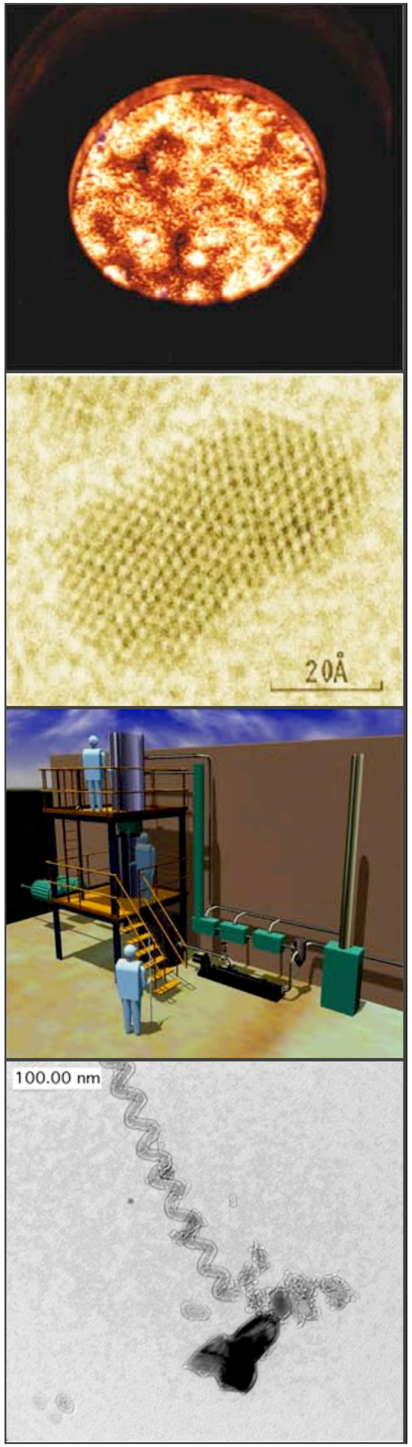

Research challenges in sustainable H_2 production

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What is hydrogen reformation?

- The process of extracting H_2 from a feedstock via thermochemical, electrochemical, photo-electrochemical or photobiological reaction[1].
- The process can be centralised (i.e. at a refinery, which then requires H_2 storage and transport) or decentralised (i.e. at the point of use, which involves conversion of a hydrogen containing fuel such as methanol)[1].
- Currently 96% of H_2 produced today is derived from fossil fuels - which rather defeats the point of using it in the first place[2].

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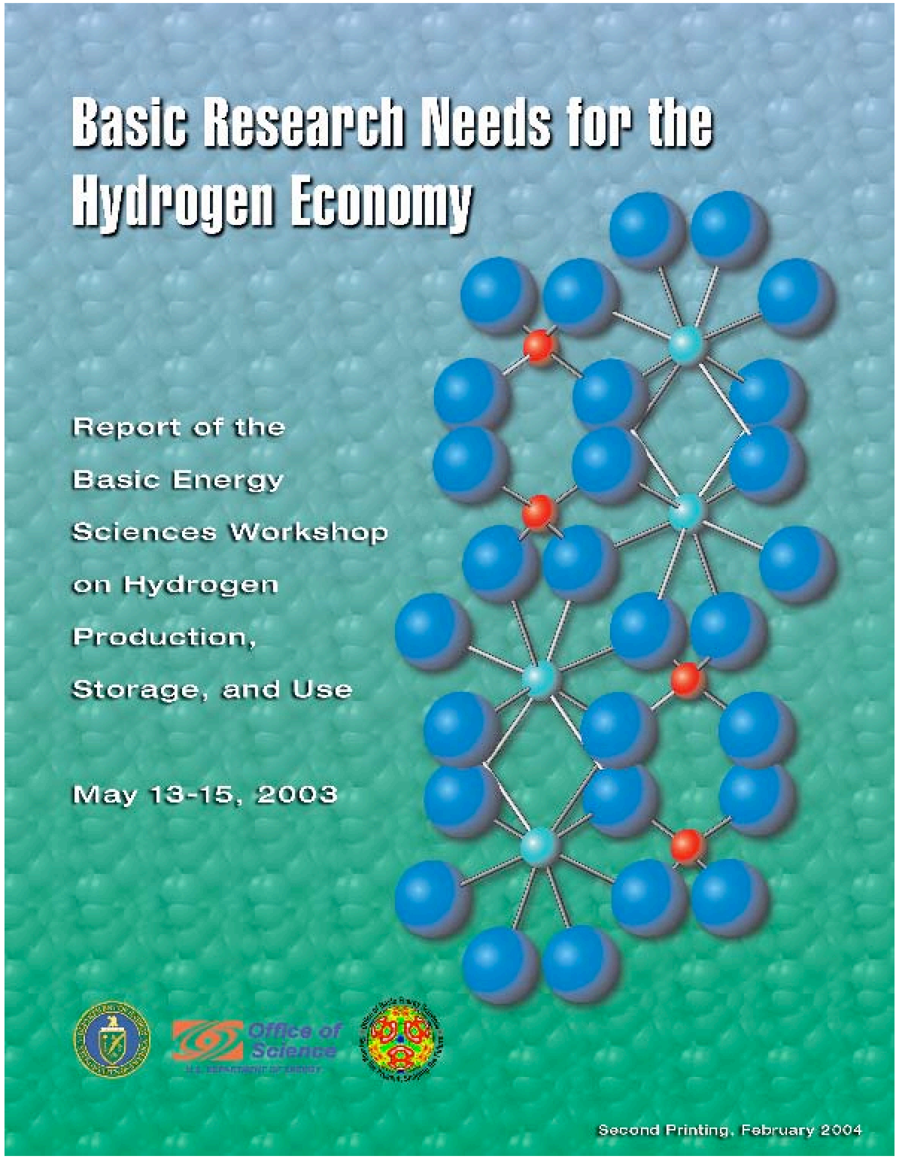
1. www.crest.org
2. Florin, N.H. and Harris, A.T. (2007) “Hydrogen production from biomass”, *The Environmentalist*, Vol. 27, No. 1, pp 207-215.



Basic Research Needs for the Hydrogen Economy

Report of the
Basic Energy
Sciences Workshop
on Hydrogen
Production,
Storage, and Use

May 13-15, 2003

Second Printing, February 2004

The Hydrogen Economy

If the fuel cell is to become the modern steam engine, basic research must provide breakthroughs in understanding, materials, and design to make a hydrogen-based energy system a vibrant and competitive force.

George W. Crabtree, Mildred S. Dresselhaus,
and Michelle V. Buchanan

Since the industrial revolution began in the 18th century, fossil fuels in the form of coal, oil, and natural gas have powered the technology and transportation networks that drive society. But continuing to power the world from fossil fuels threatens our energy supply and puts enormous strains on the environment. The world's demand for energy is projected to double by 2050 in response to population growth and the industrialization of developing countries.[1] The supply of fossil fuels is limited, with restrictive shortages of oil and gas projected to occur within our lifetimes (see the article by Paul Weisz in PHYSICS TODAY, July 2004, page 47). Global oil and gas reserves are concentrated in a few regions of the world, while demand is growing everywhere; as a result, a secure supply is increasingly difficult to assure. Moreover, the use of fossil fuels puts our own health at risk through the chemical and particulate pollution it creates. Carbon dioxide and other greenhouse gas emissions that are associated with global warming threaten the stability of Earth's climate.

A replacement for fossil fuels will not appear overnight. Extensive R&D is required before alternative sources can supply energy in quantities and at costs competitive with fossil fuels, and making those alternative sources available commercially will itself require developing the proper economic infrastructure. Each of those steps takes time, but greater global investment in R&D will most likely hasten the pace of economic change. Although it is impossible to predict when the fossil fuel supply will fall short of demand or when global warming will become acute, the present trend of yearly increases in fossil fuel use shortens our window of opportunity for a managed transition to alternative energy sources.

Hydrogen as energy carrier

One promising alternative to fossil fuels is hydrogen[2,3] (see the article by Joan Ogden, PHYSICS TODAY, April 2002, page 69). Through its reaction with oxygen, hydrogen releases energy explosively in heat engines or quietly in fuel cells to produce water as its only byproduct. Hydrogen is abundant and generously distributed throughout the world without regard for national boundaries; using it to create a hydrogen economy—a future energy system based on hydrogen and electricity—only requires technology, not political access.

Although in many ways hydrogen is an attractive replacement for fossil fuels, it does not occur in nature as the fuel H_2. Rather, it occurs in chemical compounds like water or hydrocarbons that must be chemically transformed to yield H_2. Hydrogen, like electricity, is a carrier of energy, and like electricity, it must be produced from a natural resource. At present, most of the world's hydrogen is produced from natural gas by a process called steam reforming. However, producing hydrogen from fossil fuels would rob the hydrogen economy of much of its raison d'être: Steam reforming does not reduce the use of fossil fuels but rather shifts them from end use to an earlier production step; and it still releases carbon to the environment in the form of CO_2. Thus, to achieve the benefits of the hydrogen economy, we must ultimately produce hydrogen from non-fossil resources, such as water, using a renewable energy source.

Figure 1 depicts the hydrogen economy as a network composed of three functional steps: production, storage, and use. There are basic technical means to achieve each of these steps, but none of them can yet compete with fossil fuels in cost, performance, or reliability. Even when using the cheapest production method—steam reforming of methane—hydrogen is still four times the cost of gasoline for the equivalent amount of energy. And production from methane does not reduce fossil fuel use or CO_2 emission. Hydrogen can be stored in pressurized gas containers or as a liquid in cryogenic containers, but not in densities that would allow for practical applications—driving a car up to 500 kilometers on a single tank, for example. Hydrogen can be converted to electricity in fuel cells, but the production cost of prototype fuel cells remains high: $3000 per kilowatt of power produced for prototype fuel cells (mass production could reduce this cost by a factor of 10 or more), compared with $30 per kilowatt for gasoline engines.

The gap between the present state of the art in hydrogen production, storage, and use and that needed for a competitive hydrogen economy is too wide to bridge in incremental advances. It will take fundamental breakthroughs of the kind that come only from basic research.

Beyond reforming

The US Department of Energy estimates that by 2040 cars and light trucks powered by fuel cells will require about 150 megatons per year of hydrogen.[3] The US currently produces about 9 megatons per year, almost all of it by reforming natural gas. The challenge is to find inexpensive

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3. Report of the US DoE Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use, May 13–15, 2003. (http://www.sc.doe.gov/bes/reports/files/NHE_rpt.pdf)
4. George W. Crabtree, Mildred S. Dresselhaus, and Michelle V. Buchanan, The Hydrogen Economy, *Physics Today*, December, 2004, pp 39-45.

What are the broad research challenges[5]?

1. Dramatically lower the cost of fuel cells for transportation,
2. Develop a diversity of sources for hydrogen production at energy costs comparable to gasoline,
3. Find viable methods of on-board storage of hydrogen for transportation uses, and
4. Develop a safe and effective infrastructure for seamless delivery of hydrogen from production to storage to use.

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5. US Secretary of Energy Spencer Abraham, address to the National Hydrogen Association (March 5, 2003); available at http://energy.gov/engine/content.do?PUBLIC_ID=13384&BT_CODE=PR_SPEECHES&TT_CODE=PRESS RELEASE.

What are the specific research areas?

- Catalysis[3] (catalytic performance currently limits fuel cell efficiency, storage kinetics and production capacity).
- Nanostructured[3] and other materials.

[3] Report of the US DoE Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use, May 13–15, 2003. (http://www.sc.doe.gov/bes/reports/files/NHE_rpt.pdf)

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- Characterisation and measurement techniques[3] (e.g. neutron scattering techniques which are especially sensitive to H).

[3] Report of the US DoE Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use, May 13–15, 2003. (http://www.sc.doe.gov/bes/reports/files/NHE_rpt.pdf)

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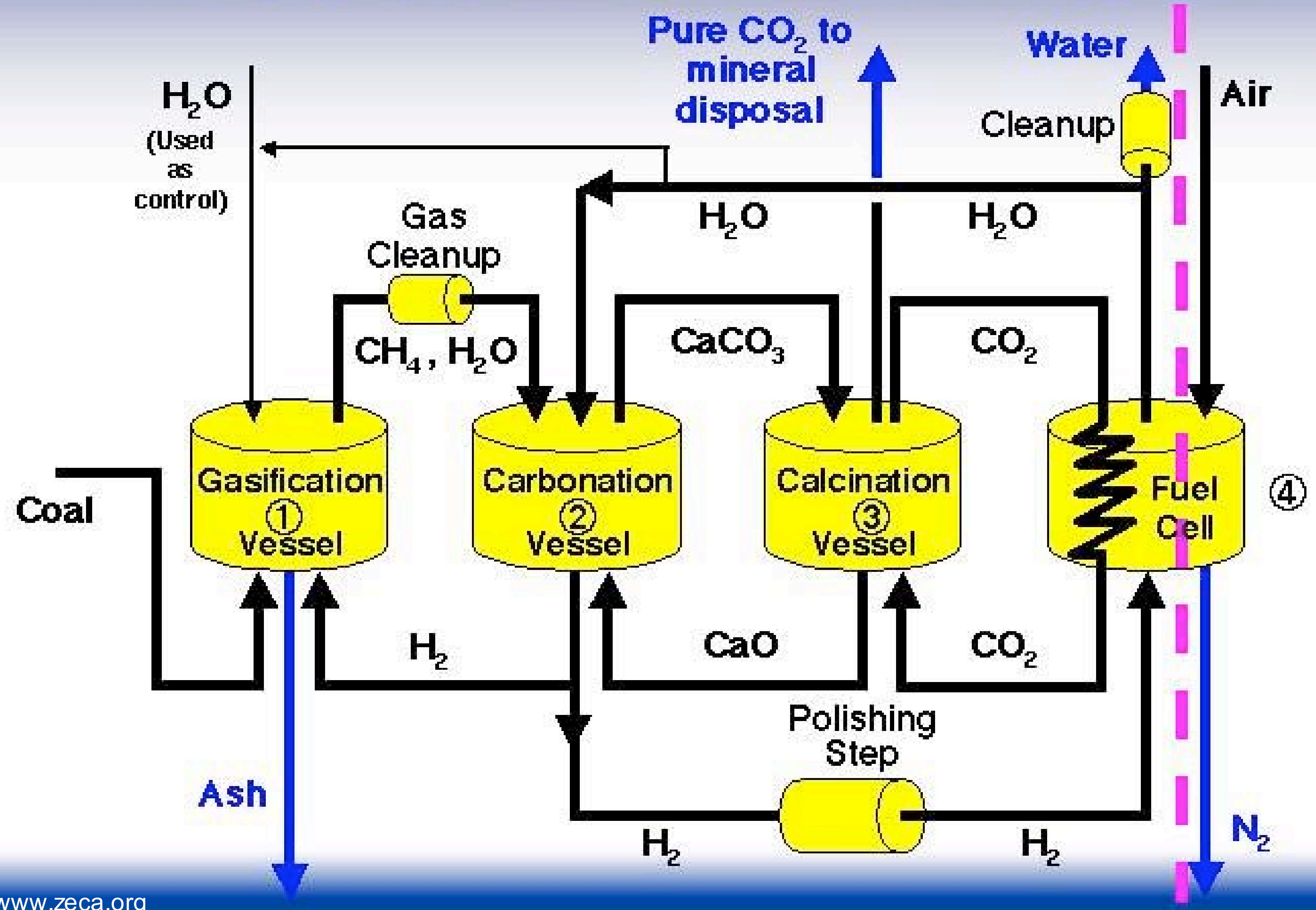
Some things to consider…

- Research targets are strongly multidisciplinary, in particular requiring expertise in biology…perfect for chemical engineers!
- Excellent opportunities for international ‘collaboration’.
- Expensive, so need to choose wisely.
- Incremental improvements won’t cut it…

www.fossil.energy.gov/programs/powersystems/futuregen/

Inside a ZEC Power Plant



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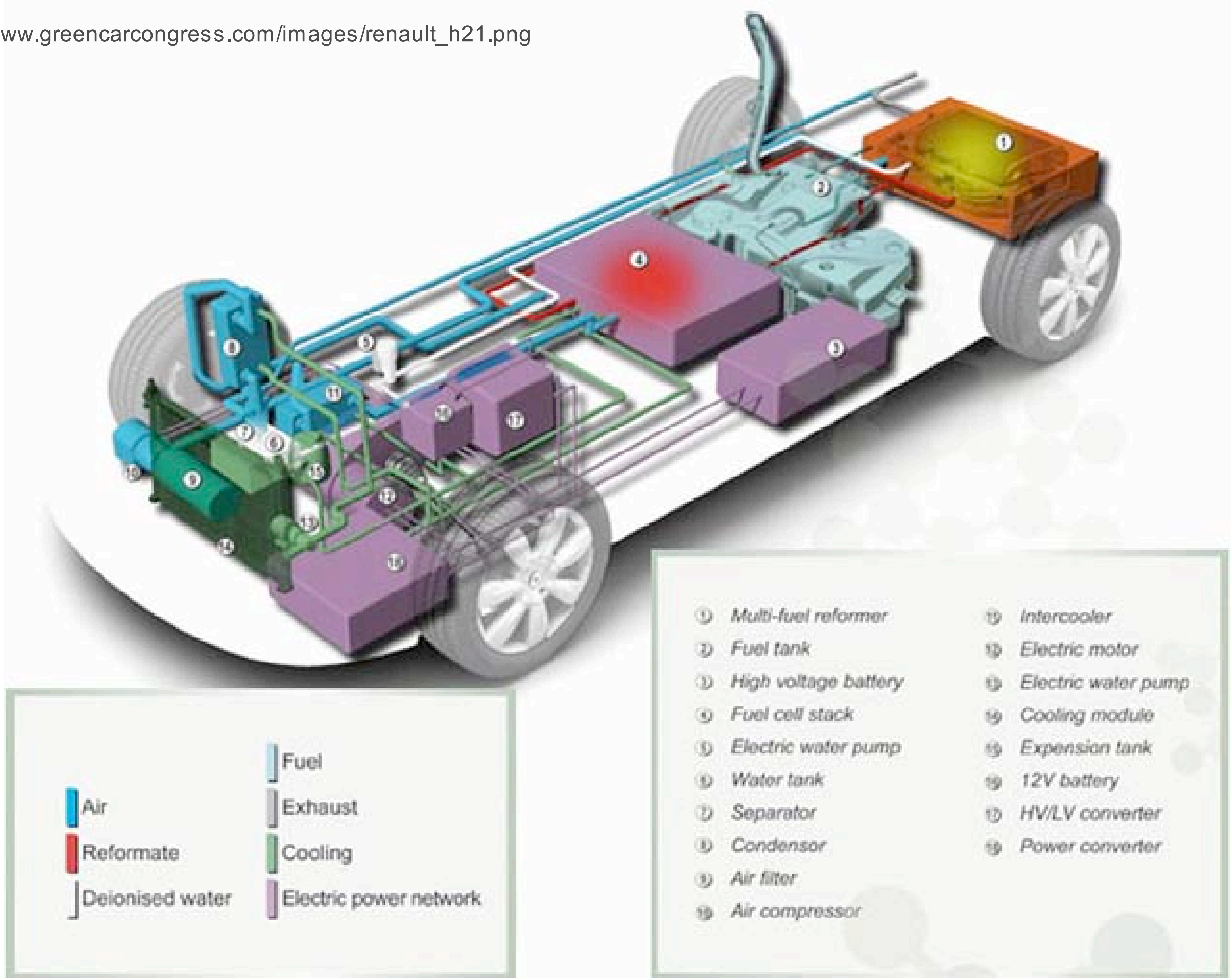

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