

WORLD·WATCH

Working For A Sustainable Future

The Hydrogen Experiment

by Seth Dunn

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The Hydrogen Experiment

In Reykjavík, Iceland, scientists, politicians, and business leaders have conspired to put into motion a grand experiment that may end the country's—and the world's—reliance on fossil fuels forever. The island has committed to becoming the world's first hydrogen economy over the next 30 years.



by Seth Dunn

Riding from the airport to Iceland's capital, Reykjavík, gives one the sensation of having landed on the moon. Black lava rocks cover the mostly barren landscape, which is articulated by craters, hills, and mountains. Other parts of the island are covered by a thin layer of green moss. American astronauts traveled here in the 1960s to practice walking the lunar surface, defining rock types, and taking specimens.

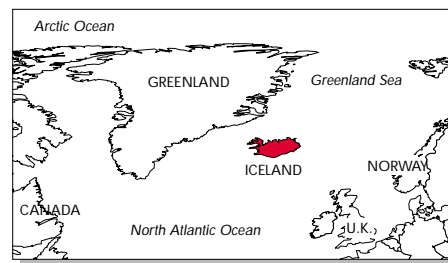
I, too, have traveled here on a journey of sorts to a new world—a world that is powered not by oil, coal, and other polluting

fossil fuels, but one that relies primarily on renewable resources for energy and on hydrogen as an energy carrier, producing electricity with only water and heat as byproducts. My quest has brought me to the cluttered office of Bragi Árnason, a chemistry professor at the University of Iceland whose 30-year-old plan to run his country on hydrogen energy has recently become an official objective of his government, to be achieved over the next 30 years. "I think we could be a pilot country, giving a vision of the world to come," he says to me with a quiet conviction and a deep, blue-



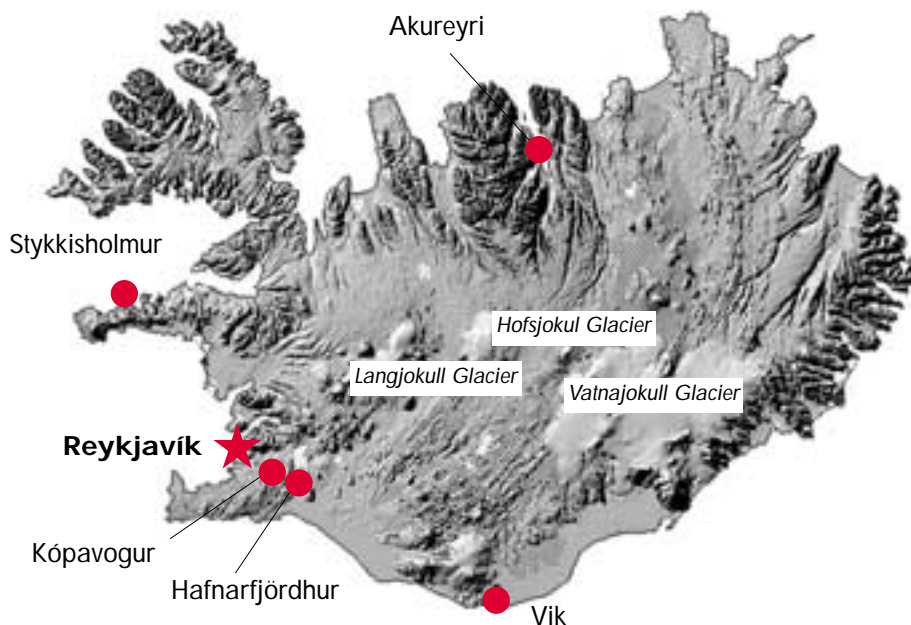
ILLUSTRATION BY JANET HAMLIN

Iceland Near the Arctic Circle, Iceland is home to about 270,000 people—90 percent of whom live in cities. While the island has some of the most active volcanoes in the world, nearly 11 percent of the land mass is buried under massive glaciers.



“Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable ... There is, therefore, nothing to fear ... Water will be the coal of the future.”

—Jules Verne
The Mysterious Island, 1874



-eyed stare that reminds me of this country’s hardy Viking past.

When he first proposed this hydrogen economy decades ago, many thought he was crazy. But today, “Professor Hydrogen,” as he has been nicknamed, is something of a national hero. And Iceland is now his 39,000-square-mile lab space for at long last conducting his ambitious experiment. Already, his scientific research has led to a multi-million-dollar hydrogen venture between his university, his government, other Iceland institutions, and a number of major multinational corporations.

I am not alone in my expedition to ground zero of the hydrogen economy: hundreds of scientists, politicians, investors, and journalists have visited over the past year to learn more about Iceland’s plans. My journey is also an echo of what happened in the 18th century, when merchants and officials flocked to another North Atlantic island—Great Britain—to witness the harnessing of coal.

Today, many experts are watching Iceland closely as a “planetary laboratory” for the anticipated global energy transition from an economy based predominantly on finite fossil fuels to one fueled by virtually unlimited renewable resources and hydrogen, the

most abundant element in the universe. The way this energy transition unfolds over the coming decades will be greatly influenced by choices made today. How will the hydrogen be produced? How will it be transported? How will it be stored and used? Iceland is facing these choices right now, and in plotting its course has reached a fork in the road. It must choose between developing an interim system that produces and delivers methanol, from which hydrogen can be later extracted, or developing a full infrastructure for directly transporting and using hydrogen. Whether the country tests incremental improvements or more ambitious steps will have important economic and environmental implications, not only for Iceland but for other countries hoping to draw conclusions from its experiment.

Iceland is not undertaking this experiment in isolation. Its hydrogen strategy is tied to three major global trends. The first of these is growing concern over the future supply and price of oil—already a heavy burden on the Icelandic economy. The second is the recent revolution in bringing hydrogen-powered fuel cells—used for decades in space travel—down to earth, making Árnason’s vision far more economically feasible than it was just ten years ago.

The third is the accelerating worldwide movement to combat climate change by reducing carbon emissions from fossil fuel burning, which in its current configuration places constraints on Iceland that make a hydrogen transition particularly palatable. How the island's plans proceed will both help to shape and be shaped by these broader international developments.

A Head Start

Straddling the Mid-Atlantic Ridge, Iceland is a geologist's dream. Providing inspiration for Jules Verne's *Journey to the Center of the Earth*, the island's volcanoes have accounted for an estimated one-third of Earth's lava output since 1500 A.D. Eruptions have featured prominently in Icelandic religion and history, at times wiping out large parts of the population. Reykjavik is the only city I know that has a museum devoted solely to volcanoes. There, one can find out the latest about the 150 volcanoes that remain active today.

Iceland's volcanic activity is accompanied by other geological processes. Earthquakes are frequent, though usually mild, which has made natives rather blasé about them. Also common are volcanically heated regions of hot water and steam, most visible in the hot springs and geysers scattered across the island. In fact, the word "geyser" originated here, derived from *geysir*, and Reykjavik translates to "smoky bay." During my visit, the well-known Geysir, which erupts higher than the United States' Old Faithful, was reemerging from years of dormancy, to the delight of Icelanders everywhere.

The country first began to tap its geothermal energy for heating homes and other buildings (also called district heating) in the 1940s. Today, 90 percent of the country's buildings—and all of the capital's—are heated with geothermal water. Several towns in the countryside use geothermal heat to run greenhouses for horticulture, and geothermal steam is also widely harnessed for power generation. One tourist hotspot, the Blue Lagoon bathing resort, is supplied by the warm, silicate-rich excess water from the nearby Reykjanes geothermal power station. Yet it is estimated that only 1 percent of the country's geothermal energy potential has been utilized.

Falling water is another abundant energy source here. Although it was floating ice floes that inspired an early (but departing) settler to christen the island Iceland, the country's high latitude has exposed it to a series of ice ages. This icy legacy lingers today in the form of sizable glaciers, including Europe's largest, which have carved deep valleys with breathtaking waterfalls and powerful rivers. The first stream was harnessed for hydroelectricity in the 1900s. The country aggressively expanded its hydro capacity after declaring independence from

But does the Iceland experiment really apply to the rest of the world?

Other countries don't have the abundant renewable (geothermal and hydroelectric) resources Iceland has, but they do have other renewable energy sources—solar, wind, biomass, and ocean tides—that can also be used to produce hydrogen. The United States has enough wind to meet its entire electricity demand, if only it can be delivered where and when it is needed. The Middle East and the tropics, with their abundant sunshine, could one day become major hydrogen producers and exporters. By allowing intermittent energy to be cheaply stored and transported, hydrogen technology will turn renewables from marginal to mainstream sources.

Because they have not developed their renewable energy resources as fully as Iceland has, other countries may first use natural gas as a "bridge" to hydrogen. This would mean using existing natural gas pipelines to transport the gas to fueling stations, reforming it to hydrogen at the stations, and using the hydrogen directly in vehicles. The ultimate step, though, is producing the hydrogen from renewable energy and delivering it through a hydrogen infrastructure—which is exactly the challenge Iceland is facing.

Denmark in the 1940s, beginning an era of economic growth that elevated it from Third World status to one of the world's most wealthy nations today. Hydroelectricity currently provides 19 percent of Iceland's energy—and that share could be significantly increased, as the country has harnessed only 15 percent of potential resources (though many regions are unlikely to be tapped, due to their natural beauty, ecological fragility, and historical significance).

Iceland is unique among modern nations in having an electricity system that is already 99.9 percent reliant on indigenous renewable energy—geothermal and hydroelectric. The overall energy system, including transportation, is roughly 58 percent dependent on renewable sources. This, some experts believe, prepares the country well to make the transition from internal combustion engines to fuel cells, and from hydrocarbon to hydrogen energy. With its extensive

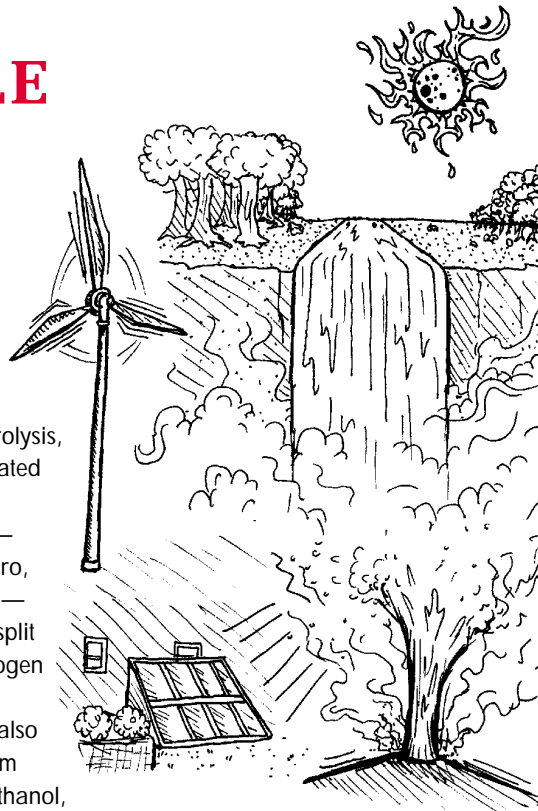
THE HYDROGEN CYCLE

A blueprint for the post-fossil fuel energy economy

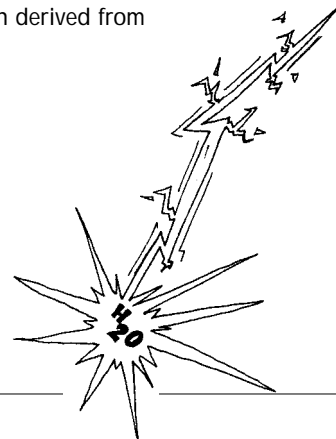
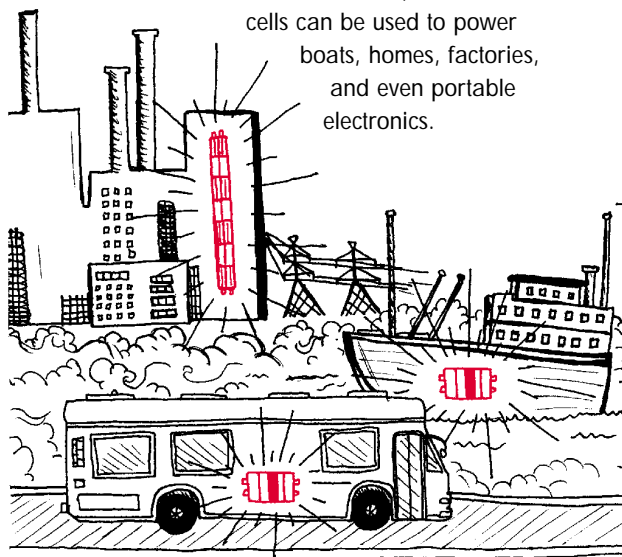


e If renewable energy is used to produce the hydrogen, the only byproducts of running a fuel cell are heat and water. (If fossil fuels are the source of the hydrogen, carbon dioxide and local air pollutants are also released—though less than if these fuels were used conventionally.)

Q Through the process of electrolysis, electricity generated from renewable energy sources—solar, wind, hydro, geothermal, etc.—can be used to split water into hydrogen and oxygen. (Hydrogen can also be extracted from natural gas, methanol, gasoline, and other fossil fuels—and the process is cleaner and more efficient than burning these fuels in internal combustion engines—but is “greenest” when derived from renewable energy.)

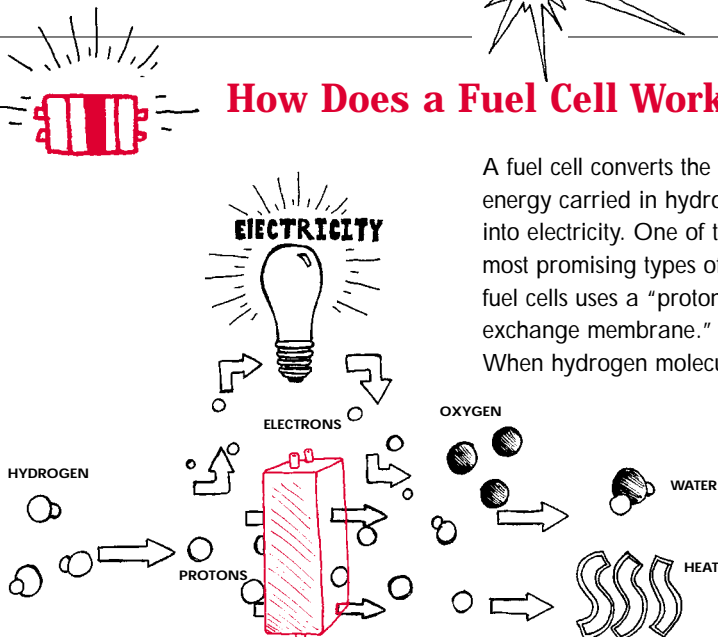


w Fuel cells essentially do the reverse of electrolysis, combining the hydrogen with oxygen and using the release of chemical energy to create an electric voltage. Combined into stacks, these fuel cells can be used to power boats, homes, factories, and even portable electronics.



How Does a Fuel Cell Work?

A fuel cell converts the energy carried in hydrogen into electricity. One of the most promising types of fuel cells uses a “proton exchange membrane.” When hydrogen molecules



renewable energy grid, Iceland has a headstart on the rest of the world, and is positioned to blaze the path to an economy free of fossil fuels.

Peat and Petroleum

When Vikings first permanently settled Iceland in the 9th century A.D., they used bushy birchwood and peat reservoirs to make fires for cooking and heating, and to fuel iron forges to craft weapons. But deforestation soon led to the end of wood supplies, and the cold climate would freeze the peat bogs, limiting their use as fuel.

Beyond its peat supplies, Iceland has virtually no indigenous fossil fuel resources. As the Industrial Revolution gathered momentum, the nation began to import coal and coke for heating purposes; coal would remain the primary heating source until the development of geothermal energy. In the late 1800s, as petroleum emerged as a fuel, Iceland turned to importing oil. Today, imported oil—about 850,000 tons per year—accounts for 38 percent of national energy use, 57 percent of this used to run its motor vehicles and the boats of its relatively large fishing industry, the nation's leading source of exports (see figure, page 20). Dependence on oil imports costs the nation \$150 million annually, and explains why transport and fishing each account for one-third of its carbon emissions.

The final third of Iceland's greenhouse emissions is found in other industries—primarily the production, or smelting, of metals like aluminum. The availability of low-cost electricity—at \$.02 per kilowatt, it is the world's cheapest—has made Iceland a welcome haven for these energy-intensive industries. Metals production, along with transport and fishing, makes the island one of

the world's top per-capita emitters of carbon dioxide, and offsets much of the greenhouse gas savings Iceland has achieved in space heating and electricity.

These features of Iceland's energy economy—a carbon-free power sector, costly dependence on oil for fishing and transportation, rising emissions from the metals industry—have placed

the nation in a difficult situation with regard to complying with international climate change commitments. The 1997 Kyoto Protocol's guidelines for reducing greenhouse gas emissions in industrial nations are based on emission levels from the year 1990, which prevents Iceland from taking credit for its previously completed transition to greenhouse gas-free space heating and electricity generation. Although the government, arguing its special situation, negotiated a 10 percent reprieve between 1990 and 2010 under the Protocol, officials estimate that plans to build new aluminum smelters will cause it to exceed this target. Because of this so-called "Kyoto dilemma," Iceland is among only a few remaining industrial nations that have not signed the agreement.

In 1997, as the Protocol talks gathered momentum and the nation's dilemma was becoming apparent, a recently elected Parliamentarian named Hjalmar Árnason submitted a resolution to the Parliament, or Althing, demanding that the government begin to explore its energy alternatives. Árnason, a former elementary-school teacher who says he was "raised by an environmental extremist" father (he is not related to the scientist Bragi Árnason), soon found himself chairing a government committee on alternative energy, which was commissioned to submit a report. One of the first people he tapped for the committee was Professor Hydrogen.

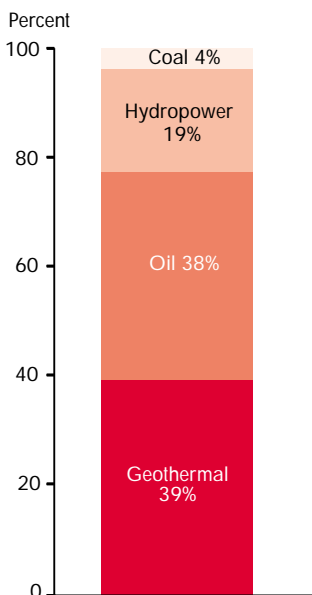
Science Meets Politics

Bragi Árnason began studying Iceland's geothermal resource "as a hobby," he tells me, while a graduate student pursuing doctoral research in the 1970s. His deep knowledge of the island's circulatory system of hot water flows enables him to explain, for example, why the water you shower with in Reykjavík probably last fell as rain back in 1000 A.D. As he came to grasp the size of the resource, he began to consider ways in which this untapped potential might be used. At the time, the climbing cost of oil imports was beginning to hit the fishing fleet, prompting discussion of alternative fuels—including hydrogen.

Iceland has been producing hydrogen since 1958, when it opened a state fertilizer plant on the outskirts of Reykjavík under the post-war Marshall Plan. The production process uses hydro-generated electricity to split water into hydrogen and oxygen molecules—a process called electrolysis (see diagram, page 18). The fertilizer plant uses about 13 megawatts of power annually to produce about 2,000 tons of liquid hydrogen, which is then used to make ammonia for the fertilizer industry. In 1980, Bragi Árnason and colleagues completed a lengthy study on the cost of electrolyzing much larger amounts of hydrogen,

are injected, the cell's membrane splits them into protons and electrons. The protons pass through the membrane and react with oxygen, forming water and releasing heat. The electrons, which cannot pass through the membrane, travel along a circuit and create electricity.

Energy Use In Iceland,
by Source



In a 1993 paper, Dr. Árnason argued that a transition in fuels from oil to hydrogen may be “a feasible future option for Iceland and a testing ground for changing fuel technology.” He also contended that the country could benefit from using hydrogen sooner than other countries. Some of his reasons included Iceland’s small population and high levels of technology; its abundance of hydropower and geothermal energy; and its absence of fossil fuel supplies. Another was the relatively simple infrastructural change involved in converting the fishing fleet from oil to hydrogen, by locating small production plants in major harbor areas and adapting the boats for liquid hydrogen.

Early on, the plan was to use liquid hydrogen to fuel the boats’ existing internal combustion engines. But “then came the fuel cell revolution,” as Dr. Árnason puts it. By the late 1990s, the fuel cell, an electrochemical device that combines hydrogen and oxygen to produce electricity and water, had achieved dramatic cost reductions over the previous two decades. The technology had become the focus of engineers aiming to make fuel cells a viable replacement not only for the internal combustion engine, but for batteries in portable electronics and for power plants as well. Demonstrations of fuel cell-powered buses in Vancouver and Chicago, and their growing use in hundreds of locations in the United States, Europe, and Japan, caught the attention of governments and major automobile manufacturers. The fuel

using not only hydroelectricity but geothermal steam as well—which can speed up what is a very high-temperature process. Their paper found that this approach would be cheaper than importing hydrogen or making it by conventional electrolysis, but it did not find a receptive audience as oil prices plummeted during the 1980s.

The early 1990s saw a reemergence of Icelandic interest in producing hydrogen, both for powering the fishing fleet and for export as a fuel to the European market.

cell was increasingly viewed as the “enabling technology” for a hydrogen economy.

One Icelander particularly taken with these developments was a young man named Jón Björn Skúlason, who while attending the University of British Columbia in Vancouver became familiar with Ballard Power Systems, a leading fuel cell manufacturer headquartered just outside the city. Upon returning home, Skúlason encouraged the politician Hjalmar Árnason in his promotion of energy alternatives and hydrogen; his enthusiasm earned him a position on the expert committee. In 1998, the panel formally recommended that the nation consider converting fully to a hydrogen economy within 30 years.

By then, Hjalmar Árnason had already given the process a push. During a phone interview with a reporter from the *Economist*, he floated the year 2030 as a target date for the government’s evolving hydrogen plans. The resulting article, published in August 1997, created a buzz abroad, and the parliamentarian received hundreds of phone calls from around the world. That fall, Iceland’s prime minister released a statement announcing that the government was officially moving the country toward a hydrogen economy. The ministers of energy and industry, commerce, and environment signed on, as well as both sides of the two-party Althing. And Árnason obtained permission to start negotiating with interested members of industry.

A Piece of the Action

Iceland has a tradition of “stock companies,” or business cooperatives that evolved in the eighteenth century to help domestic farmers and fishers compete with the formidable Danish trading companies that at the time controlled fishing and goods manufacturing. The first of these, granted royal support in 1752, brought in weavers from Germany, farmers from Norway, and other overseas experts to teach the Icelanders the best methods of agriculture, boat-building, and the manufacture of woolen goods. Over the years, these long-lasting business associations helped the nation’s enterprises survive and sometimes thrive.

The formation of the Icelandic Hydrogen and Fuel Cell Company (now Icelandic New Energy) can be seen as the latest example of this stock company tradition—but with a contemporary twist: German carmakers instead of weavers, Norwegian power companies rather than farmers. The first to contact Hjalmar Árnason after publication of the *Economist* article was DaimlerChrysler. Its roots traceable back to Otto Benz, designer of the first internal-combustion engine car, DaimlerChrysler now aspires to be the first maker of fuel cell-powered cars. The firm has

entered into a \$800 million partnership with Ballard Power Systems and Ford to produce fuel-cell cars, and plans to have the first buses and cars on European roads in 2002 and 2004, respectively—making Iceland a potentially valuable training ground, especially for testing fuel cell vehicles in a cold climate.

The second company to touch base with the Iceland government was Royal Dutch Shell, the Netherlands-based energy company that, among those now in the oil business, has perhaps the most advanced post-petroleum plans. Birthplace of the “scenario planning” technique that prepared it for the oil shocks of the 1970s better than most businesses, Shell has posited an Iceland-like future for the rest of the world, with 50 percent of energy coming from renewable sources by 2050. The firm surprised its colleagues in mid-1998 by creating a formal Shell Hydrogen division, and then sending its representatives to the World Hydrogen Energy Conference in Buenos Aires.

The third group to establish communications with island officials was Norsk Hydro, a Norwegian energy and industry conglomerate. The company is involved in a trial run of a hydrogen fuel cell bus in Oslo, and has considerable experience in hydrogen production: it has its own fertilizer business, and Norsk Hydro electrolyzers run Iceland’s hydrogen-producing fertilizer plant. Norsk Hydro is also involved in the politically sensitive issue of Iceland’s

planned aluminum smelters, having signed commitments with the national power company and the ministries of energy and industry and commerce to construct a new smelter on the island’s east coast.

Negotiations among these companies and the Icelandic government culminated in February 1999 with the creation of the Icelandic Hydrogen and Fuel Cell Company. Shell, DaimlerChrysler, and Norsk Hydro each hold shares of the company. The majority partner, *Vistorka* (which means “eco-energy”), is a holding company owned by a diverse array of Icelandic institutions and enterprises: the New Business Venture Fund, the University of Iceland, the National Fertilizer Plant, the Reykjanes Geothermal Power Plant, the Icelandic Technological Institute, and the Reykjavik Municipal Power Company. Also indirectly involved with the holding company is the Reykjavik City-Bus Company.

The stated purpose of the new joint venture is to “investigate the potential for replacing the use of fossil fuels in Iceland with hydrogen and creating the world’s first hydrogen economy.” On the day of its announcement, Iceland’s environment minister stated: “The Government of Iceland welcomes the establishment of this company by these parties and considers that the choice of location for this project is an acknowledgement of Iceland’s distinctive status and long-term potential.” Like the *Economist* article, the announcement attracted indus-

Iceland’s “Hydrogen Society” Strategy, 2000–2030

2000

2020

- ▶ Test three hydrogen fuel cell buses in Reykjavik.
- ▶ Gradually replace the entire Reykjavik city bus fleet, and possibly other bus fleets, with hydrogen fuel cell buses.
- ▶ Introduce hydrogen-based fuel cell cars for private transportation.
- ▶ Test hydrogen fuel cell fishing vessels.
- ▶ Gradually replace fishing fleet with hydrogen fuel cell fishing vessels.

try attention. But for some companies, it was too late to climb on the bandwagon. Toyota officials reportedly attempted, to no avail, to take over the project by offering to foot its entire bill and supply all the needed engineers.

Buses, Cars, and Boats

Bragi Árnason and a colleague, Thorsteinn Sigfússon, have outlined a gradual, five-phase scenario for the hydrogen transformation. (See timeline.) In phase one (an estimated \$8 million project that has received \$1 million from the government), hydrogen fuel cells are to be demonstrated in Reykjavík's 100 municipal public transit buses. The current plan is to have three buses on the streets by 2002. The fertilizer plant will serve as the filling station for the buses, its hydrogen pressurized as a gas and stored on the roofs of the vehicles. Because enough hydrogen can be stored onboard to run a bus for 250 kilometers, the average daily distance traveled by a Reykjavík bus, there is no need for a complicated infrastructure for distributing the fuel.

In phase two, the entire city bus fleet—and possibly those in other parts of the island—will be replaced by fuel cell buses. The Reykjavík bus fleet program has a price tag estimated at \$50 million, and this spring received \$3.5 million from the European Community. Phase three involves the introduction of private fuel cell passenger cars—which requires a more complicated infrastructure. At present, storing pressurized hydrogen gas onboard a large number of smaller vehicles, with more geographically dispersed refueling requirements, is too expensive to be considered a realistic option. The first fuel cell cars are therefore expected to run not on hydrogen directly, but rather on liquid methanol—which contains bound hydrogen but must be reformed, or heated, onboard the vehicle

to produce the hydrogen to power the fuel cell.

Methanol is also, at the moment, the preferred fuel for the final two phases: the testing of a fuel cell-powered fishing vessel, followed by the replacement of the entire boating fleet. These trawlers use electric motors that are in the range of one to two megawatts—larger than those for cars and buses, but close to the size of the fuel cells that are now starting to be commercialized for stationary use in homes and buildings. Several European vessel manufacturers have already expressed their interest in becoming involved in this phase, and Dr. Árnason would like to see a fuel cell boat demonstrated no later than 2006.

But using methanol as an intermediate step to hydrogen is not without its problems. Skúlason, who is now president of Icelandic New Energy, notes that Shell is concerned about the use of methanol, particularly its toxicity. And since methanol reforming releases carbon dioxide, the environmental benefit is much less than if a way can be found to store the direct hydrogen onboard, which in Iceland's case would mean complete elimination of greenhouse gas emissions. It's a difficult decision, notes Skúlason: "We must deal with the technologies we are given by the global companies."

Iceland will have to choose between two options: producing and distributing pure hydrogen and storing it onboard vehicles (the "direct hydrogen" option); or producing hydrogen onboard vehicles from other fuels—natural gas, methanol, ethanol, or gasoline—using a reformer (the "onboard reformer" option). In general, the automobile industry strongly favors the onboard option, using methanol and gasoline, because most existing service stations already handle these fuels. A third path, reforming natural gas at hydrogen refueling stations, is under consideration in countries like the United States, that already have an extensive natural gas network, but is not practical in Iceland.



The up-front costs of direct hydrogen will be high because such a change requires a new infrastructure for transporting hydrogen, handling it at fueling stations, and storing the fuel onboard as a compressed gas or liquid. According to DaimlerChrysler's Ferdinand Panik, retrofitting 30 percent of service stations in the U.S. states of New York, Massachusetts, and California for methanol distribution would cost about \$400 million. Supplying hydrogen to these stations would cost about \$1.4 billion.

But in terms of long-term societal benefits, direct hydrogen is the clear winner. Using hydrogen directly is more efficient, because of the extra weight of the processor and lower hydrogen content of the methanol or gasoline. It is also less complex than having a reformer onboard each vehicle—which adds \$1,500 to the cost of a new car, takes time to warm up, and creates maintenance problems. As the vehicle population grows large enough to cover the capital costs of providing refueling facilities, the costs of direct hydrogen will become comparable to the onboard option. Once the infrastructure and vehicles are put in place, using hydrogen fuel will be more cost-effective than having cars with reformers—even excluding the environmental gains.

If Iceland, with its heavy renewable energy reliance, were to switch directly to hydrogen, the country would have *no* greenhouse emissions. And in fact, it is much easier to produce hydrogen than methanol from renewable energy through electrolysis. Thus, as renewables become more prominent around the world, a hydrogen infrastructure will emerge as the most practical option. In Iceland, rather than require that hydrogen first be used to create, and then be reformed from, methanol, the simplest approach would be to use geothermal power and hydropower, augmented by geothermal steam, to electrolyze water, creating pure hydrogen to drive cars and boats. But behind the seeming solidar-

ity of the public/private venture, a fateful struggle may be emerging.

A Fork in the Road

In spite of the long-term economic and environmental advantages of the direct hydrogen approach, industry and government—both in Iceland and worldwide—have devoted substantially greater attention and financial support to the intermediate approach of using methanol and onboard reformers. Car companies are hesitant to mass-produce a car that cannot be easily refueled at many locations. Energy companies, similarly, are loathe to invest in pipelines and fuel stations for vehicles that have yet to hit the market. This is a classic case of what some engineers call the *chicken-and-egg* dilemma of creating a fueling infrastructure. But the potential public benefits—especially for addressing climate change—give governments around the world incentive to steer the private sector toward the optimal long-term solution of a hydrogen infrastructure, by supporting additional research into hydrogen storage and by collaborating with industry.

In Iceland's case, producing pure hydrogen through electrolysis by hydropower is at the moment three times as expensive as importing gasoline. But the fuel cells now being readied for the transporta-

“The transition is messy. We have one leg in the old world, and one in the new.”

**Hjalmar Arnason,
member of Iceland's
Parliament**



tion market are three times as efficient as an internal combustion engine. In other words, running the island's transport and fishing sectors off pure hydrogen from hydropower is becoming economically competitive with operating conventional gasoline-run cars and diesel-run boats.

Since the methanol reformers these fuel cells will presumably use are still several years away from mass production, some scientists see the next few

“Many people ask me how soon this will happen. I tell them, ‘We are living at the beginning of the transition. You will see the end of it. And your children, they will live in this world.’”

**Bragi Arnason,
University of Iceland**

years as an important window of opportunity to prove the viability of direct hydrogen technology. But the history of technology is littered with examples of inferior technologies “locking out” rivals: witness VHS versus Beta in the videocassette recorder market. If methanol does gain market dominance, and locks out the direct hydrogen approach, it may be decades before real hydrogen cars become wide-

spread—a wrong turn that could take the Icelandic venture kilometers from its destination. By the time a full-blown methanol infrastructure were put in place, it would probably no longer be the preferred fuel—committing the country to a fleet of obsolete cars and causing the consortium to strand millions of *kronur* in financial assets.

Yet some outside developments are pointing in the direction of direct hydrogen. In California, where legislation requires that 10 percent of new cars sold in 2003 must produce “zero-emissions,” a consortium called the California Fuel Cell Partnership is planning to test out 50 fuel cell vehicles and build two hydrogen fueling stations that will pump hydrogen gas into onboard fuel tanks. Hydrogen fueling stations have already been built in Sacramento (California's capital), Dearborn, Michigan (home to Ford headquarters), and the airport at Frankfurt, Germany—the last of which expects to eventually import hydrogen from Iceland. The prospect of Iceland becoming a major hydrogen exporter, perhaps the new energy era's “Kuwait of the North,” surfaces several times during my interviews—and is no doubt a good selling point for the strategy to officials inclined to think more in

narrow economic terms.

Skúlason assures me that there is a “very open discussion” underway within the consortium, and says “we have to take steps slowly because there might be a shift.” He admits that he would prefer to see compressed hydrogen gas used, noting the advantages of having direct hydrogen fuel infrastructure and vehicles. Shell and DaimlerChrysler themselves seem to recognize the potential competitive advantage of putting up hydrogen filling stations and reformer-free cars right from the beginning, giving them a headstart in preparing for a world fueled by hydrogen. At a June 2000 conference in Washington, DC, Shell Hydrogen CEO Don Huberts asserted that direct hydrogen was the best fuel for fuel cells, and suggested that geothermal energy converted to hydrogen would be the main means for converting the Icelandic economy. DaimlerChrysler representatives have admitted that their methanol reformers are relatively expensive and large—they take up the entire back seat—and the company has recently rolled out “next generation” prototype cars that run on liquid and compressed hydrogen—prime candidates for the Iceland strategy.

“The transition is messy,” the politician Hjalmar Arnason tells me. “We have one leg in the old world, and one in the new.” It's an apt metaphor, given Iceland's geography. But the question is whether the Icelandic venture will, in rather un-Viking fashion, cautiously creep ahead—sticking to the onboard methanol approach—or, brashly set *both* feet in the new world, voyaging straight to direct hydrogen. As a world leader in utilizing renewable energy sources, if Iceland does not take the “newest” path, governments and businesses elsewhere may extract the wrong conclusion from its experiment and give short shrift to the direct hydrogen option. Skúlason nails the conundrum: “How many times will we shift? Will it be cheaper for society to pay a little more now and not have to rebuild? This argument doesn't always work with government or the consumer.”

Professor Arnason is quick to note that, whichever short-term infrastructural path the country takes, “the final destination is the same:” pure hydrogen, derived from renewable energy and used directly in fuel cells. But he acknowledges that there may be significant costs in taking the gradual approach. And he agrees that the assumption on which his scenario is based—that methanol is the most economical option—is “subject to revision.” The cost and efficiency of fuel cells will continue to improve, and advances in carbon nanotubes, metal hydrides, and other storage technologies are making it more feasible to store hydrogen onboard. The high cost of electrolysis is likely to decline sharply with technical improvements, while other sources of hydrogen—tapping solar, wind, and tidal power, splitting water

with direct sunlight, playing with the metabolism of photosynthetic algae—are on the horizon. And new climate policies or fluctuating fuel prices from volatile oil markets “would change the whole picture.”

Why Iceland?

When he first met with his prospective joint venture partners, Bragi Árnason posed this query: “Why are you interested in coming to Iceland?” He asked the question because “we were quite surprised to learn about the strong interest of these companies in participating in a joint venture with little Iceland.” Their answers shed light on some of the elements that may be useful for developing a hydrogen economy elsewhere in the world.

Without a doubt, the most critical element of getting the Iceland experiment underway has been the government’s clearly stated commitment to transforming itself into a hydrogen economy within a set timeframe. A similar dynamic is at work in California, where the zero-emission mandate has forced energy and transport companies to join forces with the public sector to seriously explore hydrogen. For Dr. Árnason, the lesson is clear: a strong public commitment can attract and encourage the participation of private sector leaders, resulting in partnerships that provide the financial and technical support needed to move toward environmental solutions. “You *must* have the politicians,” he says.

In addition, companies have shown interest in the Iceland experiment because the results will be applicable around the world. While the country’s hydrogen can be produced completely by renewable energy, its car and bus system and heavy reliance on petroleum—amplified by its island setting—are common characteristics of industrial nations, making the result somewhat adaptable. The island’s head start in transitioning to renewable energy also makes it a good place to test out this larger shift.

Iceland may also have something more to tell us about the more general cultural building blocks that can enable the evolution of a hydrogen society. Icelanders treasure their hard-won independence, and the prospect of energy self-reliance is attractive. Hjalmar Árnason likes to emphasize his homeland’s “free, open society,” which he believes has maintained a political process more conducive to bold proposals and less subject to special-interest influence and partisan gridlock. He points, too, to the country’s openness to new technology—to its willingness to take part in international scientific endeavors such as global research in human genetics. He hopes Iceland will become a training ground for hydrogen scientists from around the world, cooperating internationally to convert its NATO base to hydrogen. Skúlason cites a poll of Reykjavík citizens indicating that 60 percent

of the citizens were familiar with and supportive of the hydrogen strategy—though some ask about the safety of the fuel (it is as safe as gasoline), pointing to the need for public education campaigns before people will be persuaded to buy fuel cell cars.

Another important cultural factor has been what Árni Finnsson, of the Icelandic Nature Conservation, describes as his nation’s relatively recent but increasing “encounter with the globalization of environmental issues.” This encounter originated with the emotional whaling disputes of the 1970s and 80s, and today includes debates about persistent organic pollutants and climate change. As Icelanders seek to become more a part of global society, so too do they seek legitimacy on global issues, forcing their government to sensitize itself to emerging cross-border debates—a process that has sometimes created Iceland’s political equivalent of volcanic eruptions.

Finnsson points out that, thanks to the “Kyoto dilemma,” Icelandic climate policy is not terribly progressive, consisting mainly of efforts to create loopholes that would allow additional greenhouse gas emissions from its new aluminum smelters. But there is little doubt that this dilemma has also unwittingly helped encourage the hydrogen strategy, by forcing the nation to explore deep changes in its energy system. In a land that, even as it becomes wired to the information age, routinely blocks new road projects due to age-old superstitions of upsetting elves and other “hidden people,” it’s a contradiction that somehow seems appropriate. A country that has stubbornly refused to sign the Kyoto Protocol provides the most compelling evidence to date that climate change concerns—and commitments—will increasingly drive the great hydrogen transformation.

But my favorite, if least provable, theory for “Why Iceland?” comes from the heroic ideals of its sagas. One of the recurring themes of these remarkable literary works is that a person’s true value lies in renown after death, in becoming a force in the lives of later generations through one’s deeds. Listening to Bragi Árnason, who is now 65, one cannot help but wonder whether this cultural concern for renown is playing a part in the saga now unfolding: how Iceland became the world’s first hydrogen society, inspiring the rest of the globe to follow its lead. “Many people ask me how soon this will happen. I tell them, ‘We are living at the beginning of the transition. You will see the end of it. And your children, they will live in this world.’”

Seth Dunn is a research associate at the Worldwatch Institute. He is the author of Worldwatch Paper 151, *Micropower: The Next Electrical Era*.