture Hall-1, New Delhi

8th – 10th June, 2022

List of Participants

S.No.	Name	Organization
1.	Shri. A.K. Jain	Former Commissioner, DDA
2.	Ms Arti Bhatia	Universal Public School, New Delhi
3.	Dr Anshuman Gunawat	Motilal Nehru College, New Delhi
4.	Mr Abhinav Roy	Motilal Nehru College, New Delhi
5.	Ms. Akanksha Pandey	CSIR-CIMFR, Dhanbad
6.	Shri. Amir Mansoori	Jamia Hamdard, New Delhi
7.	Shri Alok Kumar	CCRI, New Delhi
8.	Dr. Bipin Kumar Gupta	CSIR-NPL, New Delhi
9.	Dr G.D. Sharma	CEC-UGC, New Delhi
10.	Prof. G. D. Yadav	Institute of Chemical Technology, Mumbai
11.	Shri Gautam Sen	ONGC and Ex-Sr. VP, Reliance, New Delhi
12.	Ms. Gauri Jauhar	IHS Markit, Gurgaon
13.	Ms Ipshita Dutta	Universal Public School, New Delhi
14.	Md. Javvad Ullah	Indian Energy Skill Development Pvt. Ltd. Noida
15.	Shri. K.N. Shrivastava	Director, India International Centre
16.	Shri L. K. Bansal	CCRI, New Delhi
17.	Dr. (Mrs.) Malti Goel	Climate Change Research Institute, New Delhi
18.	Dr. Mollika Banerjee	CSIR-CIMFR, Dhanbad
19.	Mr Mohammad Abrar	Climate Change Research Institute, New Delhi
20.	Mr Nikhil Tomar	Motilal Nehru College, New Delhi
21.	Shri Neeraj Gupta	Climate Change Research Institute, New Delhi
22.	Ms. Priya vyas	Springer, New Delhi
23.	Dr Prakash D. Chavan	CSIR-CIMFR, Dhanbad
24.	Ms. Pooja	CSIR-NPL, New Delhi
25.	Mis Priyanka Shukla	CSIR-CIMFR, Dhanbad
26.	Mr Pranav Raj Sharma	Motilal Nehru College, New Delhi
27.	Mr. Pankaj Sharma	Srijan Investment & Properties Pvt. Ltd., Delhi
28.	Shri Rajan Varshney	NTPC Ltd., New Delhi
29.	Shri R. C. Nakul	S&S Water and Power Projects Pvt. Ltd., Delhi
30.	Dr. Sanjay K. Singh	Indian Institute of Technology, Indore
31.	Ms. Swati Meherishi	Springer, New Delhi

32.	Prof. S. Ahmad	Jamia Hamdard, New Delhi
33.	Shri. Suresh Goel	Principal Architect, New Delhi
34.	Dr. S. Nand	Fertilizers Association of India, New Delhi
35.	Mr Shashanka Pandey	CSIR-CIMFR, Dhanbad
36.	Ms. Saloni Gupta	School for Planning & Architecture, New Delhi
37.	Md. Saquib Khursheed	Indian Energy Skill Development Pvt. Ltd. Noida
38.	Shri Utkarsh Raj	Delhi Technological University, New Delhi
39.	Shri. V.S. Verma	Ex-Member, CERC, New Delhi
40.	Dr. V. A. Mendhe	CSIR-CIMFR, Dhanbad
41.	Mr Vinal Vinod Mendhe	UPES, Dehradun
42.	Dr. Vandana Maurya	Motilal Nehru College, New Delhi

Virtual

1.	Shri Abhishek Kumar	IHS Markit, Gurgaon
2.	Dr. Ankush B Bindwal	CSIR-Indian Institute of Petroleum, Dehradun
3.	Dr. Alka D Kamble	K L University, Andhra Pradesh
4.	Ms. Komal Bora	CTRAN Consulting, Bhubaneshwar
5.	Dr. Naresh Chandra Murmu	CSIR-Central Mechanical Engineering Research Institute, Durgapur
6.	Dr. Neha G. Tripathi	School of Planning Architecture (SPA)
7.	Prof Prakash C. Ghosh	Dept. of Energy Science & Engineering, IIT, Mumbai
8.	Shri R. V. Shahi	IEF, Ministry of Power, New Delhi
9.	Dr. Rakesh Kumar	OSD, CSIR Headquarters, Exe-Director NEERI
10.	Mr. Rahul Khanna	FAB Future, Nalgonda, Telengana
11.	Mr. Vipin Kumar Sharma	Indian Institute of Technology, Tirupati
12.	Mr Vedant Hanwat	Forest research Institute, Dehradun

Start-ups

13.	Mr. Gerald Hollins,	CEO, HYDROLOOP Inc. U.S.A.
14.	Ms. Florian von Hofen	RG H_2 Sustainable H_2, CO_2, No
15.	Mr. Sidharth R Mayur	Founder & CEO, H_2E Power Systems Pvt. Ltd.
16.	Mr. Prateek Vyas	Bloom Energy Overview
17.	Mr. Guy Downie	LEVIDIAN
18.	Mr. Chandrashekhar Chincholkar	Strategic Advisor, KPIT Technologies Ltd Pune
19.	Mr. Mahesh Pagnis	Paganism innovation Pvt. Ltd. (PIPL)
20.	Ms. Amy McCrae Kessler	Chief Commercialization officer PENNSACO Technologies, US
21.	Mr. Parimal Shah	CEO, Sunsys renewable
22.	Mr. Rajesh Ayyappasur	Director - GPS Renewables
23.	Dr. D.C. Patra	IESD -Indian Energy Skill Development Pvt. Ltd
24.	Dr. Sarit K. Das	Director, SMISAR Green Agro Solutions Pvt. Ltd.
25.	Dr. Ambika S.	Assistant Professor, Dept. of Civil Engineering, IIT Hyderabad


IIC One
V. S. VERMA


Dr. Rakesh Kumar


Single Use Plastic (SUP): Should it be banned?

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