Hydrogen energy carrier from coal gasification: a promising new green power source

The world's mounting energy requirements, combined with climate change concerns have ignited a ramped up international search for new means of cost effective green energy. The "green energy" movement worldwide has become a powerfully influenceable political force towards the continued evolution of recycling, repurposing and environmental conservation.

Despite the negative political ideologies towards coal, approximately 40% of the electricity generated in the United States is still generated from conventional carbon rich coal-fired power plants [1].

The use of coal provides global access to electricity to those who previously didn't have it, which is an obvious necessity for quality of life as well as poverty reduction in many regions.

In addition, developing countries such as South Africa rely heavily on coal (94%) for their electricity, while China and India consume 70-75% for their electrical needs. However, with its current population, the amount of coal China uses dwarfs most other nations . Although coal-fired plants are the most carbon intensive fossil fuel source around the world, they continued to grow to approximately 40 gigawatts (GW) in 2019, a 4% increase from past years. The remaining electricity requirements both in the U.S. and abroad come from natural gas, nuclear energy, and renewable sources such as wind, solar and others.

Although traditional coal-rich power plants are cost effective, it's negative environmental impact on the local ecosystem are well known. When coal is burned, it releases many pollutants such as nitrogen oxide, sulphuric oxide, particulate matter, carbon dioxide (CO_2), methane gas (CH_4) and others which contribute to global warming. Additionally, airborne toxins such as mercury, lead and various other heavy metals are also released during the coal burning process which has been known to lead to many severe health problems, ranging from breathing difficulties, and possibly even cancer and premature death. All of these known deleterious environmental and health impacts from old generation coal-fired power plants have accelerated the current green energy revolution now taking place, as it once did during the Industrial Revolution of the 1700-1800's during the U.S. Civil War when coal replaced charcoal for new types of energy. A similar comparison can be drawn with the transition from 'traditional use' fossil fuels to clean energy technology.

Hydrogen is an energy carrier that can be used to store, move and deliver energy produced from other common power sources [2]. Hydrogen is found in the first group in the periodic table. It is the lightest and most abundant element in the atmosphere. Hydrogen is currently one of the most ideal sources of pure green energy. When hydrogen is burned in the air, it reacts with oxygen to form water, while releasing its energy. Hydrogen is indeed considered an energy carrier, much like electricity, since it must be produced from other common domestic energy resources. The most familiar ones are from thermal processes, coal gasification, natural gas, nuclear power, biomass, electrolysis and even from renewable power such as solar and wind. Green hydrogen is an attractive clean energy carrier for a large variety of applications such as electricity generation and transportation. It may be used to power cars, cities and many other high energy consuming industries while reducing and/or eliminating the negative toxic and greenhouse effects of the past, such as outdated coal-fired power plants. That said, fossil fuels are the dominant source of industrial hydrogen. Hydrogen could soon become a common energy source in the near future, by providing a clean energy solution to global warming concerns, while utilizing fossil fuels in clean new way.

There are four main sources for the commercial production of hydrogen: biological, gas, coal and electrolysis, which currently account for 48%, 30%,18% and 4% hydrogen production respectively.

The thermal process for hydrogen production typically involves steam reforming [3] which is a high temperature production of steam that reacts with a hydrocarbon fuel to produce hydrogen. Many hydrocarbons such as natural gas, diesel, renewable liquid fuels, and gasified biomass may be used to produce hydrogen.

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The electrolytic [3] process is another modality to produce hydrogen. Water can be separated in an electrolyzer which functions much like a fuel cell in reverse, separating the water molecules into oxygen and hydrogen.

The renewable solar-driven process [3] may use light or the energy generated from the sun as the agent for hydrogen production. Several solar driven methods are currently being tested and studied. Similarly, renewable wind power energy is being tested as a power source for hydrogen production.

The biological process [3] utilizes microbes such as bacteria and micro algae that can produce hydrogen through biological reactions. Indeed, many commonly available energy sources are now being tested for hydrogen production, however, at the present time, may be limited by cost and technological advances.

Hydrogen production using advanced coal gasification technology may quickly become the most attractive source, due to many factors, including its abundance and cost effectiveness.

More than 100 coal-fired plants have been replaced or converted to natural gas since 2011. According to the EIA, 121 coal-fired plants were repurposed to burn other types of fuel between 2011 and 2019. The decision to switch from coal to natural gas is largely driven by stricter emission standards and lower gas natural gas prices. The new natural gas-fired combined cycle (NGCC) have a capacity of of generating 15.3 GW, 94% more than the 7.9 GW capacity of the coal fired plants they replaced. Coal-fired plants have been great candidates for conversion because they tend to be smaller-capacity units and are mostly over 50 years old.

In the near future, hydrogen retrofitted coal-fired power plants utilizing coal gasification methods can provide cost effective electricity while generating vast amounts of hydrogen. These short term plans will allow both U.S. and global communities to utilize vast resources of available coal at low cost, reduce global warming, while giving rise to the future source of green hydrogen energy. Coal is by far the most abundant and available fossil fuel in our country. The U.S. has the world's largest proven reserves of coal [4], near 247 billions tonnes estimated in 2007. Coal gasification technology is in the advanced state of development and appear realistic and promising.

The D.O.E. [5] explains that coal gasification is a thermo-chemical process in which the the gasifier's heat and pressure break coal down into its chemical constituents. The process of partial oxidation, or gasification, is a chemical reaction that occurs when a mixture of coal feedstock with a proportional ratio of pure oxygen are fed in the partial oxidation reactor under controlled conditions, producing a syngas. A syngas is a mixture of hydrogen, carbon monoxide and often some carbon dioxide. The hot syngas generated by this partial oxidation process is then cooled in heat exchangers, with the production of steam and cleaned before combustion in a gas turbine. Hydrogen production by coal gasification is also capable of separating and recovering the carbon dioxide simultaneously. After hydrogen separation, carbon dioxide can be captured and sequestered if the coal power plant is located close enough to a suitable sequestration site. Carbon capture may become an important operation for environmentally benign utilization of these resources in the future.

Multiple industries worldwide have developed and a few are testing industrial plants for hydrogen energy production. The Linde group [6, 7] have developed an industrial partial oxidation plant based upon the GE/Texaco gasifier for coal gasification. GenH2 (8) is a leading company with experience researching and producing technology solutions necessary for the hydrogen economy. Patented technologies developed include end to end filling stations to make clean hydrogen with zero carbon dioxide emissions [8].

Bakken Energy [9]. announced that it has reached an agreement with Basin Electric Power Cooperative (Basin Electric) to purchase the assets of the Dakota Gasification Company (Dakota gas) located in North Dakota. The synfuel plant may be transformed into one of the largest and lowest cost, clean hydrogen production facility in the U.S.

Mitsubishi Heavy Industries [10] has recently invested in an Australian hydrogen infrastructure which aims to develop some of the world's best solar and wind resources to produce zero-emissions hydrogen energy.

Choren industrietechnik GMBH [11] based in Germany has developed an efficient coal gasification technology for generation of an ultra pure, high energy syngas.

Atmos, based in the Czech Republic has developed a boiler for coal gasification [12], while Wuxi Teneng Power Machinery has manufactured a biomass gasification power generation plant [13]. Toyo Engineering Corporation [14] is working on a coal gasification project that enables coal to be used effectively both as an energy source and for chemical production.

Kawasaki Heavy Industries [15] is located in the state of Victoria, Australia, home to a quarter of the World's bituminous coal reserves. The project is key to helping Japan meet its target of achieving net-zero carbon emissions by 2050.

Japan, the world's fifth-largest energy consumer, aims to boost its annual hydrogen demand tenfold to 20 million tonnes by 2050, equivalent to about 40% of its current power generation.

The above cutting edge industries are but a handful around the world competing to develop cost effective, industrial levels of clean hydrogen energy with zero emissions. Their future success directly depends on the effectiveness of their technology, the cost of final products and their ability to commercialize it.

Today, the primary demand for hydrogen is as a chemical feedstock in petroleum refining and ammonia production, with smaller amounts being used in other industrial applications such as methanol production [16]. Approximately 10 million metric tonnes (MMT) of hydrogen are currently produced in the United States each year for these end uses, mostly from natural gas. In the future, hydrogen's versatility as an energy carrier will be needed to serve expanded end-uses such as electricity production and as fuel cells for transportation . It is estimated that more than 72 million tonnes of hydrogen per year can be produced in the U.S. within a few years. 40 million tonnes of which may be produced relatively short term from coal gasification plants alone. The remaining from natural gas resources, nuclear and hydropower [16]. These estimates consider 30% of their total current annual production [16].

Hydrogen production has increased from roughly 40 million tonnes in 2005 to approximately 72 million tonnes today [16]. In 2026 global hydrogen production is expected to reach an estimated 200 million tonnes, suggesting a compound annual growth rate of 8.1% or approximately 121 million metric tonnes [16]. Given these growth expectations, the Energy Transition Commission estimates that by 2050 the global market could reach an annual hydrogen production rate of between 425-650 million tonnes [16].

Hydrogen derived from coal is considered both a cost effective and promising near to mid-term opportunity in the U.S. due to widely available inexpensive coal reserves and improved gasification technology. The state of Virginia alone where PMO Virginia Coal owns an estimated 58 million tonnes coal reserve is estimated to produce in the forceable future at least 2 thousand tonnes per year of green hydrogen.

In 2020, 18.1 million barrels per day of petroleum products were consumed in the U.S. Assuming at least a 114 thousand tonnes of hydrogen's daily production from coal gasification alone in the near future (assuming 30% daily production), would save 0.7% of the U.S. total daily energy needs. "That's one small step for the present, but a giant leap in the right direction towards zero emission". The promise of green hydrogen energy are indispensable for the future control of global warming. With progressive worldwide research and further technological innovation, the industrial production cost of green hydrogen energy will continue to grow exponentially until our global goals are met.

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