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Emerging Trends of Artificial Photosynthesis and Green Energy

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ABSTRACT: Researchers in Switzerland took a promising lab experiment and scaled it into a real-world example of how we could use solar energy to produce green hydrogen. Their system broke the coveted 1-kilowatt ceiling for green hydrogen production, and offers a new commercialization opportunity. This efficient convertor of solar energy to fuel functions as an efficient artificial photosynthesis system, according to a new study by the Swiss Federal Institute of Technology (EPFL) published in Nature Energy. It also produces useful byproducts of oxygen and heat. "This is the first system-level demonstration of solar hydrogen generation," Sophia Haussener, head of the Laboratory of Renewable Energy Science and Engineering in the School of Engineering at EPFL, says in a news release. "Unlike typical lab-scale demonstrations, it includes all auxiliary devices and components, so it gives us a better idea of the energy efficiency you can expect once you consider the complete system, and not just the device itself." Green energy is the term used to describe sources of energy that are considered to be environmentally friendly and non-polluting, such as geothermal, wind, solar, and hydro^{[1][2][3][4]}. Sometimes nuclear power is also considered a green energy source.^{[5][6][7][8][9]} Green energy sources are often considered "green" because they are perceived to lower carbon emissions and create less pollution.

Green energy is commonly thought of in the context of electricity, mechanical power, heating and cogeneration. Consumers, businesses, and organizations may purchase green energy in order to support further development, help reduce the environmental impacts of conventional electricity generation, and increase their nation's energy independence. Renewable energy certificates (Green certificates or green tags) have been one way for consumers and businesses to support green energy.

KEYWORDS-green energy, artificial photosynthesis, environment, pollution, renewable

I. INTRODUCTION

In the media, Green energy is often used interchangeably with the term Renewable energy.^{[10][11][12]} Alternative energy and clean technologies are other terms often used instead of renewable energy. The terms suggest a non-polluting, non-fossil-fuel source. Green power is sometimes used in reference to electricity generated from "green" sources.^[13] Brown energy is sometimes used to contrast non-renewable or polluting energy sources with green energy.^[14] Green energy includes natural energetic processes that can be harnessed with little pollution. Anaerobic digestion, geothermal power, wind power, small-scale hydropower, solar energy, biomass power, tidal power, and wave power fall under such a category. Some definitions may also include power derived from the incineration of waste.^[1,2,3]

Some organizations have specifically classified nuclear power as green energy^[15], but environmental organizations indicate the problems with nuclear waste and claim that this energy is neither efficient nor effective in cutting CO₂ emissions, excluding it from clean energy^[16].

No power source is entirely impact-free. All energy sources require energy and give rise to some degree of pollution from manufacture of the technology.

The Swedish utility Vattenfall did a study of full life cycle emissions of Nuclear, Hydro, Coal, Gas, Solar Cell, Peat and Wind which the utility uses to produce electricity. The net result of the study was that nuclear power produced 3.3 grams of carbon dioxide per KW-Hr of produced power. This compares to 400 for natural gas and 700 for coal (according to this study). The study also concluded that nuclear power produced the smallest amount of CO₂ of any of their electricity sources.^[17]

Claims exist that the problems of nuclear waste do not come anywhere close to approaching the problems of fossil fuel waste.^{[18][19]} A 2004 article from the BBC states: "The World Health Organization (WHO) says 3 million people are killed worldwide by outdoor air pollution annually from vehicles and industrial emissions, and 1.6 million indoors through using solid fuel."^[20] In the U.S. alone, fossil fuel waste kills 20,000 people each year.^[21] A coal power plant releases 100 times as much radiation as a nuclear power plant of the same wattage.^[22] It is estimated that during 1982,

US coal burning released 155 times as much radioactivity into the atmosphere as the Three Mile Island incident.^[23] In addition, fossil fuel waste causes global warming, which leads to increased deaths from hurricanes, flooding, and other weather events. The World Nuclear Association provides a comparison of deaths due to accidents among different forms of energy production. In their comparison, deaths per TW-yr of electricity produced from 1970 to 1992 are quoted as 885 for hydropower, 342 for coal, 85 for natural gas, and 8 for nuclear^[4,5,6]

II. DISCUSSION

Artificial photosynthesis system (APS) uses biomimetic systems to duplicate the process of natural photosynthesis that utilizes copious resources of water, carbon dioxide and sunlight to produce oxygen and energy-rich compounds and has potential to be an alternative source of renewable energy. APS like natural photosynthesis includes the splitting of water into oxygen and hydrogen, and the reduction of carbon dioxide into various hydrocarbons such as formic acid (HCOOH), methane (CH₄) and carbon monoxide (CO), or even pure hydrogen fuel. These processes are accomplished by a handful of device designs, including photoelectrochemical cells or photovoltaic-coupled electrolyzers which are driven by energy extracted from sunlight photons as well as suitable catalysts. ^[7,8,9] Researchers are trying to combine advantageous components from both natural photosynthesis and artificial photosynthesis to create a semi-artificial photosynthesis system, involving the incorporation of enzymes or even whole-cell into synthetic devices. However, there are several limitations to the advancement of this field which are mainly centered on the inability to establish a system that is cost-effective, long-term durable and has the highest efficiency. Artificial photosynthesis devices can also function as atmospheric cleansers by extracting the excess amount of carbon dioxide and releasing back oxygen into the environment. Although there is still a long way to go to empower society with energy supplied through artificial photosynthesis, at the same time it is both desirable and necessary. To date, the efforts to commercialize APS have been fruitful, and it will soon be a viable alternative fuel source.^[10,11,12]

In several countries with common carrier arrangements, electricity retailing arrangements make it possible for consumers to purchase green electricity (renewable electricity) from either their utility or a green power provider.

When energy is purchased from the electricity network, the power reaching the consumer will not necessarily be generated from green energy sources. The local utility company, electric company, or state power pool buys their electricity from electricity producers who may be generating from fossil fuel, nuclear or renewable energy sources. In many countries green energy currently provides a very small amount of electricity, generally contributing less than 2 to 5% to the overall pool. In some U.S. states, local governments have formed regional power purchasing pools using [Community Choice Aggregation] and [Solar Bonds] to achieve a 51% renewable mix or higher, such as in the City of San Francisco.^[25]

By participating in a green energy program a consumer may be having an effect on the energy sources used and ultimately might be helping to promote and expand the use of green energy.^[13,14,15] They are also making a statement to policy makers that they are willing to pay a price premium to support renewable energy. Green energy consumers either obligate the utility companies to increase the amount of green energy that they purchase from the pool (so decreasing the amount of non-green energy they purchase), or directly fund the green energy through a green power provider. If insufficient green energy sources are available, the utility must develop new ones or contract with a third party energy supplier to provide green energy, causing more to be built. However, there is no way the consumer can check whether or not the electricity bought is "green" or otherwise.^[16,17,18]

In some countries such as the Netherlands, electricity companies guarantee to buy an equal amount of 'green power' as is being used by their green power customers. The Dutch government exempts green power from pollution taxes, which means green power is hardly any more expensive than other power.

In the United States, one of the main problems with purchasing green energy through the electrical grid is the current centralized infrastructure that supplies the consumer's electricity. This infrastructure has led to increasingly frequent brown outs and black outs, high CO₂ emissions, higher energy costs, and power quality issues ^[26]. An additional \$450 billion will be invested to expand this fledgling system over the next 20 years in order to meet increasing demand ^[27]. In addition, this centralized system is now being further overtaxed with the incorporation of renewable energies such as wind, solar, and geothermal energies. Renewable resources, due to the amount of space they require, are often located in remote areas where there is a lower energy demand. The current infrastructure would make transporting this energy to high demand areas, such as urban centers, highly inefficient and in some cases impossible. In addition, despite the amount of renewable energy produced or the economic viability of such technologies only about 20 percent will be able to be incorporated into the grid. In order to have a more sustainable energy profile, the United States has to move towards implementing changes to the electrical grid that will accommodate a mixed-fuel economy ^[19,20,21]

However, several initiatives are being proposed to mitigate these distribution problems. First and foremost, the most effective way to reduce USA's CO₂ emissions and slow global warming is through conservation efforts. Opponents of

the current US electrical grid have also advocated for decentralizing the grid. This system would increase efficiency by reducing the amount of energy lost in transmission. It would also be economically viable as it would reduce the amount of power lines that will need to be constructed in the future to keep up with demand. Merging heat and power in this system would create added benefits and help to increase its efficiency by up to 80-90%. This is a significant increase from the current fossil fuel plants which only have an efficiency of 34%^[29].

A more recent concept for improving our electrical grid is to beam microwaves from Earth-orbiting satellites or the moon to directly when and where there is demand. The power would be generated from solar energy captured on the lunar surface. In this system, the receivers would be "broad, translucent tent-like structures that would receive microwaves and convert them to electricity". NASA said in 2000 that the technology was worth pursuing but it is still too soon to say if the technology will be cost-effective^[30].

IV. RESULTS

In countries where suppliers are legally obliged to purchase a proportion of their electricity from renewable sources (for example under the Renewables Obligation in the United Kingdom), there is a danger that energy suppliers may sell such green electricity under a premium "green energy" tariff, rather than sourcing additional green electricity supplies.^[31] Where a Renewable Energy Certificate or similar scheme is in operation it is also possible for the energy supplier to sell the green electricity to the consumer, and also sell the certificate to another supplier who has failed to meet their quota, rather than "retiring" the certificate from the marketplace. In other cases green energy tariffs may involve carbon offsetting rather than purchasing or investing in renewable energy[22,23,24]

Certification schemes to minimise these and similar questionable practices are in place or are being developed in a few countries.^[34]

The World Wide Fund for Nature and several green electricity labelling organizations have created the Eugene Green Energy Standard under which the national green electricity certification schemes can be accredited to ensure that the purchase of green energy leads to the provision of additional new green energy resources.^[35] The market for heating is mostly serviced by gas and oil rather than electric power, due to the high cost per kilowatt of electricity in many countries. Distribution of renewable electric power via the electrical grid has made it possible in many countries for consumers to choose renewable electric power, and in the same manner bio-natural gas may in the future be made available to the average consumer via the existing natural gas grid.^{[36][37]}

Those not satisfied with the third-party grid approach to green energy via the power grid can install their own locally-based renewable energy system. Renewable energy electrical systems from solar to wind to even local hydro-power in some cases, are some of the many types of renewable energy systems available locally. Additionally, for those interested in heating and cooling their dwelling via renewable energy, geothermal heat pump systems that tap the constant temperature of the earth, which is around 7 to 15 degrees Celsius a few feet underground, are an option and save money over conventional natural gas and petroleum-fueled heat approaches.[25,26,27]

The advantage of this approach in the United States is that many states offer incentives to offset the cost of installation of a renewable energy system. In California, Massachusetts and several other U.S. states, a new approach to community energy supply called [Community Choice Aggregation] has provided communities with the means to solicit a competitive electricity supplier and use municipal revenue bonds to finance development of local green energy resources. Individuals are usually assured that the electricity they are using is actually produced from a green energy source that they control. Once the system is paid for, the owner of a renewable energy system will be producing their own renewable electricity for essentially no cost and can sell the excess to the local utility at a profit.

V. CONCLUSION

European Union

Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market^[38] includes the article 5 (Guarantee of origin of electricity from high-efficiency cogeneration).

United Kingdom

France

Over 75% of french electricity comes from nuclear power plants.^{[40] [41]} France is the largest net exporter of electricity in the world.^[40] Electricity exports generate over 3 billion euros of revenue a year for France.^[40] French electricity costs are among the lowest in Europe.^[40] A major factor in the low cost of electricity in France is the use of a single reactor design, which allows for economies of scale.^[41] French CO₂ emissions are among the lowest in the developed world,

with 10 tons of CO₂ equivalents per person per year.^[42] Danish citizens emit an average of 14 tons of CO₂ equivalents per person per year.^[43] Even Iceland, with its abundance of geothermal energy for heating, has higher per Capita emissions at 10.4 tons of CO₂ equivalents per Capita.^[44]

Spain

In Spain green energy is regulated by the Orden ITC/1522/2007.^[45]

Portugal

José Sócrates, the Portuguese Prime-minister said that Portugal is to become one of the largest producers and users of this type of energy in Europe by 2010, and that Portugal has a great potential to produce solar, water, waves, geothermic and wind energies.

United States

The United States Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Center for Resource Solutions (CRS)^[46] recognizes the voluntary purchase of electricity from renewable energy sources (also called renewable electricity or green electricity) as green power.

DOE selected six companies for its 2007 Green Power Supplier Awards, including Constellation NewEnergy; 3Degrees; Sterling Planet; SunEdison; Pacific Power and Rocky Mountain Power; and Silicon Valley Power. The combined green power provided by those six winners equals more than 5 billion kilowatt-hours per year, which is enough to power nearly 465,000 average U.S. households.

The EPA recognized the West Division of Macy's Inc., The Timberland Company, and the City of Chico, California, for their on-site generation of solar power, and also recognized New York University and six companies for purchasing green power. The EPA also named the city of Bellingham, Washington, and six more companies as their Green Power Partners of the Year. Among all the companies, PepsiCo stands out as a partner of the year, because three of its bottling companies were also honored for buying green power. In addition, CRS awarded its Market Development Awards to the Western Washington Green Power Campaign, Clif Bar, and two individuals: John Schaeffer and Bill Spratley.

Throughout the country, more than half of all U.S. electricity customers now have an option to purchase some type of green power product from a retail electricity provider. Roughly one-quarter of the nation's utilities offer green power programs to customers, and voluntary retail sales of renewable energy in the United States totaled more than 12 billion kilowatt-hours in 2006, a 40% increase over the previous year.^[27]

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