Questions from the audience (Third panel discussion on The Evolution and Future of Energy):

Responses colour coded: Dr PP Maitra; *Amit Pathare*; Prof AK Suresh and Dr Rohit Patwardhan

1. Pratik asked: what are the future aspects of biomass fuel, and would it be good to proceed research in the same I believe blue and grey hydrogen is more economical and sustainable though we do have issues with carbon and sulphur emission but I think we can have a solution for these ;green hydrogen will be a costly affair

Biomass fuel: Currently, biomass fuel has 2 major handicaps:

- 1st generation bio-fuel is unsustainable meaning to grow energy crops, like corn/sugarcane for ethanol & rapeseed/palm for bio-diesel, reducing food supply. Only ~4% bio-fuel is 2nd generation, bio-fuel from non-food biomass, like agriculture residue/forestry waste.
- Cost of 1st generation bio fuel is ~1.4X more expensive than fossil fuel. 2ndgeneration sustainable cellulosic biofuel is ~2X more expensive.

Without cost reduction + non-food biofuel, biomass-based fuel can only be a niche solution, driven solely by statutory mandates.

H_2: Global average for H_2 price in 2021, as per IEA, is shown below:

Type	H_2	$/kg	Remarks
Unsustainable	**Brown**	1	Coal gasification
"	**Grey**	1.5	SMR
Sustainable	**Blue**	2.3	SMR + CCS
"	**Green**	4.9	Electrolysis

SMR = Steam methane reforming; CCS = Carbon capture & sequestration

The green H_2 aspiration is to reduce to < $2/kg within this decade, mimicking Li-ion battery cost reduction from ~$900/kwh to ~130/kwh from 2010 to 2021. Why? Because the electrolyser, for green H_2, behaves just like a battery for electro-chemistry.

One added point on comparing strengths of key Electrolyser technologies:

- ***Alkaline Electrolyser**: Most common historical design. Lowest cost at present*
- ***PEM Electrolyser**: Most flexible in terms of adapting to intermittent renewable generation. Shows promise for cost reduction*
- ***Solid Oxide Electrolyser**: Highest electrical efficiency. Potential for reversibility, i.e. can also operate as Fuel Cells*

2. Dr Bharat Padekar asked: Can Hydrogen be energy of future? What area is open for research in this

Yes. H_2 is projected to be only ~20% sustainability solution to ameliorate hard-to-abate CO_2 emissions. Overall sustainability solutions can be:

Renewable power	60%
H2	20%
CCS	15%
Bio-mass/waste fuel	5%

Best applications in Industry & certain Mobility applications that cannot accommodate batteries (e.g. heavy duty trucking). Seasonal power storage is a long way from economic viability.

Electrolyser stack & system designs, new electrode materials to improve reliability & lifetime

3. Vivek Joshi asked: Pls comment on the Energy Intensity of the Economy, trends, outlook etc.

IPCC report on impact repeatedly mentions "likelihood" & "confidence interval" ie, estimate. The presentation showed the impact as a 100% certainty?

Energy intensity of the economy is total energy input vs economic/GDP output.

- All scientific reports, including IPCC, talk about the future in terms of likelihood & confidence intervals only.

Actually, the planet earth is doing worse than the IPCC projections or CO2 emissions & unsustainability is accelerating.

4. Ranjana Sutar asked: Can we get source of some of the data presented here ?

Data is from **IPCC + IEA + IHS** primarily.

5. Yogesh Padiya asked: what is stopping us to explore to use h2 based technology.. money??

H_2 based technology has **H_2 price barrier** to overcome for effective utilization + growth.

6. Krishi Mantri asked: When to enter the energy sector does enormous capital always a requirement as looking majorly a lot of larger players only dominate the market ? Can you elaborate how can young entrepreneurs contribute to it?

- Energy sector by nature is capital intensive
- However venture capital is available to support + nurture any breakthrough/novel energy idea.

For example innovation is needed for the following:

- **Maximize energy efficiency of solar photo-voltaic modules** or conversion of photons-to-electrons.
- **Reduce cost of solar PV wafer** which uses energy intensive ingots of mono-crystalline poly silicon.
- **Match price of non-Li stationary battery to Li-ion battery,** by increasing energy density + adopting frugal electrode material + improving electro-chemistry.
- *New Solar materials (e.g. perovskites, CIGS, Organic PV) and manufacturing techniques (e.g. screen printing, slot die coating) – as an alternative to the c-Si manufacturing chain*
- *Multifunctionality of ESS Systems for Revenue Stacking*
- *Intelligent and efficient Battery Management System (BMS)*
- *Battery recycling & Second-life applications*

7. Pradhyuman asked: I would like to ask question related to sea water electrolysis and what research and technology status in this area. Also, how sea water electrolysis, power generation and Sea water desalination can be combine China is building second CO2 to methanol plant. Sincere request opinion of the forum about CO2 to methanol.

- **Seawater electrolysis is a non-starter**!

Sea water needs to be converted to desalinated water via reverse osmosis to do electrolysis to green H_2

Renewable generation coupled with desalination is a concept being explored in the Middle East. We had a pilot project in partnership with ENGIE, Suez & Masdar that began in 2015. The economics of new desalination technologies like Reverse Osmosis and Forward Osmosis has been improving.

- **CO_2 to methanol is technically feasible but economically unfeasible.**

Green H_2 can reduce CO_2 to CO. Additional H_2 + CO can form syngas, which at H_2/CO ratio of 2.1/1, can be catalytically synthesized to methanol.

8. Rakesh asked: The key challenges are for businesses to: 1. what are the sustainable sources of energy to adopt 2. How to finance these solutions / sources to adopt 3.

- Sustainable sources = **Renewable power + blue/green H_2 + CCS + biomass/plastic waste circularity**
- Finance – GFANZ has $1.3 trillion capital available for preferential investment in energy transition sustainability.

GFANZ = Glasgow Financial Alliance to Net Zero. Finance is chasing the sustainability / energy transition innovation

The energy transition can be sustained only when commercial models for deployment are financially viable and are aligned with the Clients' main pain points. As an example, new "Energy as a Service" business models are being increasingly adopted, where the providers guarantee performance, and consequently get a premium return over standard infra projects. Several Utility companies and Infrastructure funds are moving towards this business model.

Sanjay Jain asked: Dr Suresh, What are the challenges in carbon capture? What are the cost of carbon capture? India has huge coal resource. if we can capture carbon, it will be huge advantage for the country. thanks.

(AKS) Some typical numbers for typical amine-based absorptive capture of CO2 are: In terms of energy: 0.5 kWh per ton CO2, and in terms of dollars USD 185 per ton CO2. Some of us are looking at the top-level issues in carbon capture, and these are typical numbers we have come up with. When you multiply these by the 39 GT/year of CO2 that is going up as emission every year, you can see that the energy and dollar requirements are really huge. Which suggests that to expect CO2 capture to be an economically rewarding exercise (even assuming we can find ways of valorising the captured CO2) may not be realistic; Govts have to pick up a big part of the tab.

9. Jayant Kanitkar asked: Is nuclear NOT part of the solution?

(Arun Joshi added: Very good point, Jayant. Nuclear has got a bad name but has a great prospect in Net Zero. Only doubt about safe disposal of radiation waste. Nuclear energy implementation process needs to be expedited. It takes decades for a power station to start producing power.)

A. Nuclear energy is unsustainable because of:
- Limited resources of uranium ore requiring energy intensive extraction to nuclear fuel.
- Long lasting + radioactive waste products without sustainable disposal
- Nuclear fusion, in contrast to fission, is sustainable but not proven

To add to the above points, the biggest issues with 3rd generation nuclear (e;g; the EPR design of Areva, or the AP1000 design of Westinghouse) are:

i. *Too expensive both in terms of upfront Capex and in terms of the "Levelised Cost of Electricity" as compared with renewables*

ii. *High volume risk – they are reliant on baseload operation, are inherently inflexible and difficult to modulate or cycle in response to intermittent renewable generation (at high levels of renewables penetration)*

iii. *High price risk – they are price takers (i.e. typically NOT the marginal price-setting plants); a huge risk over a 60 year lifetime. Alternatively if one structures a long term PPA, then it will not be competitive with Renewables (see point i above)*

These issues are being tackled with 4th generation designs that comprise SMRs (Small Modular Reactors) or TWRs (Travelling Wave reactors). But these are still early stage and far from being commercially viable.

10. S Amane asked: Namaste to Distinguished Panel and all! Energy storage = batteries is the current view. Is rampant growth in battery usage not another perilous path for sustainability? How and what can be a true sustainable path for energy storage technologies?

- Non-battery, kinetic energy storage solutions are being explored, but they areseveral decades away to being practical.
- Batteries have a long life. Li-ion battery last ~5 years. Non Li-ion batteries last > 10 years. Also the battery materials can be recovered + recycled + reused to make them sustainable via circularity.

11. Srikanth Gopalan asked: We have mostly talked about energy generation. Another important part of this puzzle is storage. We should talk about that too!

A. **Energy storage or batteries** are emerging as hot areas of research, especially for grid power balancing.

12. Adit Agrawal asked: We are often taught about scalability , as a sophomore in Chemical Eng. how can we scale our classroom learnings right away to contribute in the energy sector , if not largely but begin to do so - in obtaining the Sustainable Development Goals ?

- Undergraduate education provides a framework for problem solving + analyticalthinking throughout your professional career.
- Contribution to scalability issue require in-depth post-graduate learning & research. + work experience

13. Chandramouli asked: where are we in terms of policy for offshore windfarms

Offshore windfarms are feasible for renewable electricity generation. **Floating offshore wind farms** are the current flavour.

Costs of Offshore wind farms have dropped significantly in the last five years. From a policy perspective, a big support that can be given is preferential access to the grid; i.e. planning grid extensions to facilitate evacuation of generated electricity from identified sites. Special permitting procedures also need to be enacted to address issues related to shipping lanes, marine eco-systems & wildlife, fishing economies and national defence-related constraints.

14. Malik Aneeb asked Dr. Patwardhan: Given the low water table in the MENA region, do u see a possible acceleration in to develop Green Hydrogen in the region and given the fact that desalination of seawater is a possible route to tackle this issue, how big a stride has Saudi Aramco made in this technology?

While I cannot comment on specific strategies, I encourage you to read about the SA strategies at Technology | Aramco and Keynote address by His Excellency Yasir Al-Rumayyan at the Middle East Institute | Aramco – "The Kingdom's Sudair Power Project – a 1.5GW solar plant – is set to be among the world's largest. We're also planning one of the world's biggest green hydrogen plants with our U.S. partner Air Products, and Saudi Arabia's ACWA Power and NEOM. "

To Dr. Maitra

Q: Given the fact that RIL have targeted $2 in the near term and $1 by 2030, what key steps have been taken and where and how do you think the possible reductions in electrolysers can be made?

Forward path is global innovation eco-system survey, to provide seed capital for **disruptive breakthrough to reduce the green H_2 cost.**