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6. Water Technology and Fuels

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Abstract:

Water is considered one of the most important necessities for human survival. Apart from its role in day-to-day life human consumption, it has emerged as a potential clean energy source. Amidst of energy and economic crisis the need for alternative energy sources, with a potential to replace traditional petroleum-derived fuels has outgrown. As the abundant portion of the earth is covered with water, it becomes a vital source for renewable energy production, mainly biofuels and bioenergy. Water in all its existing forms (i.e. subcritical, supercritical, hard water and steam) is utilized in the derivation of fuels. Electrolysis, Photo-electro-chemical water splitting, Thermo-chemical water splitting, Hydrogenation, Biomass gasification and other techniques are harnessed in the fuel production processes. This chapter focuses on alternative renewable fuel sources and water technology used in their derivation. Outraging demand for alternative sources of fuels along with population explosion has emerged as a concerning global issue, which can be conquered by utilizing water for clean energy production.

Keywords:

Water, energy, fuel, bio-energy, renewable-energy sources.

6.1 Introduction:

Water technology has evolved from being just a technology to become a global need. In current scenarios where the world is in a water and energy crisis, the need to develop more and more water technology has become an emerging demand.

The role of water at an individual and societal level is very crucial. Water is needed in almost every aspect of human living. From agriculture to household chores, water is the key element to make things happen. As it is considered the most basic necessity for human survival, it has also emerged as a possible renewable energy source. Since the landscape of energy and fuels around the globe is expanding rapidly, the need to avail possible renewable energy sources has become a today's need. We require fuels and energy for transportation, heat, electricity and power. So, as to suffice all these needs, alternative sources of fuels and energy area need of this current scenario.

Along with population explosion, the global water demand is likely to rise up to 55% by 2050. Henceforth, intellectual solutions for the water crisis have become a critical need. Fossil fuels which are considerably cheaper than other fuel and energy sources; are non-renewable, to replace them with a renewable energy source; water comes out to be the most accessible and environmentally friendly renewable fuel and energy source. Transitioning to renewable sources of fuel and energy also provides energy security, reduces greenhouse gas emissions and promotes sustainable development.

Dependency on fossil-fuel-based fuels increases the chances of widespread environmental degradation as it consumes several harmful oxides including nitrogen sulphur and carbon. However, conservation of fossil-fuel-based fuels also becomes important which can optimize sustainability (Abas et al., 2015).

Thus, water as a renewable energy and fuel source can produce hydrogen, syngas which involves hydrogen and carbon monoxide; deriving methanol and synthetic diesel. Water is essential in cultivating biomass for biofuel production, hydrogenation of vegetable oils also requires water to produce hydrogen for biodiesel production.

6.2 Water Technology:

Water technology involves various techniques and tools aimed at managing and enhancing the use, quality, and distribution of water. Water technology aims to provide a dependable supply of clean and safe water for drinking, agriculture, industry, and environmental sustainability.

These technologies thrive to remove or lessen contaminants from water to meet its desirable quality at the consumer end. As a positive response towards major calamities that the world is facing in the current scenario such as climate change, population explosion and global warming, water technology serves as a carrier in utilization of resources to its fullest.

One such emerging issue is the need for an alternative energy source that must be environmentally friendly. Over the period, the utilization of energy and fuels has increased rapidly with population explosion and upgradation in the global standard of living. To address and resolve such a global emerging issue, the need to conserve non-renewable energy sources and to find and adapt possible renewable energy sources has been outgrown. Water technology in the synthesis of such fuels plays a key role. Numerous technologies such as electrolysis, thermochemical water splitting, photoelectrochemical water splitting, hydrogenation and biomass gasification are majorly acquainted in the production of such fuels.

6.2.1 Water Electrolysis

Electrochemical water splitting is an approach to producing hydrogen, and it is one of the most environmentally acceptable techniques that is followed across the globe for producing hydrogen due to its no carbon-emission methods i.e. half-cell reactions (HER and OER) (Anwar et al., 2021). We get (H_2 and O_2) as by-products after the final electrochemical decomposition of H_2O.

In thermochemical conversion, the dissociation of water into hydrogen and oxygen utilises abundant energy and is supervised at excessive temperatures (approximately 2000 degrees centigrade). With high energy expenditure and excessive temperature procedures, the risk of explosion is always high with no intermediate steps involved in the process.

Photochemical is somehow analogous to natural photosynthesis as it involves the activation of a photocatalyst through an incident light while utilising a photochemical reactor.

Photoelectrochemical conversion has turned out to be the most efficient water decomposition. This conversion is based on dye-sensitized solar cells, where the hydrogen yield is proportionate to the light energy absorbed by the hydrogen on water dissociation. Thus, it is also known as photo electrocatalytic conversion (dos Santos et al., 2017).

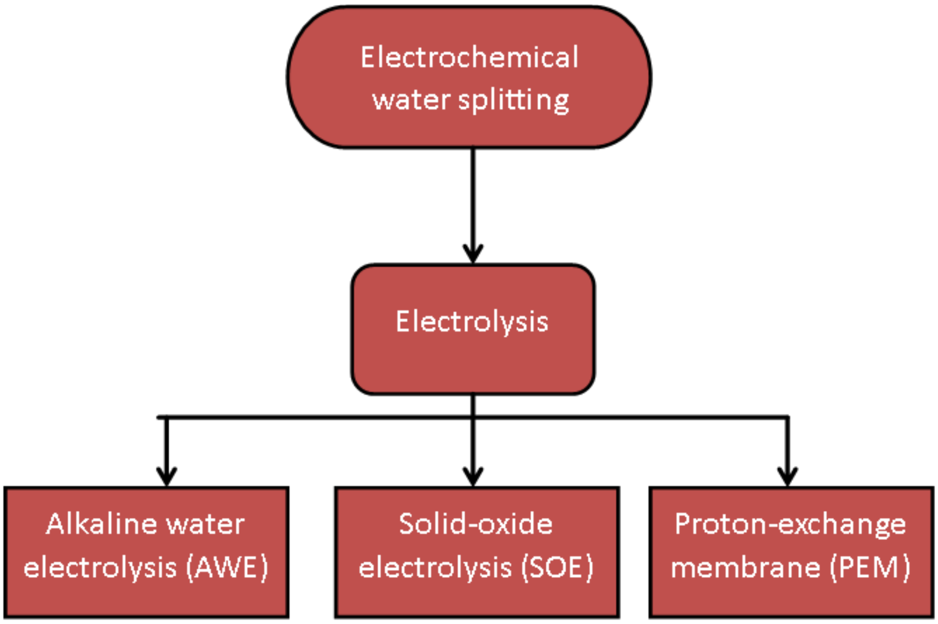

Figure 6.1: Hydrogen production from water electrolysis (Anwar et al., 2021)

6.2.2 Biomass Gasification:

Biomass gasification converts solid or liquid organic compounds into the ‘syngas’ and a solid phase. Syngas can generate and transfer high amounts of heat and can be efficiently used in the production of biofuel and power sources. The solid phase, ‘char’ is a carbon-rich organic solid residue left in the treated biomass. This conversion is achieved in the availability of a gas carrier which can be steam, air, oxygen and carbon dioxide. Biomass gasification is an efficient technology for harnessing biomass to generate energy and fuel (Molino et al., 2016).‘Syngas’ is composed of mainly hydrogen and carbon monoxide. Other constituents in the composition of syngas may vary depending on the operational conditions of the process and the gas carrier that has been used in the conversion. This conversion takes place in multiple steps, key steps that are involved in the biomass gasification process include:

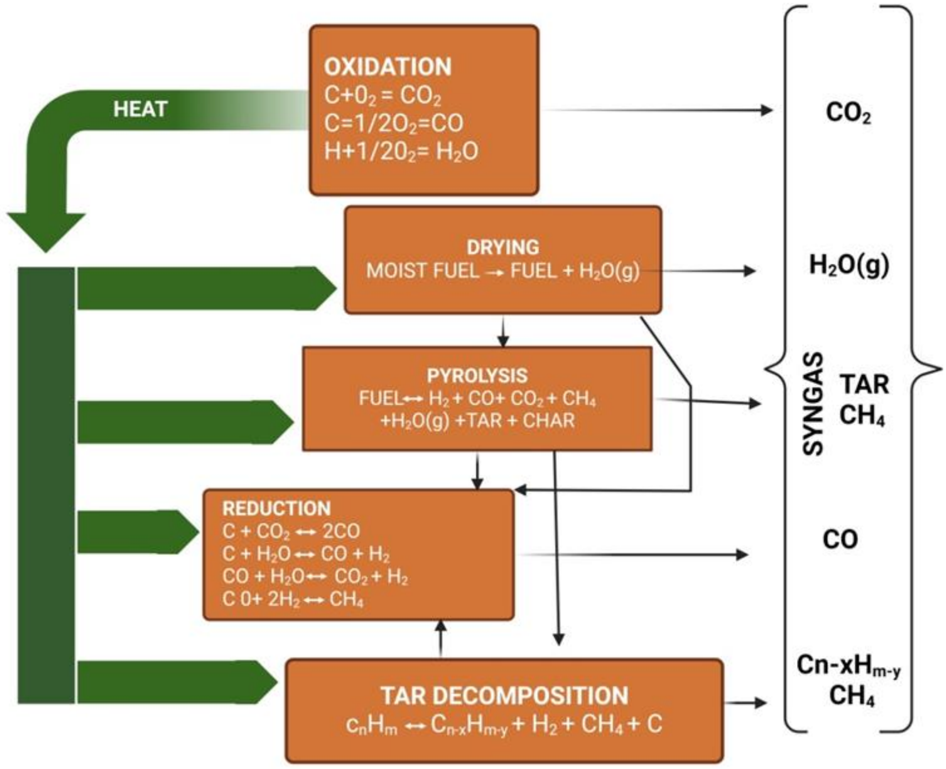

Figure 6.2: Main stages of the gasification process (Molino et al., 2016)

- Oxidation (Exothermic stage)
- Drying (Endothermic stage)
- Pyrolysis (Endothermic stage)
- Reduction (Endothermic stage)

6.2.3 Hydrogenation of CO_2:

Utilization of CO2, a greenhouse gas to produce useful compounds and fuels the process of hydrogenation is carried out. It involves a combination of CO2 and H2, resulting in the production of methanol, which is a synthetic fuel. In this technology, pure CO2 is captured from different sources such as biogas through biogas purification techniques. Wastewater treatment plants are the key source of biogas from where CO2 extraction becomes easy. H2 is also a vital element that is needed for methanol production (Tóth et al., 2011). Various fuel cells are commonly utilised to obtain hydrogen and later methanol production is carried out. One such methanol production facility (MPF) involves a PEM electrolyser and a water washing unit for hydrogen and carbon dioxide synthesis respectively. Although different techniques can be adapted to utilize CO2 to synthesise methanol. H2, on the one hand, can be obtained from any of the water electrolysis techniques and CO2capture units and methanol units can be supplied electricity through coal power plants (Tozlu, 2022).

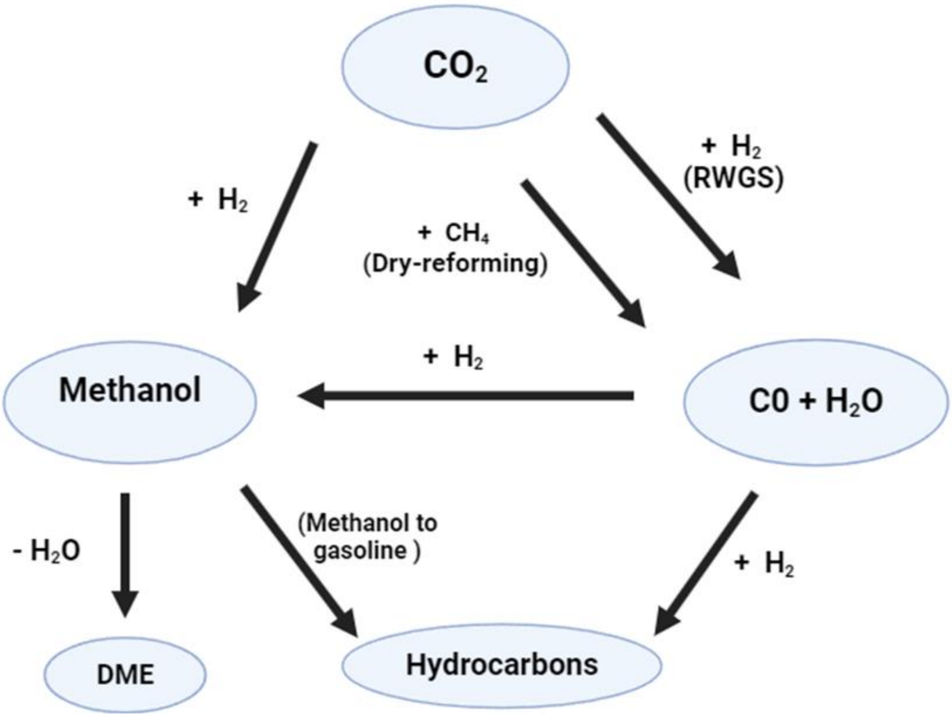

Figure 6.3: Utilization of Carbon dioxide (CO_2) (Tozlu, 2022)

6.3 Advantages of Applying Water Technology:

Concerning current scenarios, it is clear that application of water technology is very crucial. Looking at the future projections and beneficial aspects of these technologies, a few of the major advantages are listed below:

6.3.1 Decreasing the Amount of Water that does not Generate Revenue:

The supplied water that is not documented due to leaks or other reasons is referred as non-revenue water. This results in water wastage and an unhealthy supply of water. In this case, enhancing water distribution efficiency using monitoring software, Big Data, or Machine Learning can significantly reduce the 32 billion cubic meters of water lost annually to leaks, as per the World Bank. The UN highlights that new digital technologies offer unprecedented opportunities to use data and analytics for better water management.

6.3.2 Maximizing the Longevity of Assets:

Utilities face challenges with the lifespan of their infrastructure, crucial for social and economic development. Water sector experts emphasize the need to renew and build infrastructure for smooth operations. However, utilities often lack a comprehensive view of their assets, hindering effective management. Implementing intelligent, interconnected, and scalable solutions optimizes performance, unifies systems, standardizes processes, and reduces the need for constant changes, ensuring efficiency.

6.3.4 Reducing Expenses:

Implementing water technology cuts costs by optimizing efficiency, reducing water, energy, and carbon footprints, and simplifying processes. Intelligent solutions like digital twins lower maintenance expenses by predicting potential issues.

6.3.5 Enhanced Operations and Planning:

A key aspect of water technology is optimizing operational management and planning for greater efficiency. At the Smart Water Summit, Pablo Alcoriza, CTO of Idrica, highlighted that smart solutions help prevent risks, anticipate issues, and enhance system maintenance for an eco-friendly water cycle.

6.3.6 Enhanced Resilience to Extreme Events:

Climate change has increased extreme weather events like droughts, heat waves, and heavy rains, impacting water supply and causing fires and floods. Utilities must ensure supply under all conditions. Deploying intelligent solutions is essential for foresight, efficiency, and maintaining standard operations.

6.4 Fuels:

Fuel and energy are the ultimate sources of living. With dependency on fossil fuel for fuel derivation, the considerable risk of resource extinction and fuel scarcity can be possibly estimated.

Despite rapid population growth, climate change and environmental degradation, standards of living have seen growth over time. With limited fossil resources along with its foul impact on environmental standards, the need to shift from a non-renewable fuel source to a renewable and clean energy source is quite non-negotiable. Around 86% of the global energy index comprises fossil-fuel-based energies and it has been on the rise constantly.

Alternative renewable energy sources like hydrogen-based fuels, biogas, biodiesel, and biofuels can be a possible replacement for existing petroleum-based fuels with extreme carbon emissions and carcinogenic diesel exhaust (Abas et al., 2015).

Table 6.1: Global fossil fuel statistics based on proved reserves. Data extracted from (Abas et al., 2015)

Fuels	Total reserves	Production/day	End date (tentative)
Oil	1.689 Tb	86.81 Mb.	2066
Gas	6558.TCF	326 BCF	2088
Coal	891.531 BT	21.63 MT	2126

*End dates may vary depending on discoveries

6.4.1 Hydrogen:

Hydrogen as a fuel can be a reliable replacement for finite energy sources that are concurrent all around the globe. It has several prominent features that make it stand out as a clean and sustainable energy source. Irrespective of its weight it can store a vast amount of energy due to its high energy density (Nikolaidis & Poullikkas, 2017).

It can be used in fuel cells, and combustion engines and can also be used independently for heating purposes in industrial processes. It marks itself as a zero-emission fuel, leaving only water as its by-product after combustion. It can be easily produced through water electrolysis, steam methane reforming and other thermochemical processes (Wallace & Ward, 1983).Although, due to its low density as a gas it requires special storage and transport conditions. Due to less development in the area of renewable fuel sources, hydrogen-based fuels are more expensive than other existing fuels. Though the market for renewable energy production is on the rise, prices are estimated to be lowered over time. Therefore, hydrogen holds keen importance in environmental sustainability and future energy expenditure as it can be used to store excess energy that can be used in future (Singla et al., 2021).

6.4.2 Biofuels:

Biofuels are clean energy sources derived from biomass which are organic feed stocks such as agricultural residues or animal waste (Rodionova et al., 2017). In search of alternative forms of energy, several energy sources were discovered out of which biofuels marked their way as renewably produced fuels. The first generation of biofuels utilizes food items like corn, sugarcane, wood and other parts of a plant or a food item for the synthesis of fuels became widely popular. Second-generation biofuels utilize agricultural residues such as corn stover and wheat straw for bioethanol and biodiesel production. While filling the loopholes, the third generation of biofuels was introduced which utilize microalgae as a feedstock for the production of fuels (Demirbas., 2008).

6.4.3 Bioethanol

Minimizing the dependency on non-renewable sources, ethanol emerged as a viable alternative to petroleum-derivative fuels. It harnesses starch (corn grain) and sucrose (sugarcane) for its production (Ribeiro et al., 2007). Production of ethanol involves the conversion of biomass into fuel which is a multi-step process including thermochemical pretreatment, enzymatic saccharification and fermentation. Seeing the probability of the unavailability of corn grains and sugarcane as feedstock is already estimated, lignocellulosic and hemicellulosic biomass can be utilised as feedstock for fuel production.

Consuming bioethanol as a primary fuel can increase resource sustainability with no considerable risk of carbon footprint increase. As it utilises agricultural residue as a feedstock, it also poses no harm to food security. More development in conversion technologies can utilise forest residues as a major feedstock which can escalate the landscape of fuel usage at a cheaper rate of production and faster commercialisation (Balat et al., 2008)

6.4.4 Biodiesel:

Biodiesel is seen as an attractive alternative to the existing energy sources. Being produced from renewable sources, it has a higher efficiency to be used as a sustainability tool. Several techniques are used in biodiesel production, pyrolysis and transesterification are the most prominently used techniques. Natural vegetable oils and animal fats are used in the synthesis of biodiesels. High cost remains a concerning issue, although glycerol needs to be extracted as a by-product that can be used for industrial purposes, minimizing the cost eventually. Although the utilization of vegetable oil and animal fat for biofuel production presents an alarming risk to food security, other sources of clean energy production are currently under investigation to provide more sustainable and less contentious alternatives. (Ma & Hanna, n.d.).

6.4.5 Methanol:

Traditionally, methanol was produced through wood and fossil fuels. After sustainability became a major decisive factor, various production methods came into the picture. Methanol, being present in liquid form is easily scalable as it can be easily stored and transported. It can be used in its original form or else can be used as a blended solution. Internal combustion engines (ICEs) and direct methanol fuel cells are major applications of methanol. Current approaches have led to the scenario where methanol can be seen as a viable fuel option in the marine sector. As methanol is infinitely miscible in water it has led to excellent storage efficiency. As far as safety is concerned, the ability of methanol to dilute within a small range of time can prevent an accident in case of spillage. Compared with other heavy fuel oils or bunker fuels that are currently in use, methanol shows significant emission levels (Van-Dal & Bouallou, 2013). In terms of environmental safety and reliability, methanol has turned out to be a better fuel option. It can be easily produced through the hydrogenation of CO_2in synergy with $H_{2.}$In addition to other thermochemical methods being investigated for methanol production, the hydrogenation of fatty acids, carbon dioxide (CO_2), vegetable oils, and animal fats has demonstrated the highest levels of efficiency. These alternative methods are being explored to identify the most effective and sustainable approaches for producing methanol, a vital chemical and fuel source.

6.5 Advantages of water-based fuels over traditional fuel sources:

Over the centuries, petroleum derivatives have been the only fuel option that has continuously been exploited. Coal-fired thermal stations account for over one-fourth of the total energy production. Dependency on coal-fired thermal stations for energy production is extremely high. Coal is a non-renewable energy source and has a finite resource deposit. Over-exploitation of such sources will probably lead to resource exhaustion and the world will sooner or later run out of a reliable energy source. Apart from these factors, coal combustion throws out nitrogen and sulfur-based oxides, volatile compounds like ash, soot dust and even trace metals which on exposure to the environment can cause serious ill effects on human health (Nyashina.,2018). Key petroleum-derived fuels including diesel, petrol, liquified-petroleum gas (LPG), gasoline, jet fuel, heavy-fuel oils (HFO) and kerosene are utilised throughout mankind in day-to-day life activities. From household chores to transport facilities, these fuels are utilised in abundance.

Since all these are fossil fuel-based fuels and have a limited resource supply, we can run out of these fuels in a few hundred years. Apart from their finite availability, these fuels emit a large amount of carbon emissions, posing a threat risk at the global level. Diesel among which has been called out as a human carcinogenic element (Barbir et al., 1990). So, to conserve the limited resource supply and to save ourselves at an individual level as well as at a global level, a replacement for these fuels is needed. Among all the renewable sources, water has turned out to be the most efficient option as it is abundantly available and is a clean source. Hydrogen, methanol, biofuels, syngas, biodiesel, and biogas are examples of water-based fuels as water is involved as a key component in their production. With zero-carbon emissions, renewable source utilization, no harm to food security and resource availability, there are humongous advantageous aspects of water-based fuels over traditional non-renewable fuels (Peres et al., 2013). Various aspects such as environmental degradation, human health deterioration, and other signs of fatality can be tackled by adopting usage of water-based fuels as an alternative fuel source. Certainly, commercialisation of such fuels at cheaper cost prices is a major concern as development in the production of such fuels is not majorly reported. However, there are future projections that believe that in upcoming decades the world can see a whole new transition in the fuel industry. Hydrogen, biofuels and other renewable fuel source can possibly overshadow the fuel market leading in eventual cost-reduction (Germscheidt et al., 2021).

6.6 Conclusions:

In summary, water-based fuels present notable advantages over conventional fossil fuels. They contribute to the reduction of greenhouse gas emissions, thereby aiding in the fight against climate change. Their production and utilization can mitigate air pollution, fostering healthier ecosystems and human well-being. Water-based fuels, such as hydrogen and hydrocarbon fuels derived from water, capitalize on renewable resources, thus bolstering energy security and sustainability. Moreover, these fuels can seamlessly integrate into existing infrastructure through technological advancements, facilitating the transition away from fossil fuel dependency. With ongoing research and development, water-based fuels hold significant promise for a cleaner, more sustainable energy landscape.

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