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Hydrogen Futures:Toward a Sustainable Energy System

By: Seth Dunn

Citation: Seth Dunn, *Hydrogen Futures: Toward a Sustainable Energy System* (Worldwatch Institute, 2001).

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Relevant Legal and Academic Areas: Technology; Law; Literature

Summary: Dunn introduces the ongoing efforts of different nations to use hydrogen to reduce their dependence on petroleum import. He reasons nations' renewed interests in hydrogen are mainly due to the advent of technological advances as well as the resolution for the environmental risk posed by current dependence on the petroleum use.

Chapter 1: Introduction

Dunn opens the introduction with the depiction of ongoing efforts by different nations to reduce their dependence on oil. For instance, the congress of the State of Hawaii had established a legislative committee to reduce Hawaii's dependence on oil, which accounts for 88 percent of its energy and is mainly imported from Asia and Alaska.[786] Meanwhile, the leaders Vanuatu nation, a small South Pacific island, had similar vision. Recognizing that the nation has abundant geothermal and solar energy, which can be used to make hydrogen, Vanuatu sought to to conduct a feasibility study

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[786] Seth Dunn, Hydrogen Futures: Toward a Sustainable Energy System 5 (Worldwatch Institute, 2001).

for developing a hydrogen-based renewable energy economy to build a nation that is totally independent of petroleum import.[787] Moreover, Iceland, which heavily depended on oil imports, announced its intention to become the world's first hydrogen society as early as 1993.[788] With successful completion of its bold project, Iceland hopes to become a "Kuwait of the North," exporting hydrogen to Europe and other countries.[789]

Dunn gives out the first explanation for nations' renewed interest in building hydrogen-run economy as the technological advances and the advent of greater competition in the energy industry.[790] In addition, the increased interest in hydrogen stems as the counter measures to the issues of energy security, air pollution, and climate change.[791]

Dunn sees that the transition to hydrogen will not only bring enormous commercial implication but also the geopolitical implication. As the use of coal enabled the rise of Great Britain in the eighteenth century and the use of oil laid the foundation for the United States' economic prosperity in the twentieth century, Dunn argues that the countries harnessing "hydrogen as aggressively as the United States tapped the oil a century ago" will eventually seize the tomorrow's "prize."[792] He adds that "easy access to the plentiful hydrogen could . . . possibly transform today's importers into tomorrow's exporters."[793]

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787 Dunn, *supra* note 2
788 *Id*. at 6.
789 *Id*.
790 *Id*. at 7.
791 *Id*.
792 Dunn, *supra* note 2, at 8
793 *Id*.

Despite these potential benefits, hydrogen has not yet emerged into the surface because of the energy policies of governments and businesses; for instance, U.S. energy policy still maintains its emphasis on expanding fossil fuel production with annual subsidies to traditional energy sources amounting to $300 billion.[794] Dunn adds that "people are largely misguided with the false belief that building hydrogen infrastructure would incur cost of hundreds of billions of dollars to build, far more than a system based on traditional energy source," and such misconception caused the industry to continue to invest in deriving hydrogen from petroleum-based energy source.[795] He argues such incremental path taken by the government and the industry- to increasingly relying on the dirtier, less secure fossil fuels as a bridge to the new energy system— represents a wrong turn financially and environmentally.[796] He concludes the chapter with the emphasis on government role: that government role is essential to pave the road to hydrogen transition.[797] Without drastic shift in energy and environmental policies, the hydrogen economy is unlikely to emerge in the near future.[798]

Chapter 2: Gases Rising

Review of historical transition of energy system experienced from 1800s and his forecast of evolution of future energy system.

Dunn introduces the chapter with the careful review of energy history. The world shifted from the reliance on wood to liquids to gas fuels throughout the past last several

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794 Dunn, *supra* note 2, at 8.
795 *Id*. at 11.
796 *Id*.
797 *Id*.
798 *I* Dunn, *supra* note 2, at 12

centuries.[799] By 1900 the advantages of an energy system based on fluids, rather than solids, began to emerge. This shift created problems and opportunities: for coal, with its weight and volume, and for oil, with a higher energy density and an ability to flow.[800] But nowadays, the liquid faces another competitor—a gas. While the distribution of oil is cumbersome and is unevenly clustered throughout the globe, natural gas is extensive that for oil and can be efficiently distributed through a network of pipes.[801]

Dunn introduces the chemical transition called "decarbonization."[802] As the mankind moved towards more sophisticated energy source, the number of hydrogen molecule in relation to carbon has increased successively.[803] For instance, from wood to coal to oil to natural gas, the ratio of hydrogen (H) to carbon (C) in the molecule of each successive source has increased.[804] The ratio is between 1 to 3 and 1 to 10 for wood; 1 to 2 for coal; 2 to 1 for oil; and 4 to 1 for natural gas.[805] Between 1860 and 1990, the H-C ratio rose sixfold.[806] Dunn concludes that a next logical fuel in such historical progression is hydrogen.[807]

Dunn argues that the pace at which hydrogen will emerge depends on the growing energy needs, local pressures on conventional resources, and the continuing quest for more available fuels.[808] He discusses that the factor that will most likely determine the pace in which the world is shifting towards hydrogen research is whether we will run out

799 *Id*.
800 Dunn, *supra* note 2, at 14
801 *Id.* at 15.
802 *Id*.
803 *Id*. at 14.
804 *Id*.
805 Dunn, *supra* note 2, at 15
806 *Id*.
807 *Id*.
808 *Id*. at 20-21.

of cheap, available oil.[809] The urban air pollution will be another important factor for the hydrogen transition. Dunn states that "particulate pollution contributes to 500,000 premature deaths annually." [810] In addition, hydrogen transition will be pushed by environmental issues, such as the risk of climate change.[811] He points out that the higher atmospheric levels of greenhouse gases contributes in raising global surface temperatures and the increased global surface temperatures brings about the unprecedented climate change in the form of a greater frequency of floods and droughts.[812] Yet the level at which climate is stabilized will depend on the investments made now.[813]

Chapter 3: Feedstock Today, Fuel Tomorrow

At present, approximately 400 billion cubic meters of hydrogen are produced worldwide each year, with about one fifth of this total coming from the United States.[814] The most common way to produce hydrogen at present is the process called the steam methane reforming.[815] It involves the heating of methane to derive the hydrogen atoms, releasing carbon dioxide as a byproduct.[816] According to U.S. National Renewable Energy Laboratory (NREL), catalytic steam reforming of natural gas yields great harm to the environment by emitting carbon dioxide as a byproduct. [817] Coal can also be reformed to produce hydrogen, through gasification but this process similarly releases

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[809] Dunn, *supra* note 2, at 20-21
[810] *Id*. at 22.
[811] Dunn, *supra* note 2, at 22.
[812] *Id*. at 25.
[813] Dunn, *supra* note 1, at 26.
[814] *Id*. at 28.
[815] *Id*.
[816] *Id*. at 29.
[817] *Id*. at 30.

carbon into the air.[818] Hydrogen can be extracted from a number of different conventional resources, such as oil, gasoline, and methanol through reforming process called oxidation but they all emit more carbon dioxide than steam methane reforming.[819]

The most promising long-term method of deriving hydrogen is electrolysis, which uses electricity to split water into hydrogen and oxygen atoms.[820] While this process is expensive due to its heavy use of the electricity, the electrolysis from renewable energy source, such as solar, geothermal and wind power may achieve a very clean hydrogen cycle.[821] It also represents a potentially "enormous source of hydrogen."[822] The electrolysis process from renewable energy would require significant increase in the rate of installing new plants, but if such becomes reality, it is projected that hydrogen-fueled vehicles nearly replace the U.S. car fleet run by petroleum by 2050.[823]

To become a major energy carrier, the technologies that store and transport the hydrogen also need to be developed. While there are a number of storage technologies that addresses such issue, the choice will largely depend on several different factors including amount to be stored, the forms of energy available, and other economic considerations.

Chapter 4: Engines of Change

The ultimate goal to the hydrogen energy system is to use and apply the hydrogen energy in internal combustion engines, conventional combustion turbines, and fuel

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818 Dunn, *supra* note 1, at 30.
819 Dunn, *supra* note 1, at 30-31.
820 *Id*. at 31.
821 *Id*. at 32.
822 *Id*.
823 *Id*. at 34.

cells.[824] There are different types of fuel cell, each named according to the electrolyte that is used in the system. Among them, the molten carbonate fuel cell (MCFC) is being pursued by several U.S. and Japanese companies, including Energy Fuel Cell and MC Power Corporation.[825] In addition, 40 companies, including Siemens and McDermott, are investing in developing the solid-oxide fuel cell(SOFC).[826] Another type of fuel cell, Alkaline fuel cell - the type used in the Apollo program, is being developed for commercial applications.[827]

The fuel cell that garners the most attention is the proton exchange membrane (PEM). This cell's membrane acts as an electrolyte through which protons pass, bonding with oxygen to form water and thus creating electrical current.[828] In one commercial experiment, PEM cells have experienced significant reductions in the cost of producing electrolytes.[829]

While the use of fuel cells appears to reduce local air pollutants, their production also has the environmental impacts. In fact, the platinum group metals (PGMs), which is used as catalyst, emit the greenhouse gas, sulfur, and nitrogen emissions.[830] However, industry experts point to different options to improve its ecological impacts of fuel cells.[831]

The introduction of hydrogen into car fleets also brings some technical, environmental, and economic challenges. Among them is the difficulty in integrating

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824 Dunn, *supra* note 1, at 39.
825 Dunn, *supra* note 2, at 41.
826 *Id*.
827 *Id*.
828 *Id*.
829 Dunn, *supra* note 2, at 41.
830 *Id*. at 42.
831 *Id*.

small, inexpensive, and efficient fuel cells into the vehicles.[832] Another challenge exists in developing an infrastructure for producing and delivering hydrogen.[833] This is the most significant and environmentally challenging issue in terms of transitioning into hydrogen energy system.[834]

Chapter 5: The Fuel Choice Question

As fuel cells face commercialization, transport and energy companies are debating over which type of vehicle to mass produce and over the type of fuel to provide through pipelines.[835] These options include onboard gasoline and methanol reformers, the direct onboard storage, and the use of compressed gaseous and liquid hydrogen.[836]

Each fuel has advantages and drawbacks. Methanol, for instance, is the easiest of the liquids to reform on board, but it raises health/safety issues, and the industry liability concerns, as it is a classified toxin.[837] Gasoline, on the other hand, is more difficult to reform than methanol because of the high temperatures needed for the reformation process.[838] However, it can be supported with existing infrastructures and is familiar to end-users.[839]

Dunn introduces "well-to-wheels" assessments that is used compare the ecological benefits that each different types of hydrogen fuel cell brings.[840] "Well-to-wheels" evaluations examine the environmental impacts associated with the use of a fuel

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832 *Id*. at 44.
833 Dunn, *supra* note 2, at 44.
834 *Id*.
835 *Id*. at 45.
836 *Id*.
837 Dunn, *supra* note 2, at 46.
838 *Id*. at 46-47.
839 *Id*. at 47.
840 *Id*.

through each stage, from production to delivery to use.[841] While different trade groups each came out with results promoting their particular fuel, Dunn impliedly concludes that direct hydrogen using renewable energy source would best reduce both greenhouse gas emissions over other onboard reformers using gasoline or methanol.

Chapter 6*:* Greening the Infrastructure

The huge cost associated with building the hydrogen infrastructure has led experts to view the use of hydrogen for a vehicle as an impossible obstacle.[842] Dunn suggests, however, the opposite: that the direct use of hydrogen may in fact be achieved in least costly route.[843] Dunn introduces the number of studies conducted by various parties, including the ones by both industry and academics. Dunn shows that the studies conducted for Ford Motor Company which had shown that the gradual adoption of hydrogen vehicles, starting from methane reformers to serve the small fleets to mass production of direct hydrogen infrastructures.[844] He suggests that this way hydrogen vehicle could be used at a cost per mile that is "near, or even below," that of gasoline in a conventional vehicle.[845]

Dunn further suggests that there are no technical barriers to implementing a direct hydrogen infrastructure. [846] When environmental impact and the damage is considered, the direct hydrogen fuel cell vehicle emits the least environmental damage and the cost to

841 Dunn, *supra* note 2, at 47.
842 *Id*. at 54.
843 *Id*.
844 *Id*. at 55.
845 *Id*.
846 Dunn, *supra* note 1, at 55.

build the direct hydrogen infrastructure will be offset by the benefit gained by the society as the hydrogen-fueled vehicles grow, the author concludes.[847]

Chapter 7: Building the Hydrogen Economy

Dunn begins the chapter with shortcomings of private entities' efforts in financing the hydrogen transition. "Because the private bankers' need to provide a short-term rate of return", the private sector alone cannot finance the transition on their own, the author implies.[848] Dunn calls that the government should move toward a hydrogen economy. He argues that the starting point is to cut back on incentives for continued hydrocarbon production that will continue to frustrate efforts to introduce hydrogen fuels.[849] Dunn believes that artificially low fossil fuel prices will continue to delay the hydrogen transition.[850] In addition, governmental support for research and development are in need to promote innovations that have potential long-term benefit.[851]

Dunn also introduces the stronger political support in Germany which is the active leader in terms of hydrogen transition.[852] By contrast, he criticizes the United States government as lagging behind in terms of implementing hydrogen energy system. He views the United States government is still reluctant to resolve oil import dependence, and has taken an uncertain political stance toward climate change.[853] With respect to businesses in private sector, he believes that oil companies should reposition themselves as energy firms by articulating the initiatives and strategies shown by BP and Shell.

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[847] Dunn, *supra* note 1, at 57.
[848] *Id*. at 63.
[849] *Id*.
[850] *Id*. at 64.
[851] Dunn, *supra* note 1, at 66.
[852] *Id*. at 65
[853] Dunn, *supra* note 2, at 74.

Dunn acknowledges that geopolitics of energy will be affected in unpredictable ways as choices and decisions from a number of nations as well as private entities will shape the transition into hydrogen energy system. Henceforth, he calls that there exist "greatest educational need" to engage the public in making appropriate decisions regarding hydrogen infrastructure.[854] He believes such is "the vital process of introducing a new technology and it is an era in which cooperation is essential."[855] Dunn ends the chapter by stating that while there may exist risks and costs involved in introducing a hydrogen economy, they are far less than that of traditional-carbon economy.[856]

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[854] *Id*.
[855] *Id*. at 75.
[856] *Id*.