ENHANCING STRATEGIC MANAGEMENT OF THE HYDROGEN OPTION: SCENARIO PLANNING BY THE DOE HYDROGEN TECHNICAL ADVISORY PANEL

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Abstract

The Secretary of Energy's Hydrogen Technical Advisory Panel (HTAP) conducted two scenario planning workshops. At the first workshop, participants derived preliminary "storylines" that identified and structured the key driving forces and uncertainties from which focused scenarios of hydrogen energy futures can be developed. According to the participants, the key driving forces that will determine the role of hydrogen in plausible energy futures are hydrogen technology development and the interplay between market forces and social concerns. The key uncertainties that will determine how these driving forces play out are the nature and rate of hydrogen technology development and how social concerns about, for example, environmental quality and energy security, affect competitive market forces that determine fuel choice and commercial success of advanced technologies. At the second workshop, participants were asked to build on these storylines by providing more details and exploring implications for hydrogen energy in each quadrant. The Committee has synthesized the insights obtained from the two workshops and prepared more detailed, focused scenarios for hydrogen energy futures that are guided by the HTAP vision. After revision, the scenarios will be adopted by the HTAP and transmitted to DOE. The HTAP will assist DOE in planning and conducting a strategic response workshop in the late summer of 2001 to examine the DOE Hydrogen Program's RD&D portfolio in the context of the HTAP scenarios. The purpose of this workshop will be to draw out more fully the R&D implications of the scenarios and to develop recommendations to the DOE on a strategic context and priorities for its hydrogen RD&D portfolio.

Introduction

In 1992, Congress established the Hydrogen Technical Advisory Panel (HTAP) to advise the Secretary of Energy on the implementation and conduct of the Department of Energy (DOE) Hydrogen Program. The HTAP advises the Secretary on investment strategy and priorities for the research, development, and demonstration (RD&D) of advanced hydrogen energy technologies and on the economic, technical, and environmental consequences of deploying hydrogen energy systems. The Hydrogen Future Act of 1996 further required that the HTAP analyze the effectiveness of the DOE Hydrogen Program and make recommendations to improve the Program for inclusion in a report to Congress by the Secretary. One of the HTAP's recommendations was that the Program conduct scenario planning and analysis to help develop a rationale for a robust, long-term RD&D program. Such a rationale would help to link the HTAP's long-term vision with specific RD&D projects funded by the Program. Scenario planning is a tool that can help the DOE establish a long-term strategic context for its year-to-year investments in hydrogen RD&D. Scenario planning will also help the HTAP articulate a compelling perception of a hydrogen energy future for government leaders and the public.

In 1999, the HTAP established a Scenario Planning Committee to help guide scenario planning and analysis activities conducted by the Hydrogen Program. The Committee is guided by the HTAP's long-term vision for a hydrogen energy future stated below.

Hydrogen will join electricity in the 21st century as a primary energy carrier in the nation's sustainable energy future. Both electricity and hydrogen will ultimately be derived from renewable energy sources, although fossil fuels may serve as a transitional resource. Future hydrogen suppliers will meet a significant portion of America's energy needs for transportation and other applications, thus offering a non-polluting, inexhaustible, efficient, and potentially cost-effective energy system dependent entirely on domestic energy resources.(HTAP 1995)

Scenario Planning Workshops

Workshop 1

At the first HTAP scenario planning workshop, participants derived preliminary "storylines" that identified and structured the key driving forces and uncertainties from which focused scenarios of hydrogen energy futures can be developed. According to the participants, the key driving forces that will determine the role of hydrogen in plausible energy futures are hydrogen technology development and the interplay between market forces and social concerns. The key uncertainties that will determine how these driving forces play out are the nature and rate of hydrogen technology development and how social concerns about, for example, environmental quality and energy security, affect competitive market forces that determine fuel choice and commercial success of advanced technologies. These driving forces and uncertainties were distilled into two "axes" that could be used to create "quadrants" of potential futures that provide labels ("New War, Old Weapons, etc.) and beginning points for storylines as shown in Figure 1.

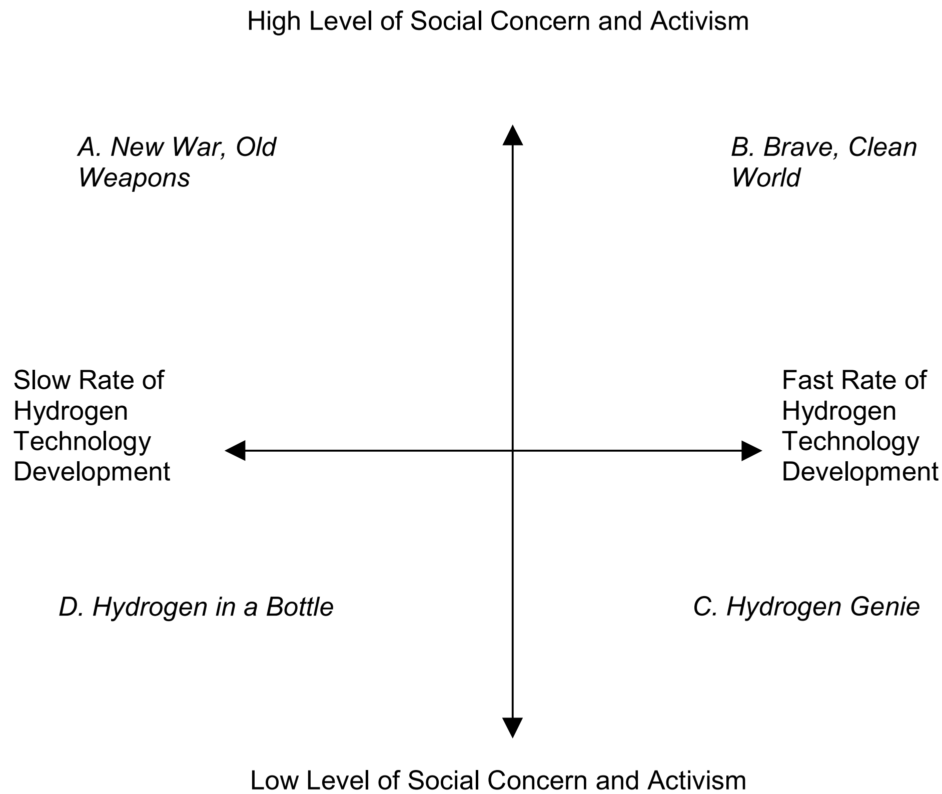


Figure 1. Storylines and Quadrants

Workshop 2

At the second workshop, participants were asked to build on these storylines by providing more details and exploring implications for hydrogen energy in each quadrant. In Workshop 2, four breakout sessions were conducted to draw the social, political, economic, and environmental details needed to prepare "end-state scenarios" for each of the quadrants. In the each of the breakout sessions, participants were asked to address three topics listed below.

- Determine the starting point, or where we are today, in terms of the level of social concern and activism and the rate of hydrogen energy technology development.
- Describe the "end-state" of each quadrant implied by the convergence of key driving forces and uncertainties.
- Decide whether the HTAP vision could be attained in the quadrant being addressed. In other words, is there an end-state in the quadrant that incorporates the HTAP vision?

Starting Point

There was near unanimity among the participants of Workshop 2 that the starting point, or current status, lies somewhere in Quadrant D. Some participants from California, which has established the strictest air quality regulations in the nation and zero-emission vehicle mandates, however, felt that the starting point is more accurately located in Quadrant B. Others felt that even though we are starting from Quadrant D, significant progress has been made in both the rate of hydrogen technology R&D and in the level of social activism and concern over the past five years. Movement from the lower left corner of Quadrant D to the current starting point in the middle of Quadrant D can be an indicator of this progress. In the discussion below on trajectory-based scenarios, the starting point is indicated by “P” in both Figures 2 and 3.

End-state Scenarios

New War, Old Weapons (Quadrant A)

In Quadrant A (Figure 1), the left end of the x-axis implies a negative rate of technology development, where capability is lost through attrition and disrepair of equipment because technology development is not supported financially. The right end of the x-axis implies a level of effort comparable to the Manhattan Project. The bottom of the y-axis indicates a level of social concern where most people don’t know that there is a problem and, if there were one, would not care enough to solve it. The top of the y-axis indicates a high level of social concern, where people are motivated to buy clean energy and support tax incentives for hydrogen systems.

Some of the key characteristics of the end-state in Quadrant A are listed below.

- Pure hydrogen from fossil fuels, with sequestration, plus some renewables, ICE (heat engines) and fuel cells
- On-board reforming of fossil fuels
- Hybrid transportation and residential CHP (perhaps offering higher system efficiency and thus lower greenhouse gas emissions)
- Hydrogen enrichment of fossil fuels for stationary applications
- Extension of DOE Office of Fossil Energy’s Vision 21: decarbonization of fossil fuels with shift plus CO_2 sequestration and hydrogen utilization leading to production of large volumes of hydrogen that can drive high levels of utilization
- Ground-support vehicles at airports and other fleet vehicles and government vehicles fueled by hydrogen (local air quality is the driver)
- Direct-hydrogen fuel cell vehicles
- Local air quality issues leading to use of compressed natural gas (CNG) as a bridge to hydrogen with final push being reduction of emissions of greenhouse gases

Brave, Clean World (Quadrant B)

The end-state in Quadrant B is characterized by a high degree of social activism, as well as a fast rate of technology development and implementation. Such a society is accustomed to affluence, characterized by 4 to 5 percent annual GNP growth and places a high value on health and food, including acceptance of what is perceived to be superior, genetically modified food sources. Members of this society live longer, with lifespans of 100-105 years, and believe in a balanced lifestyle with telecommuting as a cornerstone. This society adopts concepts of reduction, reuse, recycle, conservation, and dematerialization to minimize consumption of material and energy resources.

The end-state in Quadrant B implies a high level of energy security, including self-contained energy systems with a fuel cell power station in each home; passive solar, hydrogen generated by renewable energy; nuclear, fossil, and fusion power; limited supplies of oil and gas; and methane hydrates as a hydrogen source. Significant advances in nanotube hydrogen storage have taken place. In this Quadrant, the transportation sector enjoys moderate growth, with the emphasis remaining on individual transportation. Each home enjoys a hydrogen-fueled car without compromised drivability. Hydrogen-fueled commercial aviation is the norm. Hydrogen is also used in public transportation, including buses and trains.

In this Quadrant, society has a high level of confidence in its ability to control outcomes. The necessary drivers to reach this end-state include:

- regulatory drivers to protect the public health, such as strict air quality regulations;
- a carbon driver to control climate change, such as a carbon tax or carbon trading mechanism;
- strong economic drivers, including private incentives and public funding to accelerate the R&D cycle;
- public demand and acceptance of new technologies;
- resource availability to enable technological advancement; and
- hydrogen infrastructure readiness.

The HTAP vision can be realized in this Quadrant after a period of adjustment. Short of a monumental technological breakthrough to push the hydrogen economy forward, or the impact of a major energy security crisis, the HTAP vision will be achieved in this Quadrant through the use of regulatory drivers, economic incentives, and public funding targeted at supporting scientific research and developing resource availability. After the HTAP vision is achieved, it could be supported indefinitely in this Quadrant because society would not want to move backwards. A high level of social activism and technological growth will continue even if a rapid rate of technological advances are no longer crucial.

Hydrogen Genie (Quadrant C)

In Quadrant C, the level of social activism and concern is quite low, primarily due to lack of public awareness about hydrogen energy systems. The rate of hydrogen energy technology development, however, is rapid and comparable to the pace of innovation and technological progress in other high-tech industries.

Examples of key parameters that indicate the present status of hydrogen energy and how the "values" of these parameters would change by 2050 given the conditions of Quadrant C are listed in Table 1.

The Hydrogen Genie storyline implies an end-state defined not only by a rapid rate of hydrogen technology development but also by rapid penetration of these technologies into commercial energy markets. Of the four storylines, this storyline is most obviously consonant with the HTAP vision as presently stated. In other words, the "then" values for the parameters in Table 1 help define details of the HTAP vision.

Table 1. Present Status of and Outlook for Key Parameters

Parameter	Now	Then (2050)
Hydrogen Storage	2-5 wt% (mostly in buses)	10 wt% (light-duty vehicles)
Hydrogen Cost	3-10x per energy equivalent of petroleum-based fuels	no more than petroleum-based fuels (w/o taxes)
Hydrogen Safety	good industrial perception, perceived as issue, no codes/standards for retail/public use	non-issue
H_2 Fueling Infrastructure	H_2 stations: 3 (US), 1 (Canada), 2 (Germany), ? (Iceland)	100% of service stations have multiple fuel options, incl. H_2 container swapping
H_2 fueled mobility	about zero	universal
Propulsion	ICEs on petroleum-based fuels	diverse prime movers on H_2, universal regen braking
Electrification	US: 10% renewable	global: 100% renewable
Excise taxes	none on hydrogen	none on non-petroleum-based fuels

Hydrogen in a Bottle (Quadrant D)

The end-state in Quadrant D includes hydrogen as a commodity product, not as an energy carrier. Advances in competing technologies for energy storage (batteries, ultra-capacitors, etc.) are likely to limit the widespread introduction of hydrogen. Alternative fossil fuel sources (methane hydrates, advanced coal, and oil shale), stable prices, and breakthroughs in CO_2 recovery and disposal provide stiff competition for hydrogen technologies. Energy remains cheap, accessible, and convenient. Other ways to address climate change and other environmental issues are developed, obviating the need for hydrogen. The 2050 end-state is further described in three categories, Technology, Market, and Policy, in Table 2.

The HTAP vision could be met, in principle, within Quadrant D. A "functional equivalent" of the HTAP vision that relies on technological and market development trends that will likely continue within the constraints implicit in Quadrant D is possible. The HTAP vision would need to be modified so that the third sentence would read "…future hydrogen suppliers will meet a portion of America's energy needs for transportation and other applications, thus supporting a non-polluting, inexhaustible, efficient, and potentially cost-effective energy system dependent entirely on domestic energy sources." The HTAP vision would also need to be modified with the proviso that the transition from natural gas-based systems to renewable-based systems would be in the second half of the 21st century.

Table 2. End-state Characteristics for Quadrant D

Technology	Market	Policy
Light-weight materials	Natural gas and syngas remain relatively cheap	Strong military
Higher efficiency of conversion technologies	Residential/micro generation for CHP + Fuel (NG-fired)	Increased appreciation for global climate change but not a major policy driver
Material limitations on hydrogen storage	Stable energy price/supply	Much more stringent efficiency requirements for appliances, buildings
Modest improvements in hydrogen technologies	Electric vehicles meet performance, efficiency, and convenience targets (independent of storage system)	Policy for incentives rather than regulation
Hydrogen Program goals have been met	Communities convert to CNG/alternative fuels (based on incentives)	Policy to convert to ultra-clean fuels (but how clean is clean enough?)
Production/delivery/availability of hydrogen much improved	Airports convert to LNG (aircraft and support vehicles)	Sunk investments are protected
Advances in gas-to-liquids technologies	LNG infrastructure as bridge to future hydrogen infrastructure	Resistance to, or inertia against, change
Major increase in public/mass transit and use of electromotive drive	Slow turnover of assets	
Electric hybrids	Hydrogen niches: transit buses, portable electric devices, some fleets, localized infrastructure	

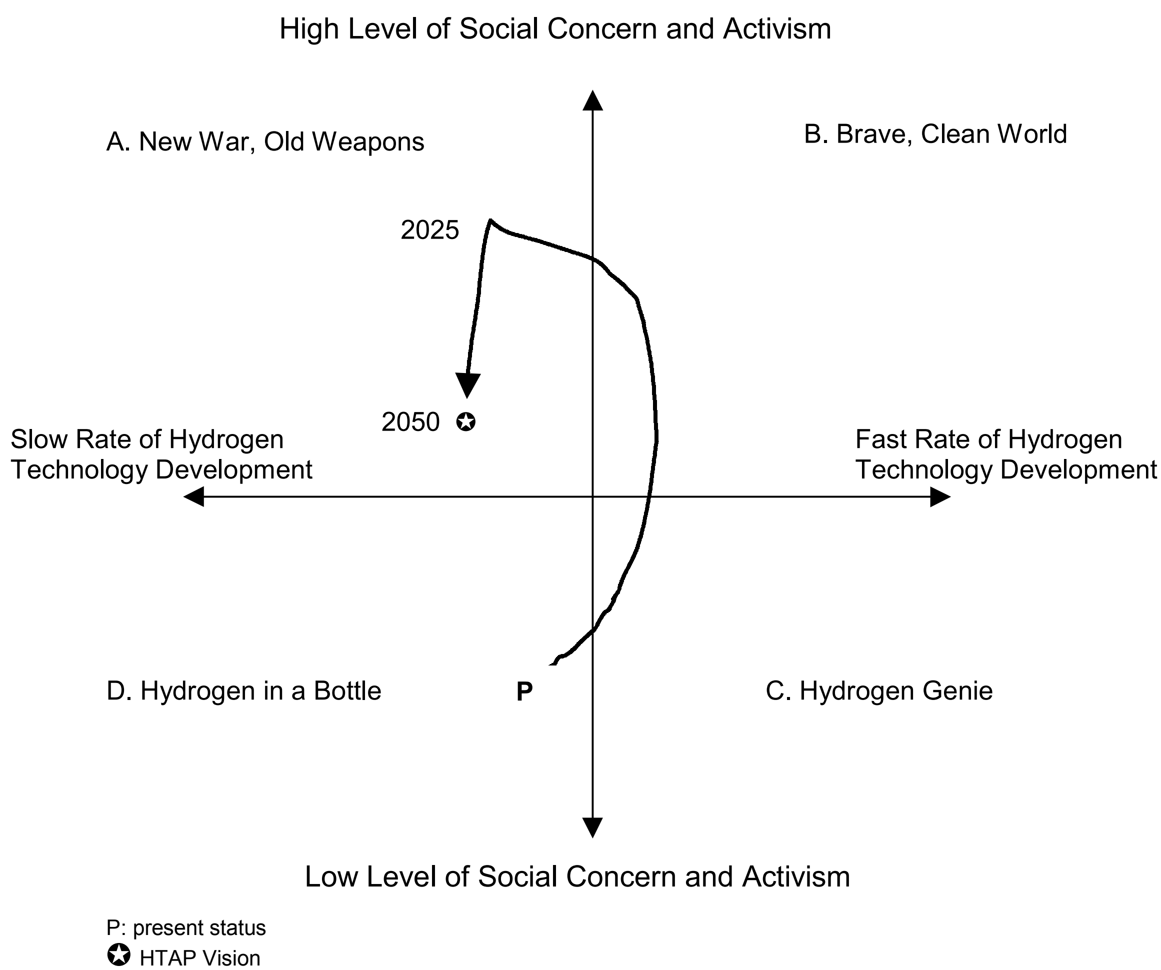
Trajectory-based Scenarios

The future, of course, will not unfold according to one storyline and to the exclusion of the others but will in all probability wind and twist its way through all four (and other) storylines. In a second set of breakout sessions, participants in Workshop 2 also examined “trajectories” that involve more than one quadrant and that can lead to a dynamic set of scenarios that cross and weave among the four quadrants. The key question here is whether there is an end-state that is most compatible with the HTAP vision and, if so, what are the most likely trajectories to reach that end-state from the starting points determined earlier. In discussing trajectories, the participants were asked to consider what might happen, or is likely to happen, as well as what one would like to have happen by applying policies involving incentives, mandates, and RD&D. Because of the focus on policies that can help influence movement from the present to future end-states, trajectory-based scenarios may be particularly relevant and of interest to public sector decision-makers. Three examples of trajectory-based scenarios are described briefly below.

New War, Old Weapons (Quadrant A)

The trajectory is shown in the Figure 2. It begins in Quadrant D and uses a combination of increased social awareness and increased hydrogen technology research. As social concern increases to the point where interest in clean energy and enactment of tax incentives drive greater use of hydrogen, a moderate rate of technological development is maintained. Before about 2025, consumer demand increases rapidly such that a lower rate of technological development is sufficient enough to increase hydrogen usage. Then, between 2025 and 2050, concern about the environment lessens as hydrogen reduces the environmental impact of energy production, conversion, and consumption. Additionally, because hydrogen systems are mass-produced, costs are lowered and tax incentives can be phased out. Note, however, that because technological development is slow and old weapons are assumed in this quadrant, today's technologies are adapted for hydrogen use, reducing the extent of the positive impact that hydrogen can make.

Figure 2. Trajectory-based Scenario for Quadrant A

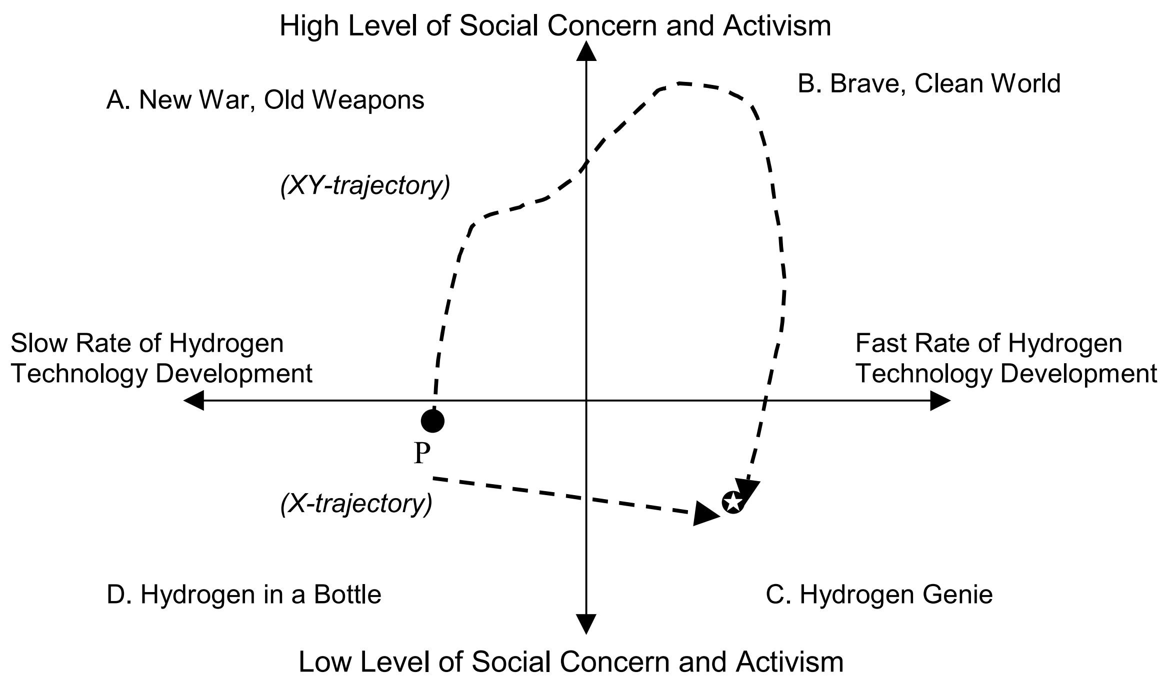


Hydrogen Genie (Quadrant C)

Since there appear to be an infinite number of trajectories to move from the starting point in Quadrant D to an end-state in Quadrant C, the boundaries of the set of possible trajectories should be defined first. These boundaries can be defined by a right angle from the starting point shown in Figure 3. A trajectory parallel to the y-axis (Trajectory Y) would be defined completely by the level of social activism and concern while a trajectory parallel to the x-axis (Trajectory X) would be defined completely by the rate of hydrogen technology development. Trajectories lying between these extreme trajectories (XY trajectories) would be defined by a blend of the two key driving forces.

Strategies based on Trajectory X to reach an end-state defined by the HTAP vision requires an R&D program with a laser-like focus that would hit "home-runs" on all critical R&D needs. Such a pure R&D path to the HTAP vision requires the responsibility to "pick winners," a role federal R&D programs have traditionally eschewed. This trajectory could also be reinforced by hydrogen R&D programs of other countries, particularly in Europe and Asia. For example, Iceland's effort to become the world's first "zero-emission country" could focus and accelerate the federal hydrogen R&D program in the U.S. by emphasizing hydrogen production based on renewable energy resources and the linking of all energy end-use sectors through hydrogen storage and utilization. Trajectory X also requires rapid commercialization of hydrogen technologies. Industry would have to "score" big on R&D home runs "hit" by researchers in national labs, universities, and in the private sector. Some "spill-over" of venture capital pursuing fuel cells investments may be possible for an emerging hydrogen energy market sector. A focused federal hydrogen R&D program could include educating the financial investment community about potential payoffs in an accelerated transition to a hydrogen economy.

Figure 3. Trajectory-based Scenarios for Quadrant C



Strategies based on Trajectory Y to achieve the HTAP vision require long-term national leadership comparable to those asserted by the Eisenhower administration in building the interstate highway system and by the Kennedy-Johnson administration in successfully completing the man-on-the-moon mission. Achieving the HTAP vision would require no less in public leadership at the highest level of the federal government. Realizing the HTAP vision is tantamount to achieving a sustainable energy future, and its realization would have even more impact on the nation and on the world than either of the two examples above has had. As Lester Brown states, “Put simply, the principles of ecological sustainability now require a shift from a carbon-based to a hydrogen-based energy economy”(Brown 2000). With the Cold War ending at the end of the 20th century, a “Green War” is needed to attain a sustainable energy future based on hydrogen and the HTAP vision. A pact between Germany and Japan to launch a political and technological war on CO_2 could help launch a world war on climate change.

Several measures to propel the nation along Trajectory Y are possible. A government-industry consortium, perhaps a Partnership for the Next Generation of Energy (PNGE), may be needed to stimulate and structure public and private sector interest in achieving a hydrogen-based energy economy. Investment credits for business and the R&D community, preferential purchasing incentives, including flexible fleet vehicle purchasing options for the Clean Cities Program, and an excise tax exemption for hydrogen fuel are examples of other Trajectory Y measures.

Both Trajectory X and Trajectory Y are “pure paths” that rely exclusively on accelerating R&D and increasing public activism, respectively. As such, neither is likely to succeed without the other. For example, it will be very difficult to accelerate R&D to the degree required by Trajectory X without heightened public support. Likewise, strong long-term leadership to achieve the vision would be difficult to sustain without significant R&D progress and technology commercialization. Strategies based on XY trajectories that blend policies (mandates and incentives) and targeted R&D investments may be more realistic than those based on X or Y trajectories. These strategies are shown (without priorities implied) in Table 3 as either incentives (Y-type) or R&D needs (X-type), although it is understood that neither type can stand alone and effect rapid movement from Quadrant D to Quadrant C.

Hydrogen in a Bottle (Quadrant D)

With both a low rate of change in hydrogen technology development and a low level of social concern that prevents adoption of policies that would accelerate deployment of hydrogen technologies, Quadrant D scenarios become, more or less, “default” scenarios for hydrogen energy futures. In other words, these scenarios will embody what may happen given the absence of driving forces for hydrogen energy futures. However, the HTAP vision (with some modifications) could be attained in Quadrant D, and robust and flexible scenarios that incorporate most of the HTAP vision are conceivable.

Table 3. Strategies for XY Trajectories

Incentives	R&D Needs
investment tax credits for H_2 fueling stations and H_2 vehicles	cost reduction through manufacturability and efficiency of production
agricultural incentives to produce H_2 feedstocks	use of lower-cost, readily available materials; minimize use of scarce resources
develop, promulgate, and adopt codes and standards for H_2 use	better sensors
protection and enhancement of public health could lead to stricter mandates on fuels and propulsion devices—incentives would be more effective	increase fuel cell energy density, improve reliability of PEM fuel cells, improve fuel system controls (refueling, pressure control, start-up)
lurking “gasoline liability” issue akin to tobacco liability suits?	high-temperature electrolysis, stationary reformers incorporating C-sequestration
	H_2 adsorbent systems
	exploit potential H_2 sources like sewage/solid wastes

The trajectories of these scenarios rely on incremental movement toward hydrogen-based energy futures implicit in current technology development programs and trends, such as those listed below.

- The U.S. space program (NASA) provides a baseline for any hydrogen technology development and deployment path.
- Industry provides a driving force for going beyond the baseline.
- Hydride storage systems and small fuel cells will evolve over the next 50 years.
- Convergence in telecommunications and consumer products markets will provide a base for technology development, mass production, and worldwide exposure of new products.
- Learning curves of manufacturers of small fuel cells will lead to larger fuel cell products.
- Hydrogen-fueled buses will lead to hydrogen cars and fleets of hydrogen vehicles.
- Hybrid vehicles, using fuel cells or internal combustion engines, are options that will be fully explored in commercial markets.
- The cost of fuel cells will be a critical success factor.
- The DOE will develop a hydrogen technology development strategy that leverages other technology development.

These and other factors will provide incremental, stepped trajectories toward the HTAP vision. Attainment of the vision will be almost completely contingent on events and initiatives outside of the DOE Hydrogen Program, especially the commercial success of fuel cell technologies.

Conclusion

The two workshops provided valuable insights and guidance for the HTAP scenario planning and analysis process. The HTAP Scenario Planning Committee will synthesize the insights obtained from the two workshops and prepare more detailed, focused scenarios for hydrogen energy futures that are guided by the HTAP vision. For example, the scenarios could be based on an elaboration of the four end-states and/or one or more trajectories to attain the HTAP vision.

After revision, the scenarios will be adopted by the HTAP and transmitted to DOE. The HTAP will assist DOE in planning and conducting a strategic response workshop in the late summer of 2001 to examine the DOE Hydrogen Program's RD&D portfolio in the context of the HTAP scenarios. The purpose of this workshop will be to draw out more fully the R&D implications of the scenarios and to develop recommendations to the DOE on a strategic context and priorities for its hydrogen RD&D portfolio.

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