

From Petroleum to Hydrogen

Costa Rica's Tantalizing Carbon-Free Possibility

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More than 130 years ago in tiny Costa Rica, Victor Manuel Dengo and Luis Batres illuminated the city of San José with electricity, making it one of the few cities in the world to begin to free themselves from kerosene for lighting. With this bold action, the two pioneers defied all possible logic, considering the size and humility of their small capital city at that time. But this event is not alone; throughout its history, from the abolition of its army in 1948 to its commitment to education and environmentalism, Costa Ricans have shed developing world stereotypes and embraced innovation.

Today, once again, despite being a small country, Costa Rica could dare to dream of a carbon-free energy self-sufficiency, which although already nearly achieved in electricity, is still pending in transportation. In recent years, our team has been studying a gradual transition of Costa Rica's transportation infrastructure from imported oil to hydrogen, a clean fuel that can be domestically produced.

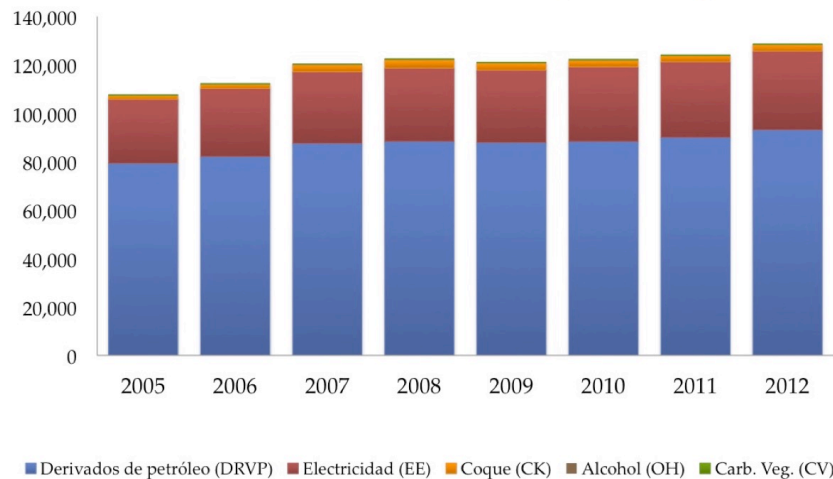
Several developed countries are pursuing this goal, supported by new technologies, reduced costs and concern for the environment (see map). For Costa Rica, this would be a gradual transition, requiring significant investment in infrastructure that, at the end of the day, would free the nation from its dependence on imported and polluting fossil fuels. For Costa Rica, this is a tantalizing possibility.



Hydrogen stations worldwide (source: <http://www.netinform.net/h2/H2Stations/Default.aspx>)

The data support the concept

Costa Rica consumes about 130,000 TJ (terajoules) of energy per year or 3.6×10^{10} kW-hr. (1TJ is equal to 277,778 kW-hr). Of that total, the electrical consumption is less than 30%. The country generates more than 90% of its electricity from renewable sources. Unfortunately, the highest energy consumption of Costa Ricans remains the hydrocarbon-based vehicular transport requirement; about 100,000 TJ burned every year in the country's congested roads (see chart).



Energy consumption (terajoules) in Costa Rica 2005-2012 (source: Recope)

Using only its wind and solar resources, Costa Rica could produce enough hydrogen to fuel its entire transportation needs. Our recent estimates, made with an abundance of conservatism, in collaboration with experts from the National Renewable Energy Laboratory of the United States (NREL), indicate that the country's solar and wind combined potential could be greater than 100,000 TJ, enough to replace petroleum. More detailed studies could reveal even more persuasive numbers.

Hydrogen is the simplest, lightest and most abundant element we know. It is not a biofuel or a hydrocarbon, although both of these contain hydrogen. On Earth, hydrogen is always bound to other elements such as carbon and nitrogen in hydrocarbons (oil, natural gas) and in plants and animals (biomass) or directly to oxygen in water. Therefore, to use hydrogen, we must first set it free and this requires energy. The value proposition is precisely this energy, which can be partly recovered and used when hydrogen recombines back with atmospheric oxygen to produce pure water.

Hydrogen is, therefore, not a source of energy on our planet (at least until we succeed in controlling thermonuclear fusion), but a way of storing energy, an "energy vector." Kilogram for kilogram, hydrogen packs far more energy than any other fuel. Its disadvantage is, however, its low density, so we have to compress or liquefy it to make it attractive and this requires additional energy. However, even with this added energy "tax," hydrogen from solar and wind sources, retains

its appeal and continues to gain ground in the energy mix of developed countries, especially those lacking domestic sources of fossil fuels.



Hydrogen filling station, Torrance, California, two vehicles fill up with hydrogen in 5 to 10 minutes. Dispenser screen (top, left) shows full service cost (source: Ad Astra Rocket Company)

In an electric vehicle powered by hydrogen fuel cells (FCEV), hydrogen in the tank of the car is combined with oxygen from the air to produce electricity that drives the vehicle and water vapor, which is discarded. The carbon footprint is zero. Modern hydrogen vehicles use compressed hydrogen at pressures of 350 to 700 atmospheres (~5,000 to 10,000 psi). One kilogram of hydrogen contains about the same energy as a gallon (3.8 liters) of gasoline. Hydrogen vehicles, such as the Toyota Mirai or Hyundai Tucson, store ~5 kg of hydrogen in their tanks, which provides a range of about 450 km (equivalent to ~24 km/liter, a rare level of performance in a gasoline vehicle). That range is also higher than a battery electric vehicle with the additional advantage that the hydrogen tank is filled in ~5-10 minutes, compared with fully charging a battery, which requires several hours. In the domestic market for hydrogen vehicles in the United States, the cost to the consumer of a kg of hydrogen delivered to the vehicle tank is about \$5.0, the approximate cost in Costa Rica of a gallon of gasoline. However, the range of the hydrogen vehicle at that price, compared with gasoline, is more than double. In other words, the cost per kilometer is reduced to less than half.

When natural gas is abundant, hydrogen can be produced by "reformation," a process, which combines natural gas and water vapor at high temperatures. In these regions, the use of hydrogen instead of the natural gas is subject to debate. However, some communities in the United States have implemented reformer hydrogen for vehicular applications. In countries like Costa Rica, with no natural gas but with abundant wind and solar energy, hydrogen can be released by water electrolysis. That process is being explored in several niche markets in Canada, Japan, Europe, and in some states in the United States.

The Ad Astra – Recope hydrogen project in Costa Rica, delivered on December 20, 2013, a pilot hydrogen production and storage plant with the most advanced technology. The plant is the first in Central America and third in Latin

America (after Brazil and Argentina) and produces hydrogen by electrolysis of water, storing it at pressures of 700 atm (the new standard in the industry). The integrated system is located 10 km west of the city of Liberia in the province of Guanacaste.



Hydrogen production and storage facility in Liberia, Guanacaste, Costa Rica. Ad Astra – Recope Project (source: Ad Astra Rocket Company)

The possible applications of hydrogen for transport go far beyond private vehicles, also including mass transit buses, trains and service vehicles in warehouses and airports. Companies like Bridgestone, Procter & Gamble and FedEx, among others, have moved to hydrogen vehicles for their operations. Wal-Mart, for example, already has more than 2,000 hydrogen forklifts in their centers of operations, replacing battery driven units.



1. Connecticut Hydrogen Metro bus (source: Connecticut Department of Transportation); 2. Qingdao Sifang Co. Hydrogen Tram, (source: Bloomberg Business); 3. Plug Power GenDrive forklift (source: Plug Power); 4. Toyota Mirai, (source: Toyota); 5. FedEx Hydrogen Service Vehicle, Memphis TN Airport (source: FedEx); 6. Hyundai Tucson FCEV, (source: Hyundai)

Skepticism is normal when paradigms are being broken

It is healthy and natural for any new technology to see skeptics who reject it. Hydrogen is no exception. But before considering it a pipe dream, it is important to assess the large investments from companies like Toyota, Hyundai, GM, Honda, BMW, Mercedes Benz, and many others, and their careful market research and field testing of technology over several years. In 1997, Toyota made a calculated business bet by introducing its pioneering Prius hybrid model to the mass market. Today sales exceed 6 million cars and have stimulated competition from other companies with similar models. Next year, two companies will debut hydrogen vehicles: the Hyundai Tucson and the Toyota Mirai. Honda and GM plan to introduce hydrogen vehicles in the coming years. In Costa Rica, Purdy Motor Company wants to bring the Mirai to the domestic market. Skepticism or not, technology moves forward. It is worth recalling some statements of experts in the past.

"It is doubtful if aeroplanes will ever cross the ocean.... The public has greatly over-estimated the possibilities of the aeroplane, imagining that in another generation they will be able to fly over to London in a day. This is manifestly impossible." — William Pickering, astronomer, Harvard University, 1908

"In the opinion of competent experts it is idle to look for a commercial future for the flying machine. There is, and always will be, a limit to its carrying capacity which will prohibit its employment for passenger or freight purposes in a wholesale or general way. There are some, of course, who will argue that because a machine will carry two people another may be constructed that will carry a dozen, but those who make this contention do not understand the theory of weight sustentation in the air." — W. J. Jackman and Thomas Russell, Flying Machines: Construction and Operation, 1912.

Respecting those who may differ and regardless of the discussions that are generated, our team sees hydrogen as an extraordinary opportunity for Costa Rica. The solar and wind "crude" is free and the funds used to produce hydrogen from this resource in Costa Rica will stay at home, generating jobs and indigenous technology that could even be exported. After 130 years, the organic and gradual transformation initiated by Dengo and Batres should continue to a full energy self-sufficiency and carbon free horizon, ensuring a more sustainable environment for our children and grandchildren. The future has arrived.