

Powering the World with Hydrogen

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Abstract: *The global energy consumption has been on the rise worldwide as developing nations begin to industrialize and as consumers in developed nations buy more energy consuming appliances to make life more comfortable. If the current trends continue, we may face an energy shortage in future. The phrase "hydrogen economy" refers to programs at using hydrogen as an energy carrier to replace hydrocarbon fuels and reduce emissions produced by their consumption. Technologies such as fuel cells developed for cars, buses, power generation and other applications, along with the infra-structural implications of their broad and increasing use, are being demonstrated in many countries around the world. Activities related to the hydrogen economy are covered on a country by country basis, where applicable.*

Keyword: *climate change; clean energy; energy challenge; renewable energy; hydrogen; hydrogen economy; innovation, fuel cell*

A. Background

The beginning of world energy problem starts when the scientists agree that climate change is bound to happen in a certain time in the future. This adds to other significant problem surrounding energy consumption such as the scarcity of fossil fuel. Energy has been the reason behind some political movement which are currently revolving on how to find an endless source, whatever it takes.

The search of that kind of source is motivated by the imagination of a world powered almost entirely by an infinite endless and totally clean fuel. Hydrogen is just such a fuel. It is one of the most common elements in the universe, can be made from water, and used to generate simple electricity for homes and cars.

In such a world energy would come from an easily stored and domestically produced fuel. Electric power and transportation would be totally clean and entirely free of messy geopolitical problems.

Unlike fossil fuels used in today's almost all human daily activities, the only by-product of hydrogen power would be pure water. With hydrogen, the challenge isn't finding a supply, but extracting the hydrogen cheaply and cleanly. For decades, scientists has been and still trying to find ways to do so.

This is when a coherent energy strategy is required. Which are addressing both energy supply and demand. Then, taking account of the whole energy lifecycle including fuel production, transmission and distribution, and energy conversion. Also, the impact on energy equipment manufacturers and the end-users of energy systems.

Problem

While the scientists are fighting in their own way to create the most balanced energy sources, how much exactly is the damage that we have been tortured the world with? Implementing the idea of hydrogen as a source can't be taken for granted. Such problems follows:

- Can hydrogen be used as a more efficient and cleaner alternative energy source?
- How far the idea of using hydrogen as an energy source can be implemented?

Purpose

The aim is to know if there are possibilities in achieving higher energy efficiency in renewable resources, particularly hydrogen.

Energy, Natural Resources and Environment:

1. Energy Markets

Commodities markets that deal specifically with the trade and supply of energy are called energy markets. It is not only refer to an electricity market, but also to other sources of energy like oil and gas. When the government creating an energy policy that encourages the development of an energy industry in a competitive manner, it results as an energy development.

a. Energy Production

As of 2011, world primary energy production grew at the slower pace of 2.7%, from 4.5% in 2010. In Asia, where the growth of primary energy production it increased 7.1% in 2010. It hardly caught up with the consumption growth in 2011, where there was a 3.7% increase against 5.1% for the consumption.

Production rose by 7.1% or 163 million tonnes of oil equivalent (Mtoe) in China, a little less than consumption. It stagnated in India, slightly increased by 0.4% and even fell by 36% or 34 Mtoe in Japan following the 2011 Fukushima disaster. The sharp reduction in Japan contributed to the stagnation of the primary production in the OECD countries, which was increase 14 Mtoe.

The dynamic production trend in North America, 3.8% rose by 81 Mtoe, was partially offset by the 3% or 33 Mtoe decrease in Europe. In Africa, primary production decreased by 5.7%, while it rose by 2% in Latin America and the former Soviet Union territories, Commonwealth of Independent States (CIS).

Oil and gas producing countries in the Middle East posted 10% increase or 165 Mtoe in production in 2011. As of 2011, OECD accounted for 30% of the world primary energy production, same as Asia. While China alone is 19%.

b. Energy Trade

By 2011, the Middle East region strengthened its position as the world's largest net exporter of energy with 12% increase in the trade surplus and only added 2% in Russia. In North America, shale gas resources contributed to the 4.8% increase in Canadian net exports and to the 12% fall in net energy imports in the United States.

The trade surplus increased only 2% in Latin America, even though Argentina became a net importer in 2011. In Africa, the trade surplus dropped by 14% due to the reduction in Algeria and Nigeria net exports, 5.2% and 2.3% respectively.

In Europe, net energy imports increased by only 1.1% as energy demand was impacted by the economic crisis. In Asia, net imports continued to soar to sustain the 9.8% on average in industrial growth, but 14% in China and 21% in India.

c. Energy Consumption

Primary energy consumption increased at a much slower pace in 2011, by 2.2%, after the strong growth noticed in 2010, which was 4.9%. As an impact of economic crisis, energy consumption in OECD countries fell by 1.3%, in line with the 3.2% drop in the European Union and the stagnation in North America, including 0.7% drop in the United States.

In China and India, energy consumption continued to grow steadily, 7.7% and 6.2% respectively, with China widening the gap with the United States, 19% above

the USA. Energy demand in Japan fell by 6.6% compared to a 6.3% hike in 2010, while it increased at a slower pace in many southeastern Asian countries. Thus, limiting the growth in energy demand in Asia to 5.1% in 2011.

The dynamic trend in Africa and Latin America, 3.1% and 5.1% respectively, in 2010 and stalled in 2011 WITH less than 1% growth.

2. Renewable Energy

Climate change raises the world's concerns. There is this urgent need to reduce carbon emissions that are driving increasing growth in the renewable energy industries. Many countries now have targets for their own renewable energy futures, and have enacted wide-ranging public policies to promote renewables.

Low-carbon renewable energy replaces conventional fossil fuels in three main areas. They are power generation, hot water or space heating, and transport fuels. Total investment in renewable energy reached US\$257 billion in 2011, up from US\$211 billion in 2010. The top countries for investment in 2011 Were China, Germany, the United States, Italy, and Brazil.

a. Electricity Production

The share of renewables in global power generation slightly exceeded 20% in the world in 2011. Renewables, mainly hydro, account for more than 58% of the power mix in Latin America. Their share increased by two percentage points in North America. In the United States, hydropower production and wind generation rose by more than 25% and solar production by 50%. In Canada, hydropower production which was 60% of total generation, increased by 7% and wind generation doubled.

In Europe, the share of renewables in power generation increased slightly to nearly 26% in 2011. In Italy and the United Kingdom, changes in the financial incentive schemes boosted solar power generation, which increased by 65% in the United Kingdom and rose fivefold in Italy. On the contrary, coal promotion policies, and to a lesser extent adverse hydro conditions, reduced the share of renewables in power generation from nearly 33% to 29% in Spain.

In China, the steady progression of renewables in the power mix since 2007 stalled in 2011, 16% of the power generation, from 18% in 2010, in spite of a 22% increase in wind generation, owing to a rising coal-fired production. In India on the contrary, the share of renewables in the power mix gained one percentage point driven by hydropower of 14% and wind 23%.

b. Primary Consumption

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3. Natural Resources

Natural resources are materials and components that can be found within the environment. Every man-made product is composed of natural resources, at its fundamental level. A natural resource may exist as a separate entity such as fresh water, and air, as well as a living organism such as a fish, or it may exist in an alternate form which must be processed to obtain the resource such as metal ores, oil, and most forms of energy.

Natural resources occur naturally within environments that exist relatively undisturbed by mankind, in a natural form. A natural resource is often characterized by amounts of biodiversity and geodiversity existent in various ecosystems. It covers management of resources in industries such as fishing, mining and minerals.

Some natural resources such as sunlight and air can be found everywhere. However, most resources only occur in small sporadic areas and are referred to as localized resources. There are very few resources that are considered inexhaustible or will not run out in foreseeable future. These are solar radiation, geothermal energy, and air, though access to clean air may not be. The vast majority of resources are exhaustible, which means they have a finite quantity, and can be depleted if managed improperly.

a. Classification By Renewability

Many natural resources can be categorized as either renewable or non-renewable.

Renewable resources are ones that can be replenished naturally. Some of these resources, like sunlight, air, wind, etc., are continuously available and their quantity is not noticeably affected by human consumption. Though many renewable resources do not have such a rapid recovery rate, these resources are susceptible to depletion by overuse. Resources from a human use perspective are classified as renewable only so long as the rate of replenishment/recovery exceeds that of the rate of consumption.

Non-renewable resources are resources that form extremely slowly and those that do not naturally form in the environment. Minerals are the most common resource included in this category. By the human perspective, resources are non-renewable when their rate of consumption exceeds the rate of replenishment or recovery. A good example of this are fossil fuels, which are in this category because their rate of formation is extremely slow, potentially millions of years, meaning they are considered non-renewable.

Some resources naturally deplete in amount without human interference, the most notable of these being radioactive elements such as uranium, which naturally decay into heavy metals. Of these, the metallic minerals can be re-used by recycling them, but coal and petroleum cannot be recycled.

b. Natural Resource Management

How managing natural resources such as land, water, soil, plants and animals, with a particular focus on how it affects the quality of life for both present and future generations.

It involves identifying who has the right to use the resources and who does not for defining the boundaries of the resource. The resources are managed by the users according to the rules governing of when and how the resource is conditioned depending on local. A successful management of natural resources should engage the community because of the nature of the shared resources the individuals who are affected by the rules can participate in setting or changing them.

The users have rights to device their own management institutions and plans under the recognition by the government. The right to resources includes land, water, fisheries and pastoral rights. The users or parties accountable to the users have to actively monitor and ensure the utilisation of the resource compliance with the rules and to impose penalty on those peoples who violates the rules. These conflicts are resolved in a quick and low cost manner by the local institution according to the seriousness and context of the offence. The global science-based platform to discuss natural resources management is the World Resources Forum, based in Switzerland.

4. Hydrogen Economy

a. Energy Challenge

The global demand for energy is growing at an alarming rate. The European's World Energy Technology and Climate Policy Outlook (WETO) predicts an average growth rate of 1.8% annually during the period 2000-2030 for primary energy worldwide. The increasing demand is being met largely by reserves of fossil fuel that emit both greenhouse gasses and other pollutants. Those reserves are gradually decreasing and they will become increasingly expensive.

Currently, the level of CO₂ emissions per capita for developing nations is 20% of that for the major industrial nations. As developing nations industrialise, this will increase substantially. By 2030, CO₂ emissions from developing nations could account for more than half the world CO₂ emissions.

Energy security is a major issue. Fossil fuel, particularly crude oil, is confined to a few areas of the world and continuity of supply is governed by political, economic and ecological factors. These factors conspire to force volatile, often high fuel prices while, at the same time, environmental policy is demanding a reduction in greenhouse gases and toxic emissions.

In view of technological developments, vehicle and component manufacturers, transport providers, the energy industry, and even house-holders are seriously looking at alternative energy sources and fuels and more efficient and cleaner technologies, especially hydrogen.

In the early 21ST Century, using hydrogen as a clean fuel became an increasingly attractive prospect. It is so light, however, that all atmospheric hydrogen has evaporated into space, which means it needs to be created artificially.

Nevertheless, the environmentally friendly nature of using hydrogen to create fuel cells was still somewhat questionable, since large quantities of fossil fuels may be consumed to generate it. Fortunately, as technology has improved, new methods for creating these fuel cells have been developed that make them more practical and cleaner than directly using fossil fuels.

b. Uses of Hydrogen

1) Commercial and Consumer

Petroleum and chemical industries companies often use hydro- gen in significant quantities. In a petrochemical plant, it can be used for hydrodesulfurization, which removes sulfur from other natural gas, and hydrocracking, a process by which complex chemicals are broken down into simpler components.

Food companies often use it to hydrogenate oils or fats, which permits the production of margarine from liquid vegetable oil. Chemists also use it to produce methanol and hydrochloric acid, both of which can be used commercially or as part of consumer products.

2) Past Use in Aviation

In the early 20TH century, hydrogen was used as a lifting gas for airships. This ended in 1937 when the Hindenburg disaster effectively brought an end to airships for commercial travel. While the exact cause of the disaster remains unknown, some individuals blamed it on the fuel. Modern zeppelins and blimps use helium or heated air.

3) Science and Manufacturing

Hydrogen also has applications in physics and engineering. It is used as a shielding gas for welding, isolating the site of the weld from atmospheric gases such as oxygen and nitrogen. Some companies use it for cooling rotors in electrical power generators because of its high thermal conductivity. In its liquid form, it is colder than 14 degree Kelvin (K). Thus, scientists have used it for research in cryogenics and superconductivity.

Hydrogen's isotopes, especially deuterium, are used in nuclear reactors. Deuterium can be used as a neutron moderator for fission reactions, in which an atom is split, or a fuel for fusion reactions, in which atoms are combined. Tritium, another isotope, acts as a radiation source in luminous paints and is a component in some bombs.

c. Hydrogen Economy

There have been news stories for decades about the problems associated with petroleum or fossil fuel. Everything from oil spills to ozone alerts to global warming gets blamed on our dependence on fossil fuels. These two forces are leading the world toward what is broadly known as the hydrogen economy.

Hydrogen economy was first coined by John Bockris, an expert in physical electrochemistry, during a talk he gave in 1970 at General Motors (GM) Technical Center. The hydrogen economy is a proposed system of delivering energy using hydrogen. The hydrogen economy promises to eliminate all of the problems that the fossil fuel economy creates.

Currently in hydrogen economy, transportation is fueled mainly by petroleum. Unfortunately, burning of hydrocarbon fuels emits carbon dioxide and other pollutants. The supply of economically usable hydro- carbon resources in the world is limited, and the demand for hydro- carbon fuels is increasing, particularly in China, India, and other developing countries.

In the world scale, there is an argument that hydrogen can be an environmentally cleaner source of energy to end-users, particularly in transportation applications, without release of pollutants such as particulate matter or carbon dioxide at the point of end use.

Hydrogen advocates promote hydrogen as a potential fuel for motive power, including cars and boats, and the energy needs of buildings and portable electronics. However, the high

capital costs of fuel cells, are one of the major obstacles of its development, meaning that the fuel cell is only technically, but not economically, more efficient than an internal-combustion engine.

Other technical obstacles include hydrogen storage issues and the purity requirement of hydrogen used in fuel cells – with current technology, an operating fuel cell requires the purity of hydrogen to be as high as 99.999%. On the other hand, hydrogen engine conversion technology is more economical than fuel cells.

Nevertheless, hydrogen can contribute to economic growth through job development, investment opportunities, and the creation of a sustainable, secure energy supply.

1) Creating Hydrogen Economy

In the hydrogen economy, there is no storehouse to tap into. We have to actually create the energy in real-time. Having variety of choices when making hydrogen is part of what makes it a universal fuel.

Thus, Hydrogen can be prepared in various ways. But, there are two possible sources for the hydrogen.

First is electrolysis of water or using electricity. It is easy to split water molecules to create pure hydrogen and oxygen. One big advantage of this process is that you can do it anywhere. For example, you could have a box in your garage producing hydrogen from tap water, and you could fuel your car with that hydrogen.

This option is the core of the real hydrogen economy. To have a pure hydrogen economy, the hydrogen must be derived from renewable sources rather than fossil fuels so that we stop releasing carbon into the atmosphere. Having enough electricity to separate hydrogen from water, and generating that electricity without using fossil fuels, will be the biggest change that we see in creating the hydrogen economy.

Where will the electricity for the electrolysis of water come from? Right now, mostly comes from coal or natural gas. All of that generating capacity will have to be replaced by renewable sources in the hydrogen economy. In addition, all of the fossil fuel energy now used for transportation will have to convert to hydrogen, and that hydrogen will be created with electricity, as well.

The second option is reforming fossil fuel, oil and natural gas contain hydrocarbons, which is molecules consisting of hydrogen and carbon. This process is using a device called a fuel pro- cessor or a reformer to split the hydrogen off the carbon in a hydrocarbon relatively easily and then use the hydrogen. The carbon leftover is discarded to the atmosphere as carbon dioxide.

This option is still argumentated, because fossil fuel is used as the source of hydrogen for the hydrogen economy. The approach reduces air pollution, but it doesn't solve either the greenhouse gas problem because there is still carbon going into the atmosphere or the fuel dependence problem. However, it may be a good temporary step to take during the transition to the hydrogen economy.

Many car companies are developing fuel-cell-powered vehicles and almost all of them plan to get the hydrogen for the fuel cells from gasoline using a reformer. The reason is because gaso- line is an easily available source of hydrogen. Until there are hydrogen stations on every corner like gas stations, this is the easiest way to obtain hydrogen to power a vehicle's fuel cell.

2) Storage and Transportation

Hydrogen-filling stations are already open in several countries like the United States, Iceland, Japan and Germany. At this moment, the problem with putting pure-hydrogen vehicles on the road is the storage and transportation problem. Hydrogen is a bulky gas, and it is not nearly as easy to work with as gasoline. Compressing the gas requires energy. Compressed hydrogen contains far less energy than the same volume of gasoline.

However, solutions to the hydrogen storage problem are surfacing. For example, hydrogen can be stored in a solid form in a chemical called sodium borohydride. This technology has appeared in the news recently because US car maker Chrysler is testing it. This chemical is created from borax, a common ingredient in some detergents. As sodium borohydride releases its hydrogen, it turns back into borax so it can be recycled.

Once the storage problem is solved and standardized, then a network of hydrogen stations and the transportation infrastructure will have to develop around it. The main barrier to this might be the technological sorting-out process. Stations will not develop quickly until there is a storage technology that clearly dominates the marketplace. For instance, if all hydrogen-powered cars from all manufacturers used sodium borohydride, then a station network could develop quickly; that sort of standardization is unlikely to happen rapidly, if history is any guide.

There might also be a technological breakthrough that could rapidly change the playing field. For example, if someone could develop an inexpensive rechargeable battery with high capacity and a quick recharge time, electric cars would not need fuel cells and there would be no need for hydrogen on the road. Cars would recharge using electricity directly.

3) Cost

In cost evaluation, fossil fuels are generally used as the reference. The energy content of these fuels is not a product of human effort and so has no cost assigned to it. Only the extraction, refining, transportation and production costs are considered. However, the energy content of a unit of hydrogen fuel must be manufactured, and so has a significant cost, on top of all the costs of refining, transportation, and distribution.

Systems which use renewably generated electricity more directly, may have a significant economic advantage because there are fewer conversion processes required between primary energy source and point of use. The barrier to lowering the price of high purity hydrogen is a cost of more than 35 kWh of electricity used to generate each kilogram of hydrogen gas.

Demonstrated advances in electrolyzer and fuel cell technology by ITM Power, company that specializes in electrolyzers and hydrogen fuel cell products, are claimed to have made significant in-roads into addressing the cost of electrolyzing water to make hydrogen. Cost reduction would make hydrogen from off-grid renewable sources economic for refueling vehicles.

Hydrogen pipelines are more expensive than even long-distance electric lines. Hydrogen is about three times bulkier in volume than natural gas for the same enthalpy. Hydrogen accelerates the cracking of steel (hydrogen embrittlement), which increases maintenance costs, leakage rates, and material costs.

The difference in cost is likely to expand with newer technology: wires suspended in air can use higher voltage with only marginally increased material costs, but higher pressure pipes require proportionally more material.

Setting up a hydrogen economy would require huge investments in the infrastructure to store and distribute hydrogen to vehicles. In contrast, battery electric vehicles, which are

already publicly available, would not necessitate immediate expansion of the existing infrastructure for electricity transmission and distribution.

Power plant capacity that now goes unused at night could be used for recharging electric vehicles. A study conducted by the Pacific Northwest National Laboratory for the US Department of Energy in December 2006 found that the idle off-peak grid capacity in the US would be sufficient to power 84% of all vehicles in the US if they all were immediately replaced with electric vehicles.

Different production methods each have differing associated investment and marginal costs. The energy and feedstock could originate from a multitude of sources i.e. natural gas, nuclear, solar, wind, biomass, coal, other fossil fuels, and geothermal.

4) Spending and Investment

Global spending in the hydrogen technology exceeded US\$5.6 billion in 2008 and is growing in manufacturing, research & development, demonstrations, and other key market sectors.

On the other hand, global investments in building the hydrogen economy cost over US\$1.3 billion in 2006 and rise to nearly US\$1.7 billion in 2007 and US\$5.5 billion in 2012. Technologies for converting hydrogen to energy, particularly fuel cells but also hydrogen internal combustion engines and turbines account for the bulk of the investment in research.

Global investments in plant and equipment, through 2012 (US\$ million)

	2006	2007	2012
Hydrogen Production	143.3	160.1	786.4
Storage and Distribution	74.7	106.7	214.8
Energy Conversion	1,055.0	1,305.0	4,185.4
Other	80.9	98.8	323.8
Total	1,353.9	1,670.6	5,510.4

The transition to a hydrogen economy will require large investments in capital equipment and durable goods at every stage of the hydrogen chain, from production of hydrogen through its distribution and storage to the conversion of the hydrogen to useful work or energy. These investments are both an economic challenge, to the extent that they require the mobilization of sufficient financial resources, and a business opportunity for providers of related goods and services.

Fuel cells are a fairly old concept, but are still not economical. The timeframe for fuel cell commercialization is not entirely clear, but some experts expect fuel cells to play a major role in the renewable energy equation by about 2020.

D. Conclusion and Suggestion

Conclusion

There is no doubt we will face oil crisis peak. Each year in future, there will be less oil available than there has been in the past. To some extent, this forecast will force us to consider cleaner alternatives.

Renewable energy is an obvious choice to reduce carbon dioxide and other atmospheric pollutants contributing to global warming. A promising possibility is to exploit the energy potential of the most plentiful element in the known universe hydrogen. Hydrogen has been looked at as the ultimate clean fuel because it burns nearly pollution-free. When burned, it turns into heat and water vapor.

When burned in an internal combustion engine, the kind of engine in gasoline cars today, the combustion also produces small amounts of other gases. These other gases are mostly oxides of nitrogen because the hydrogen is being burned with air, which is about two-thirds nitrogen. Being a non-carbon fuel, the exhaust is free of carbon dioxide.

The environmental advantages of the hydrogen economy is so significant, because the problems with the fossil fuel economy are so great. That push toward the hydrogen economy is very strong. One of the more interesting problems with the hydrogen economy is the hydrogen itself. Where will it come from? In the hydrogen economy, there is no storehouse to tap into. We have to actually create the energy in real-time, by using electricity and reforming fossil fuels. Hydrogen is normally a gas and can be compressed and stored in cylinders. A fuel cell combines hydrogen and oxygen to produce electricity, heat, and water. Fuel cells are often compared to batteries. Both convert the energy produced by a chemical reaction into usable electric power. However, the fuel cell will produce electricity as long as fuel (hydrogen) is supplied, never losing its charge.

The main problem with hydrogen is bulk of the cylinders (fuel tanks). Compressed hydrogen contains less energy per volume compared to liquid fuels like gasoline or ethanol. Hydrogen can also be cooled to produce liquid hydrogen, but it is costly.

Hydrogen's clean burning characteristics may, one day, make it a popular transportation fuel. For now, the problem of how to store enough hydrogen on a vehicle for a reasonable range, and its high cost, compared to gasoline, are critical barriers to widespread commercial use.

Nearly all hydrogen currently is made from natural gas. For that reason, hydrogen usually costs more than natural gas.

In the future, hydrogen could also join electricity as an important energy carrier, that moves and delivers energy in a usable form to consumers. Renewable energy sources, like the sun and wind, can't produce energy all the time. But they could, for example, produce electric energy and hydrogen, which can be stored until it's needed. Hydrogen can also be transported (like electricity) to locations where it is needed.

Suggestion

1. Successful implementation of a hydrogen and fuel cell economy is still far from complete. It requires a continued and steady commitment by industry, government, and academia, including significant levels of private investment from energy companies, automotive manufacturers, public utilities, and public investment.
2. The environmental benefits of hydrogen are a very positive attribute. When used in a fuel cell to power an electric vehicle, the emissions include only water and heat. Passion to the clean energy could maximize the research of technology to produce and storage hydrogen energy, as long as build the infrastructure at lower cost.
3. With governmental support at the national and local levels, and strategic partnerships between industry and research organizations, hydrogen can be highways have emerged in parts of many activities around the world.

4. The hydrogen and fuel cell industry now become a multi-billion dollar industry and continues to attract the attention of the public through participation in large global technology expos and public events. Integrate global energy policy with research and development towards a hydrogen economy in light of the global energy challenge.

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