## Water To Burn

Iceland's experiment with hydrogen points toward an oil-free world.

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A cool September dusk had settled over Reykjavik as tourists strolled down the gravel path leading into Villi Knudsen's backyard. Knudsen was waiting in a dirty red parka and ragged jeans at the entrance to his makeshift theatre, which has room for maybe seventy people; seventeen dollars gets you into the cramped rows of fold-down seats. With the coming of fall, the days were getting shorter and the tourists were mostly gone. When he decided no one else was coming, Knudsen shut the door, mounted the wooden stage, and introduced his film, The Volcano Show, by telling stories about tilting lakes, lurching mountains, and other signs of impending doom. He had an enormous rusty pipe beside him, which he lifted before dropping it to the floor with a crash. The pipe, he explained to his startled guests, formed part of a line that brought hot water from a kilometre below ground until 1977, when a volcanic eruption flooded it with lava and ripped it apart. Hefting the pipe to his shoulder again, Knudsen turned it toward the audience so they could see the jagged blowhole.

Knudsen had been filming The Volcano Show on the day of the eruption, and soon the assembled group was watching images of a razor-sharp crack in the ground, a kilometre long and the colour of blood. A small section of the Mid-Atlantic Ridge had split open, revealing the guts of a tectonic fissure running through the middle of the country. This is where North America and Europe are pulling away from each other, tearing Iceland in half as they separate.

As unsettling as Knudsen's film may be, there are real advantages to sitting on top of a molten cauldron. Knudsen's pipe once belonged to the same vast underground network that now heats 87 percent of all homes and buildings in Iceland – turn on any hot water tap and you'll catch a sulphurous whiff from the local borehole. Geothermal heat captured far below the surface is used for everything from drying seaweed and producing electricity to de-icing the streets of Reykjavik. In terms of raw, primary energy, it provides half of what Iceland's 300,000 people and the country's

businesses consume each year. Along with hydroelectric dams, the geothermal network has displaced oil as Iceland ‘s major source of energy – displaced it entirely, in fact, except for the fourteen million barrels needed annually by industry and for the nation’s vehicles and fishing fleet.

Being all alone in the middle of the Atlantic Ocean with few resources has economic consequences: Reykjavik is the world’s fourth most expensive city to live in, with gasoline selling for $2.20 a litre. To ensure its future prosperity and provide work for its young and growing population, Iceland has embarked on a massive experiment to use its supplies of cheap energy to produce hydrogen power and be nothing less than oil-free by 2050. “We want to become the first hydrogen society in the world,” says Hjalmar Arnason, caucus chairman of the ruling Progressive Party. “There is no other government that has given such a clear statement.”

Politicians in foreign capitals, with their own citizens growing restless over the spectre of $100-a-barrel oil and crushing home-heating costs, are now starting to take note of Iceland’s attempt to do away with oil. But hardly anyone was paying attention back in 1996, when Arnason met in Reykjavik with officials from Volkswagen to discuss supplying the company with metal. At the meeting, a prominent lawyer, representing a number of European automakers, approached Arnason about an altogether different matter. “This lawyer was not interested in light metals at all,” recalls Arnason. Instead, he suggested looking at hydrogen and fuel cells, saying that the car industry would move in that direction and that Iceland would be the ideal testing ground for the new technology.

So began Iceland’s energy odyssey – an experiment that Canadians who live in smog-filled cities and face escalating gasoline prices might want Ottawa to join, or at least consider. It conceives of a future in which oil and its attendant environmental damage have been vanquished and replaced by clean energy alternatives. But so far, despite the fact that the fuel cells powering Iceland’s revolution are manufactured by Ballard Power Systems in Vancouver, Ottawa’s energy planners seem content to look backward to so-called big-energy solutions. After years of neglect, Canada’s alternative-energy sector produces just 4.5 percent of Canada’s total production. As if declaring its preference, Ottawa gives the oil industry $1.6 billion in subsidies each year, and companies such as Suncor and Canadian Natural Resources will spend nearly $100 billion to develop the Alberta oil sands over the next two decades. In so doing, vast amounts of new carbon

emissions will be created in almost open defiance of the Kyoto Protocol. The situation won't change, says Victoria Liberal MP and former environment minister David Anderson, until Ottawa, like Iceland, is seized by a cleaner vision of the future. "We are light years behind," he says. "Oil has a built-in subsidy advantage, and we haven't compensated the other side by giving subsidies to other energy sources."

The debate doesn't end with oil. The thirst for more energy recently led Ontario to consider, after years of failing to develop its alternative-energy resources, constructing another round of multi-billion-dollar nuclear power plants – a technology so mismanaged in the past that it contributed to the breakup of Ontario Hydro, one of the country's largest companies, leaving the province with a $20-billion debt. (The French energy giant Total has also proposed building a nuclear plant in Alberta to power the extraction of oil from the tar sands.)

Prime Minister Paul Martin recently announced that he wanted Canada to take the lead in renewable-energy technology. But with so much policy emphasis on big energy, many people involved in the renewable-energy sector have their doubts. "It's great to have a vision like that," says Rob McMonagle, executive director of the Canadian Solar Industries Association, "but my comment is, well, Germany has been working on solar for fifteen years while Canada did nothing."

Asked how Canada might finally buy into an oil-free vision of the future, Maria Maack, a senior official in Iceland's hydrogen program, rolled her eyes in disgust, declaring: "You have solar! You have wind! You have hydro! Many countries have geothermal power too, but they are just waiting for the world to run out of oil before they do anything about it."

Iceland is seen by many energy strategists as the ideal place to break the back of oil dependency. "Because we are a small island [with a] small but real-scale infrastructure," explains Arnason, "we have experienced changing from one source of energy to another – we went from coal and petroleum to hydropower and geothermal. It's easier to change the buses in Reykjavik, where we have eighty, rather than, let's say, the thousands of buses you have in London."

Arnason, a slim, soft-spoken man who says he doesn't believe in coincidence, was chairing a parliamentary committee on industry and energy

before his serendipitous meeting with Volkswagen. "So I raised this as a resolution," he says, "a very simple resolution stating that the government should select a task force to look upon this." The resolution passed, though not without ridicule. "My colleagues here were saying, 'Ah, you like hydrogen my friend. The idea is nice, but that's just a science-fiction novel.'"

Initially, little was accomplished, but that changed when Daimler-Benz sent a delegation to Iceland's parliament in 1997, offering to join the country in a sweeping plan to convert it to hydrogen by 2050.

"People woke up and said this might be something serious," says Arnason. " Everything went crazy."

Icelandic New Energy was created in 1999 to supervise the $7-billion project. Forty-nine percent of the company is divided between Netherlands-based Shell Hydrogen, the now-merged DaimlerChrysler of Germany, and Norwegian oil and aluminum giant Norsk Hydro. Shell will supply the country with hydrogen filling stations, Daimler with hydrogen vehicles, and Norsk Hydro with the electrolyzing equipment needed to create fuel by extracting hydrogen from water.

While hydrogen may be the fuel of tomorrow, it's not the only candidate – alternatives vary from biofuels to battery-powered cars. But in Iceland, hydrogen clearly offers the best substitute for petroleum. Biofuels, which require an enormous agricultural land base, aren't an option for a country where only 0.1 percent of the land grows anything more than moss and grass. Battery-powered vehicles were ruled out, according to Maack, because "the best batteries are still polluting and take an entire night to recharge."

Critics of the hydrogen option point out, with reason, that most of the hydrogen made today – some 50 million metric tons a year worldwide, enough to power 200 million fuel-cell vehicles, according to General Motors – is derived from natural gas and produces a considerable amount of carbon dioxide. Others argue that electricity and cleaner-burning fuels like natural gas should be conserved rather than used to make hydrogen, and that research money would be better spent developing mass transit, energy-efficient homes, and alternatives such as solar power.

Iceland, though, has enough untapped geothermal and hydroelectric power to produce hydrogen exclusively from electrolysis – that is, by running an electric current through water to split the molecules. The

Icelandic National Energy Authority estimates that the country could easily produce six times more electricity than it currently does. Ten percent of that would be enough to electrolyze the 100,000 metric tons of hydrogen needed to replace almost all of the country's future oil imports. "Instead of importing fossil fuels," explains Arnason, "we could export hydrogen and import money."

**S**prawled over a small patch of the Reykjanes Peninsula in the southwest corner of Iceland, Reykjavik starts at the gasoline terminal in the west end of town. Tankers from the North Sea pull in every few weeks to refill the glistening white silos built along the shore. Each one holds eight million litres of fuel, and collectively they store the country's gasoline reserve. From here trucks fan out to stock Iceland's 175 gas stations.

By comparison, the emerging hydrogen infrastructure is all but invisible. The tourist office doesn't advertise the hydrogen-powered buses whizzing through the capital, and the bureau's polite receptionist looked at me with a blank expression when I asked where I could find the hydrogen filling station.

For all ReykjavÌk's futuristic aspects – the glass dome of the Pearl Restaurant overlooking the city, wireless Internet in the grocery stores – anyone expecting to see the Jetsons humming around in hydrogen-powered cars is bound for disappointment.

But hydrogen-fuelled buses do run here, and the filling station, the first commercial hydrogen facility in the world when it opened in April 2003, does exist. It's on the opposite end of town from the gas terminal, trying hard to get noticed with a towering aqua-blue sign, visible from the nation's sole freeway, that reads 'The Ultimate Fuel.' Hydrogen is produced on site, electrolyzed inside a mass of pipes, coiled-metal tubes, and compression tanks. The apparatus is on display behind a Plexiglas wall, although the only evidence of any activity is a low, vibrating hum when the hydrogen is being made and compressed.

With only three buses – and not a single car – filling up here, this solitary station exemplifies the chicken-or-egg challenge of building an infrastructure whose parts rely on one another. Because only one facility is available, few people would want to order hydrogen-powered cars, and yet, without such vehicles, who will build another filling station? But that problem is about to be remedied. Virtually every major automaker, according to Ballard, is on the brink of mass-producing hydrogen vehicles. GM hopes to market its first fuel-cell cars in 2010; DaimlerChrysler could

follow by 2012 and plans to sell 100,000 annually. Toyota is planning a high-end, $60,000 version. To encourage sales, the government has exempted hydrogen-fuelled cars from import taxes. And Icelandic energy officials estimate that six filling stations would be enough to make owning the cars feasible in the capital.

Looking further ahead, Icelandic New Energy is crunching numbers on everything from producing hydrogen for export to replacing the national fishing fleet with hydrogen-powered ships. Fishing trawlers currently account for 30 percent of the country's oil consumption. But the long periods that crews remain at sea make this one of the most challenging steps, and the first of the new ships isn't expected to leave port for another ten years. By then, however, all 110 buses in greater Reykjavik could be running on hydrogen. "I thought it would take twenty, maybe thirty years," says Asgeir Eiriksson, managing director of Greater Reykjavik Transport. "But after seeing how well these buses have operated, I would say closer to ten or fifteen."

Curious about their performance, I convinced Rognvaldur Jonatansson, a member of the country's bus-racing team, which competes against other Nordic countries, to pick me up in a hydrogen-powered bus one drizzling afternoon.

"It drives quite similar to a regular bus," he said diplomatically as we headed out. Did he really think he could beat the Norwegians in the next round of races in one of these? He conceded that it was "maybe a little bit slower. But the next generation will be better."

**F**uel cells don't burn hydrogen the way an internal combustion engine does gasoline. Instead, a fuel cell works by peeling electrons off hydrogen atoms and then feeding the current through an electric motor. On this trip, the only noise the bus made came from the brakes and windshield wipers; as well, the only emission was water. Nine computers monitored every performance indicator, and Jonatansson said that anyone at Ballard's headquarters in Vancouver could turn on a computer and see exactly how the fuel cell was performing.

Ballard engineers aren't the only ones watching. Iceland is full of international visitors studying the country's hydrogen experiment. A delegation from Turkey preceded my trip to Iceland's oldest geothermal plant, set in a picturesque valley thirty kilometres outside the capital. And two Scottish parliamentarians were waiting to speak with Arnason after I had coffee with him in the government cafeteria. Jonatansson has chauffeured the presidents of India, China, and General Motors in his

revolutionary bus. "All kinds of goofy characters, he says. "But the president of GM was the nicest. He wore a baseball hat. He was a very funny man."

**I**celand's president, Olafur Grimsson, is not a funny man, and he doesn't wear a baseball hat. He was wearing a black pinstriped suit the day I met him, and he spoke in careful, measured tones. But he likes to talk about hydrogen and has done so with many foreign leaders. "[The president of India] had never experienced going to a hydrogen station or riding a hydrogen bus," Grimsson recalled. "For a small country like Iceland to take the lead in having a dialogue with [India and China], both of them together having almost a third of mankind, is a major contribution to the energy future of the world."

**H**ydrogen may be the most common element on earth, but since virtually all of it is bound up in molecular compounds like water, that abundance is misleading. It takes a great deal of energy to create pure hydrogen – so much, in fact, that critics claim it will never become a dominant source of energy.

With soaring petroleum prices, however, the energy equation may be tilting in hydrogen's favour. At the start of the oil age a century ago, the energy from a single barrel of oil used in the development of an oil field yielded a hundred barrels in return. Now, many fields are being pumped dry, and the global average has dropped to ten barrels of oil for every barrel expended to produce it. Alberta's oil sands currently yield as little as one-and-a-half barrels for every barrel used to extract oil. Once the ratio falls to one-for-one, there won't be much point in drilling for the last few drops, and hydrogen just may become an economical alternative.

Studying the competitive difference between oil and hydrogen has preoccupied Bragi Arnason (no relation to Hjalmar), a retired chemist at the University of Iceland, for years. During the OPEC oil embargo in the 1970s, Arnason criss-crossed the country to map out its geothermal resources. He was one of the first to realize that the energy lying underground far exceeded the amount of petroleum his country imported each year. In 1978, he published his first paper arguing for displacing oil with hydrogen, which earned him the dismissive moniker Professor Hydrogen. Recalls Arnason, "People used to say, 'Well, it's a beautiful vision, very elegant, but we are

just not ready yet.'"

Now seventy, with a shock of white hair, and a bad back from a recent fall, Arnason is getting old. But he still plays his role as Iceland's hydrogen ambassador.

"Hydrogen costs twice as much to produce as gasoline," he says, pronouncing hydrogen with a hard g, as in get. "But that doesn't tell the whole story. You see, a fuel cell is twice as efficient as an internal combustion engine. Hydrogen also contains three times as much chemical energy as gasoline, so while a car might go 400 kilometres on twenty-four kilograms of gasoline, only four kilograms of hydrogen are needed to drive the same distance."

The real competitive problem with hydrogen, argues Arnason, is storage. Four kilograms of hydrogen take up forty-five cubic metres of space at room temperature. That can be compressed to some extent; Reykjavik's hydrogen buses store enough fuel to drive half the distance of their gasoline counterparts. Nevertheless, "It is a fact, Arnason admits, "that no one would buy a hydrogen car if it can't go as far as a gasoline car."

But recent technological advances may allow hydrogen to squeeze through that competitive bottleneck. Solutions range from storing hydrogen in magnesium powder and then heating it to release the hydrogen or storing it in ultra-high-pressure tanks. "GM has just test-run a car that drove 480 kilometres on a single filling," Arnason happily reports. "These days, I am getting calls from all the Japanese automakers who promise me, "Bragi, we will have hydrogen cars on the market by the end of the decade."

Despite importing almost all of its oil, Japan faces a reluctant public that associates hydrogen with the destruction of Hiroshima in the deadliest explosion in history. On a blustery morning at the University of Iceland campus, I found myself at a seminar alongside seventeen delegates from the Japanese Society of Energy and Resources, who were looking for advice on how to sway public opinion in favour of hydrogen. The advice given by Maack boiled down to a replay of Nike's famous dictum: just do it. "One of the biggest differences between our societies," she explained to her audience, "is that we don't worry about etiquette. There are no rules in Iceland about who can say what and to whom. If I want the prime minister to bring something up in parliament, I can tell him about it when I see him at the hot tub in the morning – and I do." She has little patience for critics. "Ours is an Icelandic solution to an Icelandic problem," says Maack. "But I can't save the world from running out of oil. Energy is everywhere. Figure it out for yourselves how to get it."

**F**iguring it out in Canada always seems to lead to the same conclusion: produce more oil. That is somewhat ironic in light of the fact that in 1979, just as Bragi Arnason was starting to conceptualize Iceland's hydrogen economy, Ballard Research was opening its doors. By 1983, scientists at Ballard had invented a prototype of the fuel cell that is now key to making Iceland's oil-free dream a reality.

Ballard continued refining its technology largely in anonymity until 1993, when Daimler bought into the company, which is now known as Ballard Power Systems. Twelve years later Ballard is one of the world's leading manufacturers of fuel cells, and its technology is powering 130 hydrogen vehicles in Iceland, Europe, Vancouver, Australia, and California. If the numbers sound modest, the client list does not. It includes Daimler, Ford, Honda, the European Union, and the Japanese government, which in 2005 spent almost $27 million to subsidize the installation of Ballard fuel cells in individual homes to produce electricity.

Research into the development of a hydrogen-based economy is also taking place at Prince Edward Island's Wind-Hydrogen Village, which is being developed by Hydrogenics, an Ontario company. Hydrogenics scientists hope to use a windmill to produce the electricity needed to create hydrogen, which will in turn be used to power vehicles, a ferry, and several homes and buildings in Canada's first hydrogen-powered community. It will take years to develop, but scientists point out that the industry has already come a long way. "The thing to remember is that we're using a nascent technology that has only been developed for automotive applications in the last twelve years," says Noordin Nanji, Ballard's vice-president of marketing.

According to a 2004 survey produced by Pricewaterhouse Coopers, the Canadian hydrogen-technology sector employs a third of all scientists and technicians working in the field around the world. And due at least in part to hydrogen's political currency, in 2003 Ottawa agreed to give the industry $215 million for research and development over five years. In contrast, the EU has committed $2.5 billion, and the Bush administration, no enemy of the internal combustion engine, has earmarked $3.8 billion.

Canada, some analysts say, is being held back in the production of hydrogen and alternative fuels precisely because the country holds vast oil and gas resources. Nowhere is this more apparent than in the Alberta oil sands. "We have [governments] really focused on the tar sands, says McMonagle, of the Solar Industries Association, "but 30 or 40 percent of natural gas production is going to be used to generate the heat required to get the oil out. But that in turn is using up another valuable source of energy. So

we're going around in circles without saying, "Where do we want to be in forty or fifty years?" NDP leader Jack Layton points out that in the wake of the energy crisis in the 1970s a number of initiatives, including research into wind turbines and cars powered by hybrid gas/electric motors, sprang up in Canada. But then the price of oil fell and the push to develop alternative-energy sources slowed. Since then, Layton says Canada has been languishing at the back of the pack, with little commitment to developing clean energy sources. "We have put so much investment into fossil-fuel exploration and production, while doing orders of magnitude less on renewables," says Layton. "The result is that our greenhouse-gas emissions have gone up faster than the United States." People involved in the alternative-energy sector believe Ottawa must play a bigger role. "European countries like Spain, Germany, and Denmark have used something called a Standard Offer Contract," says Robert Hornung, president of the Canadian Wind Energy Association. "They essentially go to the utilities and say, 'Look, we're going to pass a law that says if somebody wants to build wind energy, you have to buy it and you have to buy it at this price.' So it guarantees demand."

In 1999, Spain produced the same amount of electricity generated by wind as Canada. Now, Spain has 8,000 megawatts in place and expects to have 20,000 by 2011. Canada, by comparison, has 590 megawatts of installed capacity and is aiming for 7,500 megawatts by 2013. "What that does is take us from being out of the game totally to being in the middle of the pack," says Hornung. "If we look around, we can see that a country like Germany put in 10,000 megawatts of wind energy in the last four years. And yet Canada has a much better wind resource." In fact, the Wind Energy Association calculates that Ontario alone has the potential to produce 40,000 megawatts, and puts Quebec's potential at a whopping 100,000 megawatts – nearly equivalent to the country's entire electrical consumption. "Canada's wind resource is probably unparalleled," says Hornung. "I mean, Russia might have a better resource but that's about it."

Canada's solar association, meanwhile, estimates that 70 percent of the country's homes could be retrofitted with solar hot-water heating and 40 percent with electricity-generating photovoltaic cells. The sector is benefiting competitively as oil prices rise and the cost of photovoltaics drops. "There's a price reduction on average of about 3 percent a year," says McMonagle. "We're running at $10 a watt now, where twenty years ago we were running at $100 a watt." Despite this, Canada isn't investing in the technology. "In Germany they grew [photovoltaics] by 87 percent last year," notes McMonagle. "They installed 316 megawatts on the grid,

whereas we installed 0.1 megawatts."

Although it's rarely discussed in this country, Canada also has considerable potential as a producer of geothermal energy. Mory Ghomshei, chair of the Canadian Geothermal Energy Association, puts British Columbia's geothermal potential at 3,000 megawatts, more than enough to power the Greater Vancouver region. "All the countries around the Pacific Rim have developed their geothermal power except Canada," says Ghomshei. "In the Philippines about 25 percent of the total electric power capacity is geothermal."

Heat-drawing geothermal pumps could help warm buildings throughout the country. "It's simple enough to drill a well," explains Kenneth Macleod, another director at the association. "Anything from thirty to fifty metres down will provide as much as 70 percent of the [heating] requirements of your home. With today's energy prices, by installing heat-pump geothermal technology, you can recover your costs in anything from five to fifteen years. From then on it's free."

**C**anada invited world scrutiny of its addiction to big energy this fall by hosting the United Nations climate conference in Montreal. It was the first meeting of representatives from governments and the private sector since the Kyoto Protocol came into effect in February. Albert Koehl, a lawyer with the Sierra Legal Defence Fund, says that since 1997, when Canada first agreed to reduce greenhouse gases, Ottawa has been spending $2 a barrel on oil and gas tax subsidies for every $1 it has spent on reaching its Kyoto goal. "We are asking the obvious question," says Koehl. "How can this possibly be part of a consistent government policy?"

**I**celand's president Grimsson lives in a centuries-old stone mansion perched on the edge of a peninsula with a view of the capital across the water. A cold and ever-present wind was buffeting the ocean when I arrived, but the sun shone and Reykjavik glistened beneath snow-capped hills. I asked Grimsson how this tiny nation had the imagination to envision becoming the first oil-free country in the world. "We are like a Renaissance melting pot of influences from all over the world," he replied. "That has created a very dynamic society. Although it is geographically isolated, it has always been willing to blend influences from afar with our own thinking. Perhaps that is because we are so confident in our own traditions."

As I left, I couldn't help thinking of the giant but solitary windmill that

cuts through the polluted haze on Toronto's waterfront, the work of Toronto Hydro and a local energy co-op. It stands in sad contrast to the massive hydrogen experiment under way in Iceland, which has spent the last forty years weaning itself off oil. Theirs is but the final stage of a transition for which Canada has yet to lay the foundations. Here at home, neck-deep in tar sands, floundering over Kyoto, with our glaciers shrinking and our smog index rising, perhaps the question isn't how long will the oil last, but rather will it run out soon enough?