Highlights of 5th Lecture of the Distinguished Lecture Series Organized by INAE Bhubaneswar Chapter, SOA University & IMMT Bhubaneswar on 8th March 2022.

Title: Achieving Sustainability and Net Zero Mandate through Adoption of Hydrogen Economy, CO_2 Refineries & Biomass Conversion

Speaker: Prof Ganapati D. Yadav, Emeritus Professor of Eminence & J.C. Bose National fellow Form Vice Chancellor, Institute of Chemical Technology Mumbai

- **Energy, Environment and Climate Change**. Energy and environment are intimately connected. More energy, more environmental damage. The climate change is due to the overuse of fossil fuels leading to emissions of CO_2 which is currently at 419.2 ppm. The energy needs of the world are increasing day by day and use of carbon-based fuels will continue to rise. Jan. 2020; 410 ppm, Jan. 2021: 412 ppm (Slowdown in economy). In order to meet the requirements of international treaties, the use of renewable resource is advanced.

- **Carbon based fuel and H_2 as Saviour**
  Whether the carbon is coming from, fossil fuels or biofuels there is a need to cover 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. And treatment of (waste) biomass into hydrocarbons with the help of novel catalysts. Hydrocarbons can also be reformed into hydrogen, but CO_2 needs to be utilized.
  Hydrogen will be the SAVOUR for the planet EARTH.

- **Basic Questions for planners and Energy Experts**

➢ Should biomass be wasted on making low value high volume biofuels?
➢ Biomass to chemicals & materials.
➢ What will happen in 2054?
➢ How to have a net-zero economy by 2050

Is biomass as energy source new? Should it be used for energy?

Hydrogen production

- For the hydrogen economy to be a reality, hydrogen must be produced cheaply and in an eco-friendly manner, and it should serve as the commercial fuel that would provide a substantial portion of the country's energy demand and services.

- **Green, Blue and Grey Hydrogen**

Green H_2: Electrolysis of water using clean electricity from wind, solar, hydro, or nuclear energy. Gold standard, Zero GHG emissions.

Blue H_2: Steam reforming of biomass, biogas, bio oil, or natural gas giving the other C as CO_2. Captures up to 90% of the C having low to moderate carbon intensity

Grey H_2: Steam reforming of fossil coupled with co-generation of carbon dioxide: and this method is the most common technology which is increasingly unpalatable because of the emissions of carbon dioxide,

- **Blue hydrogen**

Methane from natural gas is converted to hydrogen and carbon dioxide at high temperature.
The CO_2 is captured and stored permanently underground.

Hydrogen is an essential complement to electrification and a clean energy carrier for industry, transport, power and buildings.

- **Five shades of hydrogen**
- **Green**

Electricity for renewable sources is used to electrolyse water and separate the hydrogen and oxygen

- **Blue**

Produced suing natural gas via "stem reformation" most of the greenhouse gas emissions are captured and stored

- **Turquoise**

Produced using natural gas via "pyrolysis" by separating methane into hydrogen and solid carbon dioxide

- **Grey**

Produced using natural gas via "steam reformation" but with no carbon capture and storage

- **Brown**

Produced using coal instead of natural gas, but with no carbon capture and storage; this remains the cheapest form

- **Consumer Plastics as Waste**

Type 1; polyethylene terephthalate (PET) e.g. plastic beverage bottles
Type 2: high density polyethylene [HDPE] e.g milk jugs
Type 3: polyvinyl chloride (PVC), e.g., pipes used in plumbing, vinyl tubing, and wire insulation
Type 4: low-density polyethylene (LDPE), found in plastic sheets or packaging (e.g., bread bags)
Type 5: polypropylene (PP), in bottle caps, packaging, and plastic furniture
Type 6: polystyrene (PS), e.g drinking straws, beverage lids, and Styrofoam
Type7: other non-recyclable plastics and all thermoset plastics (e.g., acrylics, nylons, polycarbonates, acrylonitrile butadiene styrene [ABS', and polylactic acid).

- **EU SUP DIRECTIVE**

Product bans
SUP ban (July 2021) where non-plastic alternatives are available
Cotton bud sticks, cutlery, plates, straws, stirrers, balloon sticks, oxo-degradable plastics, EPS food containers and cups

- **Design requirement**

2025: 25% recycling content in PET beverage bottles
2030: 30% recycling content in all beverage bottles
2024: Container caps and lids to remain attached to the container

- **Target for separate collection**

77% of single-use plastic bottles with caps and lids by 2025
90% of single-use plastic bottles with caps and lids by 2029

- **EPR obligation**

All Member States must establish EPR schemes by 2021
Includes cost of litter clean-up, transport, and treatment, and awareness
Food containers, packets, and wrappers, beverage containers and cups, tobacco products with filters, wet wipes, balloons, and lightweight plastic carrier bags

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

Chemolysis

- Chemolysis is the use of a chemical to break down the back-bone of the polymer
- Hydrolysis
- Glycolysis
- Aminolysis

- Alcoholysis
- Acidolysis

- **Hydrogenation of Plastic**
- Advantages of hydrogenation
- General
- High value product
- Can handle troublesome atoms (CI, N, O, S)
- Dioxin does not survive the process
- Over incineration
- Does not produce super taxis products
- Metal impurities remain in present state

- **Blofuels**
- **Primary**

Firewood, wood chips, pellets animal waste, forest and crop residues, landfill gas

- **Secondary**
  - **1st generation**

Bioethanol or butanal by fermentation of starch (from wheat, barley, corn, potato) or sugars beet, etc.)
Biodiesel by: transesterification of oil crops grapeseed, soyabeans, sunflower, palm, coconut, used cooking oil, animal fats, etc.)

  - **2nd generation**

Bioethanol and biodiesel produced from conventional technologies but based on novel starch, oil and sugar crops such as jatropha, cassava or miscanthus;
Bioethanol, biobutanol, syndiesel produced from lignocellulosic materials (e.g. straw, wood, and grass)

  - **3rd generation**

Biodiesel from microalgae
bioethanol from microalgae and seaweeds
hydrogen from green microalgae and microbes
Ban is not the solution

- If one technology creates societal problems due to irresponsible usage by citizens, another technology should solve it. Legislation is then secondary.
- SUP can be recycled using Chemical Processes

- **Catalysis and New Materials Development**

Better catalytic materials for conversions on carbon-based feedstock
Waste minimization and process intensification
Renewable sources of energy
Hydrogen as source of energy and conversion of biomass into fuels and chemicals

- **H_2 The Cleanest Fuel**

Colourless and odourless
Does not easily spontaneously combust, ignition point 570^oC (PETROL 500 ^oC)
Lightest weight
Extremely low boiling temperature (-253 ^oC)
High combustion temperature (3000 ^oC)
Produces no flames when burnt; reduces greenhouse effects

- **ICT Mumbai-OED Hydrogen Production Technology**

The ICT-OEC technology for hydrogen production has a huge potential to generate hydrogen at 0.95 USD without valorization of coproduce oxygen.
This hydrogen will be useful for the hydrogen economy including ammonia synthesis, hydrogen fuel cells, electricity generation, e-vehicles.

It is also coupled with solar energy through molten salts. In other words, utilization CO_2 water and catalysis will lead to sustainability.

- **Hydrogen Safety**

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 (speak or heat), oxidant (air), and fuel-are present.
A number of hydrogen's properties make it safer to handle and use then the fuels commonly used today. For example, hydrogen is non-toxic. In addition, because 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 system-tank leak tests, garage leak simulations, and hydrogen tank drop tests-shows that hydrogen can be produced, stored, and dispensed safely.

- **Way Forward**

Green Hydrogen will be the saviour of the world.
CO_2 should not be liability but an asset to convert.

Hydrogen economy can be elegantly intertwined to make many chemicals from waste carbon sources including biomass and C1 off-gases.
Govt of India should adopt hydrogen economy to meet the demands of the Paris Agreement.

ICT-OEC Hydrogen Production Technology is very promising at USD-1.00
That is the only way to meet the goals of the Parts Agreement 2015.
We can make it

Hydrogen production without carbon dioxide

Brown	Grey	Blue	Green
Coal	Natural gas	Natural gas	Renewable electricity
Gasification No CCS	Steam methane reforming no CCS	Advanced gas reforming CCS	Electrolysis
High GHG emission (19 Tco_2 /Th_2)	High GHG emissions (11 Tco_2 /Th_2)	Low GHG emissions (0.2 Tco_2 /Th_2)	Potential for zero GHG emissions
\$ 1.2 to \$ 2.1 per kg H_2	\$1 \$ 2.1 per kg H_2	\$ 1.5 to \$ 2.9 per kg H_2	\$3 - \$ 7.5 per kg H_2

Industrial Hydrogen Production

Steam reforming of NG (48%)
Oil/ naphtha reforming (30%)
Coal gasification (18%)
Water electrolysis (3.9%)
Others (0.1%)

Life Cycle Analysis: Well-to-Gate GHG Emission

Renewable/Green hydrogen from renewable electricity are close to zero

Steam reforming of natural gas are 9 kg carbon dioxide equivalent per kg of hydrogen.
Steam reforming of natural gas with CCS with 90% and 56% respectively are 1 are and 4.
Natural gas prices for the EU are taken as 26.8 USD/MWh, electricity prices from 43-106 USD/MWh, and capacity costs of USD 730/Kw.
Source: International Energy Agency, IEA (2019), IHC, BNEF
Cost of Hydrogen

- Electrolyser costs: 1100 u$$ kw (2020) (2030), 220 USD/kw (2040)
- Cost of CCS increases the cost of steam reforming of natural gas from 990 USD/kWh to 1850/kWh.
- Low –carbon fossil-based hydrogen: Cost in 2030 from 2.5-3.0 USD in the EU,
- Green hydrogen; USD 1.3-2.9kg
- Target for solar electricity is to be cost competitive with the current fossil-fuelled system.
- If the cost of installed PV power can be reduced from the present cost of about USD 5/W installed to about USD1/W installed, the cost of solar electricity is predicted to reach USD 0.10/kWh.