CURRENT SCIENCE

Volume 120 Number 6 **25 March 2021**

GUEST EDITORIAL

The case for hydrogen economy

The hydrogen economy is opportune for India because it has great potential for boosting her energy security and alleviating greenhouse gas (GHG) emissions. Hydrogen can be employed as a fuel in a variety of applications, including fuel-cell power generation and fuel-cell vehicles. It combusts cleanly, producing only water and can be used as a fuel in conventional internal combustion engines (ICEs) to generate mechanical or electrical power. The overall energy efficiency is higher than that of conventional ICEs. The efficiency of hydrogen ICE is ~38%, 8% higher than that of petrol ICE. The hydrogen fuel cell is 2–3 times more efficient than an ICE.

Energy and environment are interconnected. Oil-based economy for the manufacture of fuels, chemicals and materials is not sustainable. By the mid-2050s, there may not be a viable source of crude oil and hence alternative sources must be tapped. Over-use of oil products has caused major damage to the environment, ultimately culminating in the Paris Agreement of 2015. Can hydrogen be the saviour of the environment and, if so, how? According to BP Energy, the renewable energy share will increase from the current ~27% to ~51% by 2035 and to ~73% by 2050, totalling 49,000 TWh. The contribution of solar-, wind- and hydropower will be more than 50%; coal will still play a role. The European Union (EU), the Hydrogen Council and the Bloomberg New Energy Finance (BNEF) have reported that hydrogen could grow from 2% of the global energy mix in 2018 to 13–24% by 2050, at ~8% compound annual growth rate at the midpoint. The Hydrogen Council predicts an investment of USD 150 billion by 2030. In the net (carbon) zero economy, green hydrogen will have a dominant role, not only in achieving the objective of converting carbon dioxide (CO_2) into fuels and chemicals, but also transforming (waste) biomass and waste plastics into the same. CO_2 and hydrogen are connected in more than one way for protection of the environment and provision of future stocks of chemicals and energy.

Hydrogen production technologies cover grey hydrogen, blue hydrogen and green hydrogen which are produced using fossil fuels, non-renewable energy (meeting the low-carbon threshold) and renewable energy respectively. Electrolysis of water using clean electricity from wind, solar, hydro, or nuclear energy sources will give green hydrogen, which is the gold standard, because it produces zero GHG emissions. Steam reforming of biomass, biogas, bio-oil or natural gas gives blue hydrogen coupled with CO_2. Blue hydrogen captures up to 90% of the carbon having low to moderate carbon intensity. The steam reforming of fossil fuels, which is the dominant route now, gives grey hydrogen with co-generation of CO_2, which is increasingly unpalatable.

Green hydrogen can be used as a feedstock, fuel, or as energy carrier and storage, and has numerous applications across different industries, and in transport, power and building sectors. It is the key to decarbonize industrial processes reducing carbon emissions, which is both important and challenging to achieve. This is part of the net-zero policy by 2050 in consonance with the Paris Agreement. However, hydrogen represents a modest fraction of the global energy mix and is still largely produced as grey hydrogen from fossil fuels, notably from natural gas or coal, resulting in the release of tonnes of CO_2. The reduction of CO_2 emissions of ~35 Gigatonnes (Gt) in 2020 to ~10 Gt will contain the global temperature to within 1.5°C by 2050. For hydrogen to contribute to mitigate climate change and climate neutrality, it has to attain much larger scale of production, totally derived from water splitting using green technologies. During November 2019–March 2020, the planned global investments for hydrogen production increased from 3.2 to 8.2 GW of electrolysers by 2030, of which 57% was in Europe. The Hydrogen Council founded in 2017 by 13 companies has now 109 companies as members from more than 20 countries, bringing together a broader range of sectors along with the complete hydrogen value chain, which augurs well.

The hydrogen economy encounters many challenges, including large-scale infrastructure for refilling stations of hydrogen akin to those of petrol, diesel and natural gas, and the cost of hydrogen production, transport and storage. These challenges can be surmounted collectively by multiple partnerships among companies, nations and research across institutions, and above all local government policies. Grey hydrogen is much cheaper than green or blue hydrogen. The cost today for grey hydrogen is ~1.83 USD/kg in the EU and is highly dependent on natural gas prices, and this is disregarding the cost of CO_2. Projected costs today for grey hydrogen with carbon capture and storage (CCS) are ~2.44 USD/kg, and renewable hydrogen 3.05–6.71 USD/kg. Further, grey hydrogen with carbon capture can become competitive, only if carbon prices are in the range 70–110 USD/t of CO_2. Electrolyser costs have decreased during the past decade by ~60% and will reduce further to 50% by 2030 due to the economies of scale. Hydrogen must cost below 1.5–2 USD/kg to make the hydrogen economy a reality. Incidentally, the cost of hydrogen production using the technology developed by the Institute of Chemical Technology – ONGC Energy Centre using water splitting in conjunction with solar energy is less than USD 1/kg. It is hoped that the Government will evince interest in such a development.

The planning for hydrogen economy by the EU is excellent. According to International Energy Agency (IEA) (2019), the well-to-gate GHG (WG-GHG) emission for green hydrogen from renewable electricity is close to zero. Whereas the WG-GHG emission of steam reforming of natural gas (SRNG) without CCS is 9 kg CO_2 equivalent per kg hydrogen, and that for SRNG with CCS with 90% and 56% respectively, is 1 and 4. The EU natural gas price is 26.8 USD/MWh, electricity price ranges from 43 to 106 USD/MWh and capacity cost is USD 730/kW. Based on cost assessments of the IEA, the International Renewable Energy Agency and BNEF, the electrolyser cost will decline from 1100 to 550 USD/kW or less after 2030, and to 220 USD/kW after 2040. Costs of CCS increase the cost of SRNG from 990 to 1850 USD/kWh. Based on current electricity and gas prices, low-carbon fossil fuel-based hydrogen is projected to cost about 2.5–3.0 USD in 2030 in the EU, and green hydrogen is projected to cost USD 1.3–2.9/kg. If the cost of installed photovoltaics (PV) power can be reduced from the current ~USD 5/W installed to ~USD 1/W, solar electricity is predicted to cost USD 0.10/kWh.

One of the issues of using carbon-based technology, whether renewable or fossil, is the emission of CO_2 associated with hydrogen production, which can be valorized using hydrogen into a few chemical products such as methane and higher hydrocarbons, methanol, dimethyl ether (DME), formic acid, formates, carbonates, ammonia, urea, etc. DME is the cleanest, colourless, non-toxic, non-corrosive, non-carcinogenic and environment-friendly chemical, that is used as an aerosol propellant in various spray cans, replacing chlorofluorocarbons (CFC). Due to its high cetane rating of 55–60, compared to 40–55 for conventional diesel fuel, much higher than that of methanol, DME can be effectively used in diesel engines. Like methanol, it is a clean-burning fuel and produces no soot and black smoke. DME is the best substitute for propane and butane in liquefied petroleum gas (LPG) as a cooking fuel, and the well-established LPG industry infrastructure can be used for DME. The worldwide demand for DME is currently only about 150,000 t/yr, which could be considerably increased if large quantities of this chemical are needed as fuel.

There are many points to advocate hydrogen economy for India's transition to clean and green energy. Hydrogen can serve as a vector for renewable energy storage in conjunction with batteries, guaranteeing as a back-up for season variation. Hydrogen can substitute fossil fuels in some carbon-intensive industrial processes, such as steel, chemical and allied industries, lowering GHG emissions and further bolstering global competitiveness for such industries. It can present solutions for difficult to abate parts of the transport system, in addition to what can be accomplished through electrification and other renewable and low-carbon fuels. India can learn a lot from the experiences and policies of USA, the EU, Japan, and China to promote hydrogen economy.

The Indian Oil Corporation has planned to purchase 15 polymer electrolyte membrane fuel-cell buses using hydrogen fuel and is also setting up a facility to produce hydrogen to run these buses. In the recent Union Budget of India, the Finance Minister has allotted substantial funds for the National Hydrogen Mission. The Ministry of Natural Gas and Petroleum, Government of India (GoI) must be applauded for creating the hydrogen corpus fund. The renewable energy resources like solar, wind, etc. are environment-friendly alternatives to produce electricity for hydrogen production. The potential of solar energy for producing sustainable electric power (solar PV or solar heat), or by the direct use of solar heat to produce hydrogen for fuel-cell power generation and as fuel for ICEs, merits attention. However, the high capital cost of fuel cells, ~USD 5500/kW, is one of the major hurdles of fuel development for commercialization.

With maturity of fuel-cell technology and fuel cells, fuel-cell vehicles will gain substantial market share vis-à-vis conventional power-generation sources and transportation vehicles. Thus, the entire world would benefit from lower dependence on carbon-based economy, leading to a cleaner environment. What we need in the future are integrated plants for hydrogen production from water-splitting and its use in controlling environmental pollution and climate change, as well as production of many chemicals by the CO_2 refineries. We need a novel, realistic rethinking of the energy policy – from transitioning from coal to petroleum to gas and eventually to electrification of transport, to carbon pricing and a focus on new technologies. Why and how of the energy and material policies should consider (renewable) carbon for chemicals and materials with non-carbon renewable sources of energy should be abundantly clear now. Before this vision becomes a reality and the transition to hydrogen economy happens, many technical, social and policy challenges must be conquered. GoI should make the first move, sooner than later, in consonance with its grand objectives, the 5 trillion dollar economy notwithstanding.

Ganapati D. Yadav

Institute of Chemical Technology,
Mumbai 400 019, India
e-mail: gd.yadav@ictmumbai.edu.in