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The US Hydrogen Roadmap 2030
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Sponsors: The U.S. Department of Energy
Type: A National Foresight initiative focusing on hydrogen production, delivery and applications
Organizer: The U.S. Department of Energy
Duration: 2002+ **Budget:** Not available **Time Horizon:** 2010-2030

Purpose

The U.S. Department of Energy or DOE began sponsoring the development of a national hydrogen energy roadmap process in March 2002. Since its initial workshop, the DOE has released three separate but related reports outlining a strategy to assist the US in a transition from a petroleum based economy to one relying on hydrogen as its principle energy supply.

A Comprehensive Energy Policy

The National Energy Policy – issued in May 2001 – was the initial effort by the new Bush administration to form a comprehensive energy policy. The energy policy covered virtually every aspect and all forms of conventional and advanced energy production and consumption. Its sweeping nature reflected inputs by stakeholders in each of these areas. With regard to the emergence of a hydrogen-based, as opposed to petroleum-based economy, however, the National Energy Policy helped redirect a group of somewhat unrelated, ongoing programs within DOE to place greater importance on hydrogen research in the context of a comprehensive energy policy. The energy policy stimulated formation of a National Hydrogen Energy Roadmap that laid out a more systematic approach to implementing and coordinating hydrogen research projects within the Department of Energy and across other parts of the U.S. government.

The Roadmap

Concurrent with the development and public release of the National Energy Policy, the Department of Energy sponsored multiple workshops to attract inputs into the formation of a national "vision" on hydrogen in 2001-2002.

The Department of Energy convened a series of panels under the direction of industry experts to identify challenges in achieving the hydrogen economy. Panels received inputs from industry and academic specialists, national laboratories and company officials currently engaged in hydrogen-related activities. The panels also benefited from modelling and analytical work performed at the national laboratories under the energy Department's direction. These included system-level tradeoff analyses and assessments of infrastructure requirements. Comprehensive workshops were held in November 2001 and April 2002 to finalize details of the Roadmap and its underlying Vision. These inputs were used to form the National Hydrogen Energy Roadmap, a programmatic framework for addressing each of the critical elements in achieving this vision, including production, delivery, storage, conversion and application.

Over time and in part reflecting earlier priorities, programs evolving from this framework have centred on transportation and stationary/portable power generation.

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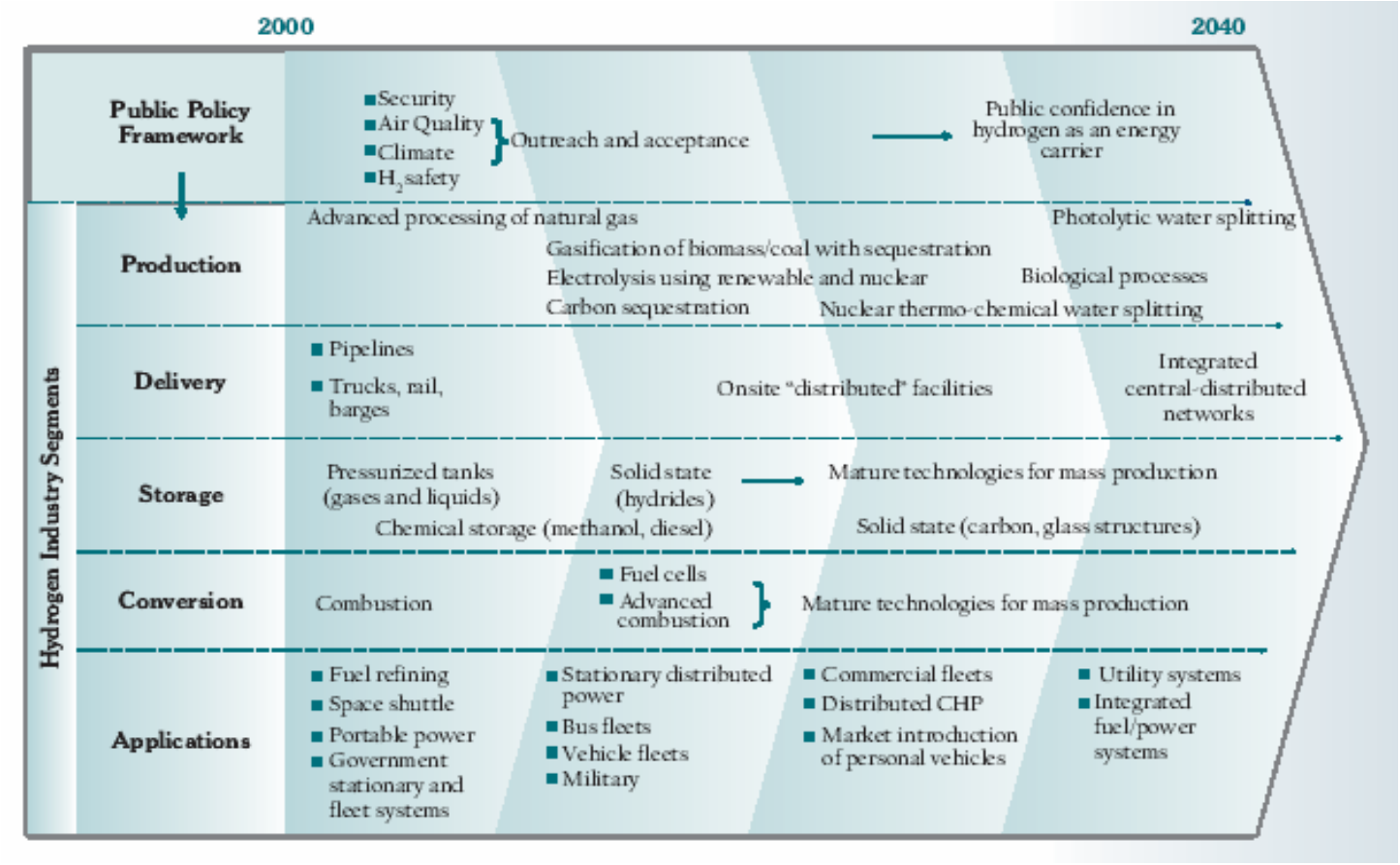

Figure: 40 year lead-times

Three Imperatives for the Hydrogen Economy

The Roadmap offered multiple observations and conclusions regarding the transition to a hydrogen economy. Three broad areas, however, stand out among them involving the scale of the task, the problem of achieving cost-effective production and the daunting problem of developing an infrastructure sufficient to deliver hydrogen to end users:

- **Technology development and system integration:** The roadmap counts heavily on government-industry partnerships to fulfil requirements. Hydrogen production today is limited to a few regions in the United States – mostly farm belt locations and coastal areas with high concentrations of oil refineries. Quantities reflect the currently specialized use of hydrogen in industrial production (although U.S. consumption reflects 20% of global hydrogen production today).
- **Lower costs and greater efficiency:** Because many anticipated production technologies remain immature, the Roadmap supports broad development efforts for both central-station and distributed hydrogen production. The Roadmap called on efforts to focus on improving existing commercial processes such as steam methane reformation, multi-fuel gasification and electrolysis. Next-generation production technologies include biological and nuclear- or solar-powered thermo-chemical water-splitting.
- **Challenges posed by the delivery of hydrogen:** Current delivery systems reflect hydrogen's localized production. Some 1,130 km of hydrogen pipelines exist across the United States today – a miniscule amount compared with over 290,000 km of natural gas pipelines currently in use. Construction of hydrogen pipelines using existing technology costs between $180,000 and $840,000 per kilometre – slightly more than twice the cost of natural gas pipeline construction.

Investing in the Value Chain

Bulk transportation, delivery and storage require capital investments in existing or near-term technologies, including hydrogen sensors, pipeline materials, compressors and high-pressure breakaway hoses. End-user delivery systems are more problematic due to immature market development, according to the Roadmap.

Producing the Earth's Most Abundant Element

Although hydrogen is the most abundant element on earth, it must be produced. Steam methane reforming currently accounts for 95 percent of the hydrogen produced in the United States. It is the most energy efficient means of producing hydrogen in large quantities for bulk, industrial use.

The Roadmap anticipates that conversion of hydrogen into useful forms of electric and thermal energy involves use of fuel cells, reciprocating engines, turbines, and process heaters. Identification of candidate manufacturing technologies is a high early priority in the Roadmap.

There are no delusions in the Roadmap concerning the timeframe required to achieve a conversion to a hydrogen-based economy, even though several objectives might be considered optimistic. The transition is expected to require fifty years or more. Current planning, research and development activities are aimed at laying the groundwork necessary to begin that transition in earnest during the 2010-2030 period. This timeframe was underscored in DOE's subsequent *Hydrogen Posture Plan: An Integrated Research, Development and Demonstration Plan* (February 2004).

These goals may still be ambitious, but are more realistic than earlier estimates. For example, the Partnership for a New Generation of Vehicles (PNGV) of the Clinton administration optimistically predicted PNGV prototype fuel cell vehicles to move into commercialization by 2005.

IMPACT

DOE Programs: Roadmap-Induced Discipline

The Hydrogen Roadmap has helped organized Energy Department programs under a coherent umbrella. The ambitious plans laid out in the Roadmap, however, have not been fully realized through federal funding. For example, total hydrogen and fuel cell R&D under the Energy Department's Office of Science has grown from just $92.0 million in FY 2003 to $159.5 in FY 2005.

Rapid Growth but a Small Base

The growth rate is significant, but after allocating funds among the many and varied projects comprising the Roadmap, individual efforts experience diluted funding. Furthermore, for the last three years, budgets approved by Congress consistently have been roughly half the amounts requested by DOE agencies involved in hydrogen research programs. This is further complicated by the currently heavy emphasis on transportation aspects of the Roadmap, particularly introduction of hydrogen powered fuel cells.

FY 2003-05 Hydrogen and Fuel Cell R&D Funding by Activity			
Activity *Fiscal Year*	*2003*	*2004*	*2005*
Hydrogen technology			
Production/delivery	6.4	10.3	14.4
Storage	10.8	14.0	23.8
Infrastructure validation	3.0	5.9	9.6
Safety, codes & standards	2.6	3.9	3.4
Congressionally mandated projects	13.4	42.0	37.3
Fuel cell technology			
Transportation systems	6.1	7.5	7.5
Distributed energy systems	7.3	7.4	6.9
Fuel processing	23.5	14.8	9.7
Stack components	14.8	25.2	32.5
Technology validation	1.8	9.9	17.8
Technical/program support	0.4	0.4	0.5
Total	92.0	147.2	169.5

National laboratories under the Energy Department's jurisdiction share these funds but also are engaged in a variety of independent R&D activities as well as contract and cooperative R&D with industry partners. Funding for these arrangements sometimes fall outside of the budget of the DOE.

Energy Policy Act of 2005 – Authorized Funding Levels ($millions)					
Fiscal Year	*2006*	*2007*	*2008*	*2009*	*2010*
Research Area					
Hydrogen supply	160	200	220	230	250
Fuel cell technologies	150	160	170	180	200
Hydrogen/fuel cell demonstrations	185	200	250	300	375
Regulatory codes & standards	4	7	8	10	9
Total	499	567	648	720	834

The Funding Dearth

The funding outlook may be improved with the recent approval by Congress of the Energy Policy Act of 2005. Authorized funding for all hydrogen Roadmap R&D plans will increase from $499 million in FY 2006 to $834.0 million in FY 2010 – the point at which the Roadmap anticipates the beginning of greater commercialization of hydrogen technologies. These funds must be shared among individual projects. They also represent authorized *ceilings*. Actual funding levels will be determined by annual appropriations cycles. Finally, it is questionable whether funding levels are sufficient at an absolute level to achieve technical goals, although they may be sufficient to encourage the government-industry partnerships that are a centrepiece of the Roadmap.

Significant Pilot Projects

Two pilot programs could affect the prospects for realizing the Roadmap's ambitious goals. The first is **FutureGen** – an initiative announced in February 2003 to produce hydrogen from clean coal sources. The project received loan guarantees and other forms of funding support in the 2005 Energy Policy

Act. Total direct funding was announced at $1.0 billion over ten years. Details of the program are outlined in *Hydrogen from Coal Program: Research, Development and Demonstration Plan for the Period 2004 through 2015* (June 10, 2004). The second pilot – **the Nuclear Hydrogen R&D Plan** – was approved in the Energy Policy Act after many years of advocacy by some of the national laboratories. This will demonstrate hydrogen production using a high temperature nuclear gas reactor. Plans call for combined electricity and hydrogen production by 2017. The program is further detailed in the *Nuclear Hydrogen R&D Plan* of the DOE (March 2004). This pilot falls under the DOE Office of Nuclear Energy, Science & Technology and is part of a broader program to identify and test next generation nuclear reactors.

National Labs - High Ambitions but Funding Uncertainties

National laboratories under direction of the DOE were important players in influencing the development of the Roadmap, in part because of research projects and analytical studies performed prior to its publication. National laboratory activities are funded through a combination of sources, including:

- DOE budgets
- Independent research and development
- Contract research funds from other government agencies and
- Cooperative research contracts with industry.

This funding variety has contributed to a diversity of research projects, although sufficiency of funding may yet be an issue.

Good Intentions but Few Resources

The Hydrogen Roadmap by its nature is a political guide but nevertheless has been important in helping develop a long-term agenda toward diversifying clean and reliable fuel sources for multiple applications. The difficulty facing the Roadmap – particularly given the long timeframes necessary to achieve significant technical results and technology development – is in matching appropriate funding to its ambitious goals. With this in mind, three broad conclusions can be offered concerning the Roadmap, its impact and prospects:

- **The Hydrogen Roadmap has been successful to the extent that it has helped policymakers and government research organizations consolidate and articulate their programs under a comprehensive philosophy toward bringing the hydrogen economy to fruition.** Various hydrogen research projects had been under way with DOE support for more than a decade prior to conclusion of the Roadmap. Most of the projects applied to transportation applications under programs that had mixed results. Other aspects relating to production, delivery and applications, while not lost within DOE, nevertheless lacked context. The Roadmap has provided that context.
- **Many ambitious program goals may be betrayed by less than generous funding by Congress.** While the Roadmap provides context, direction and objectives, its goals may not be achieved due to relatively low congressional funding.
- **Government-industry partnership programs could influence the future direction of specific aspects of the Roadmap.** Newly introduced pilot projects could influence long-term government funding. Funding support and subsidies provided the FutureGen and nuclear-hydrogen production pilot project could help these projects achieve their respective technical performance and technology development goals (cost effectiveness is another matter, one that is not considered here). Should these pilots demonstrate successful results, they could influence future investment and funding decisions, and thus the overall direction of the Roadmap.

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