The Hydrogen Myth

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Stephen Fleming

- 12+ years investment experience.
  - General Partner, Alliance Technology Ventures.
  - 18 investments as lead investor, 15 exits to date.
- BS, Physics, Ga. Tech *(Highest Honors)*.
- 15 years operational experience at AT&T Bell Labs, Nortel, LICOM *(venture-backed startup)*.
  - Supervised startups developing first ADSL modem and one of the first cablemodems in early 1990s.
- Multiple advisory boards at Georgia Tech; endowed chair in telecomm; occasional instructor in MBA entrepreneurship program.
- Strong regional technology leader.

Disclaimer

- All material in this presentation reflects the personal opinion of Stephen Fleming, and does not necessarily represent the position of Georgia Tech, the University System of Georgia, or the State of Georgia. And that's a damned shame.

Further Disclaimers

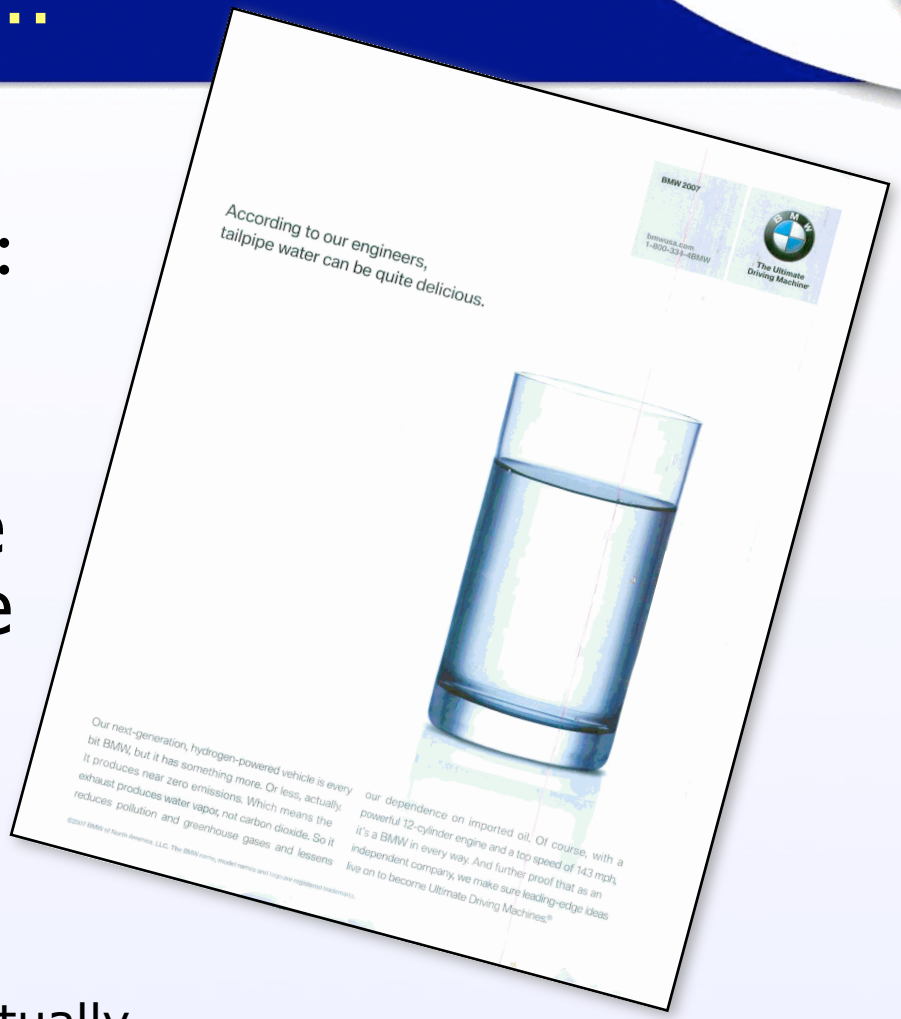
- Please don't confuse the debate by throwing in references to hydrogen *fusion*. Large-scale fusion would be wonderful, but we don't know how to do it yet.
- The much-derided "cold fusion" would be even better, but we don't know how to do it yet, either. (But hope springs eternal…)
- Everything in this presentation refers to *burning* hydrogen, either in an internal combustion engine or in a fuel cell.

The Hydrogen Hype

- Clean-burning
- No CO_2 emissions
- Inexhaustible supply

The Promises…

BMW ad, June 2007:

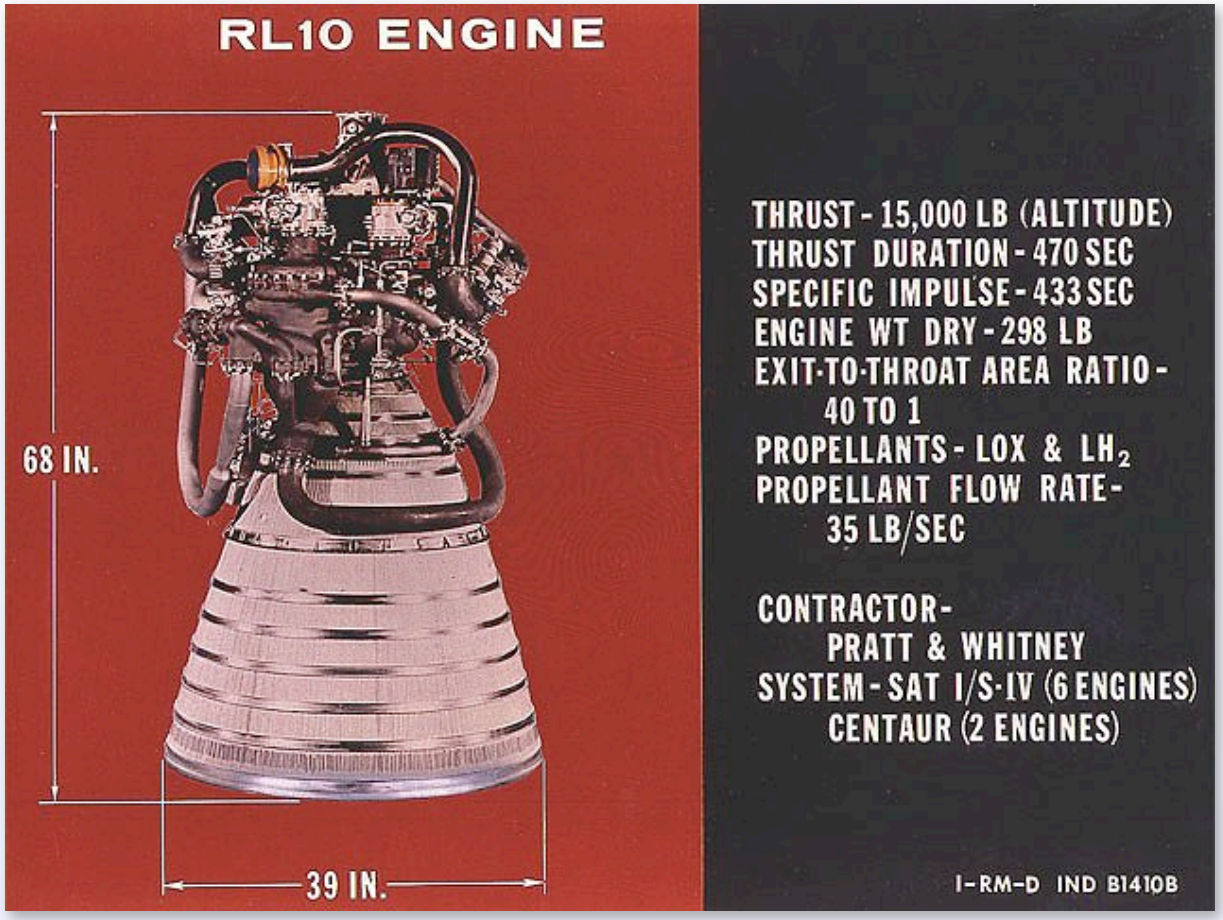


According to our engineers, tailpipe water can be quite delicious.

Our next-generation hydrogen-powered vehicle is every bit BMW, but it has something more. Or less, actually. It produces near zero emissions. Which means the exhaust produces water vapor, not carbon dioxide. So it reduces pollution and greenhouse gases and lessens our dependence on imported oil.

Not So Fast…

Hydrogen Experience



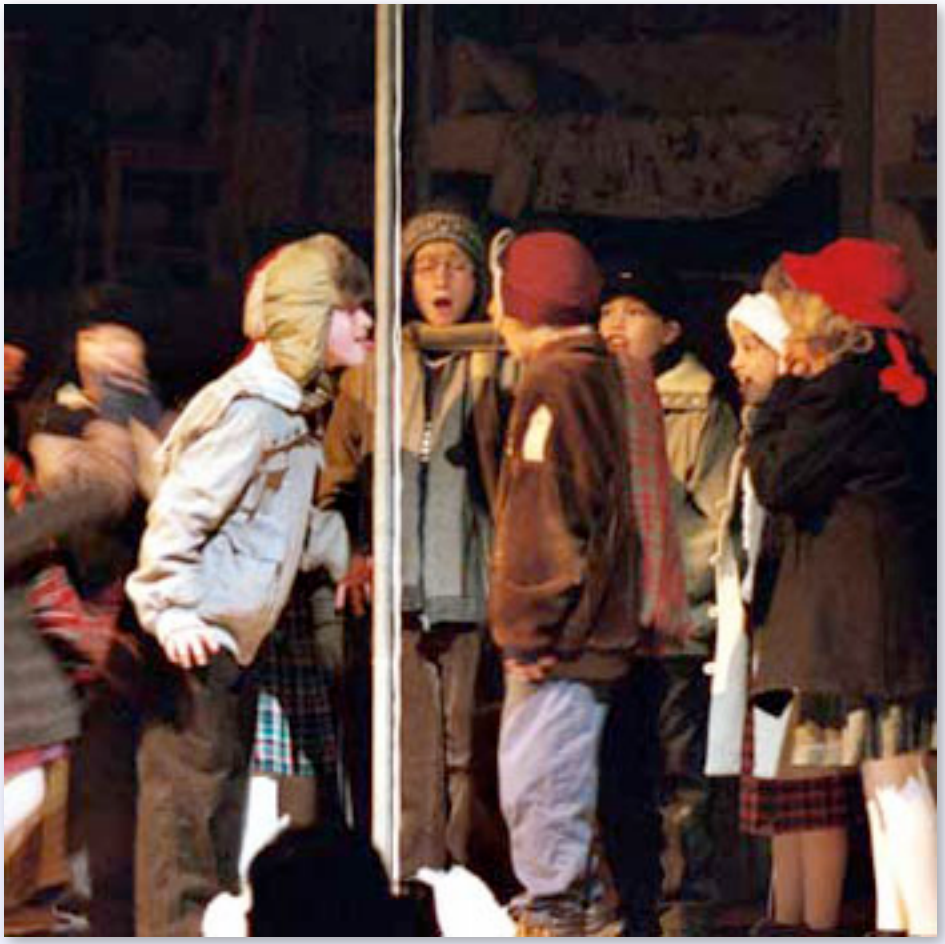
We've been using hydrogen as a fuel for quite a while now. The RL-10 engine will turn 50 next year!

Problems with Hydrogen

- The opposite of dense
  - That's why you lift dirigibles with it!
  - Not good when you want to fill a fuel tank
- Difficult to work with
  - Hard to carry useful quantity in gaseous state
  - Hard to maintain liquid state
    - Boils at -423°F (20°K)… *seriously* cryogenic
  - Hard to maintain under high pressure
    - Passes through most standard pipes, tubes, valves, gaskets, etc.
    - Compressing takes 30% or more of energy content

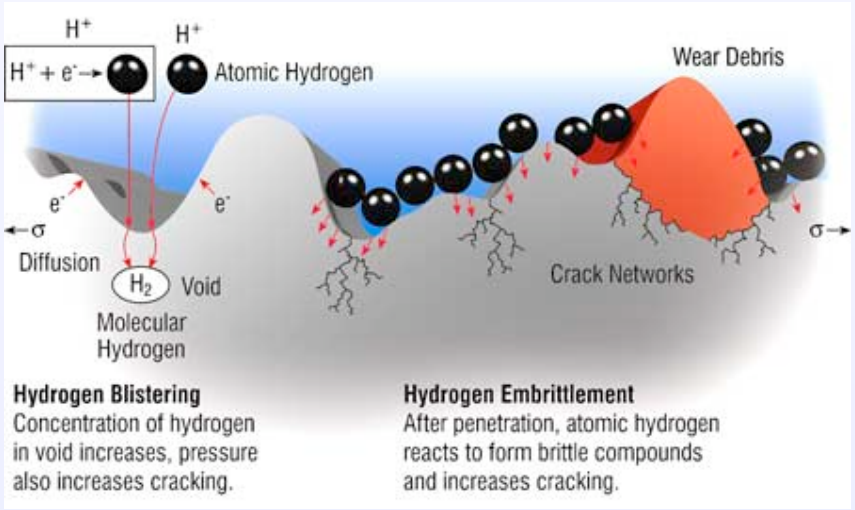
Cryogenic Storage

- Imagine the corner mechanic trying to deal with cryogenic storage…
- Requires special equipment, training, and working brain cells!



Embrittlement

- H_2 molecule is so small that it penetrates most metals
  - Crack propagation leads to embrittlement
  - Continuous maintenance
  - Chance of catastrophic failure

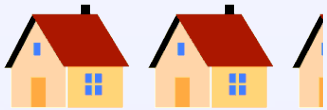
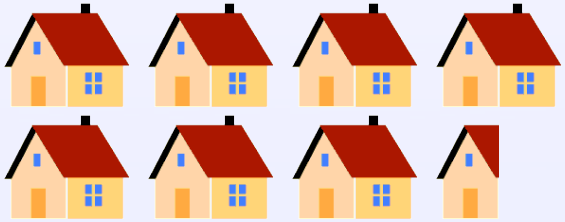


5-Gallon Energy Density

How much energy is contained in a 5-gallon tank of fuel?

(*not* counting volume of insulation or pressure vessel required for H_2 tanks)

 = daily power consumption of typical American home

Compressed H_2 gas*	24.7 kWh	 * at 700 atm pressure
Liquid Hydrogen	53.1 kWh	
Gasoline	181.9 kWh	 7.4x!

Hydrogen Density

- *Fun fact:* There is actually more hydrogen in a liter of gasoline (116 grams) than there is in a liter of pure liquid hydrogen (71 grams)!
- Some hydrogen advocates claim this means we should extract the hydrogen at the point of use (on-board reformation)
  - If you've gotten the fossil fuel all the way to your vehicle, **just burn it!**

Filling the H_2 Tank

- Gasoline pump
  - Approx. 1 gigajoule/minute
  - Operable by 16-year-old kid
  - Proven safe: millions uses/day
- Hydrogen pump
  - Either cryogenic (low temp) or high-pressure (compressed H_2)
  - Slow flow rates, pricey components
  - Dangerous, finicky, requires special training

More Problems

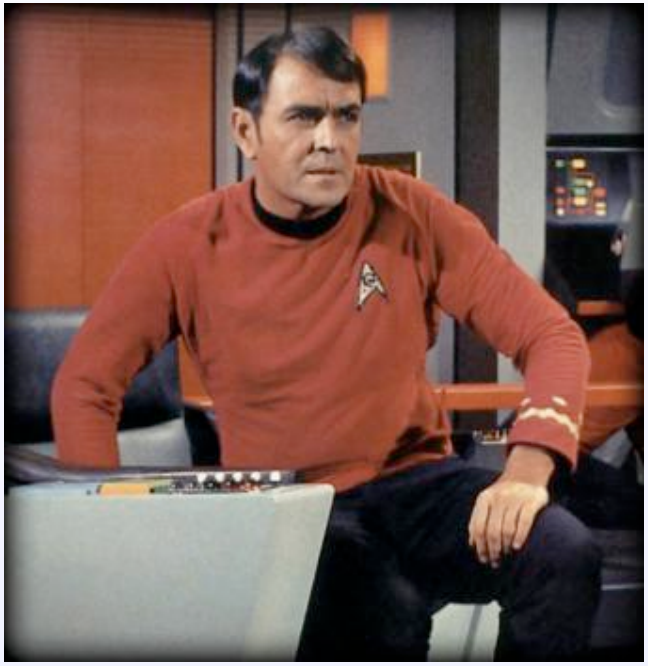
- Violently explosive in concentrations ranging from 4% to 75% (with O_2 present)
- Leaks from pressurized tanks can ignite just from the static electricity of gas escaping the leak!
- And, just for extra fun, hydrogen flames are invisible!
  - Energetic enough that most emissions are in the ultraviolet

Invisible Flame

Hydrogen refinery

Same refinery on fire!

Fundamental Problems



"Captain, I canna change the laws of physics!"

Some problems cannot be solved by throwing money at the problem.

Sources of Hydrogen

- There are no hydrogen wells!

Hydrogen as Storage

- Hydrogen is not a primary fuel.
- It is a *storage medium*, carrying energy from the point of manufacture to the point of use.
- Think of it as a battery:
  - A dangerously explosive battery that is hard to work with, has a lousy power-to-weight ratio, and tends to self-discharge (from boil-off) if you don't use it promptly.

Gee, Li-Ion batteries are looking better and better!

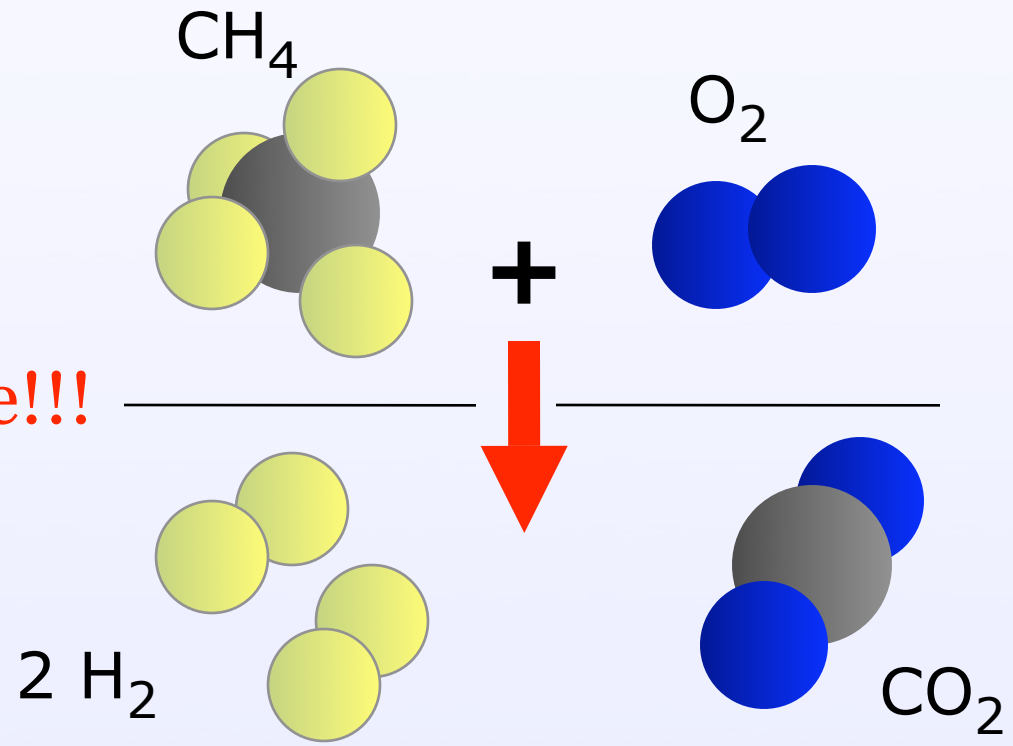
Exotic Storage Concepts

- Various metal hydrides
- Carbon nanotubes
- Magnesium slurry
- Even stranger things

Unfortunately, the common thread is that we don't yet know how to do any of them in volume!

Hydrogen Manufacturing

- Since you can't pump hydrogen out of the ground, you have to manufacture it.
- Most popular process: reformation of methane.
- Produces:
  - Hydrogen
  - Waste heat
  - Carbon dioxide!!!

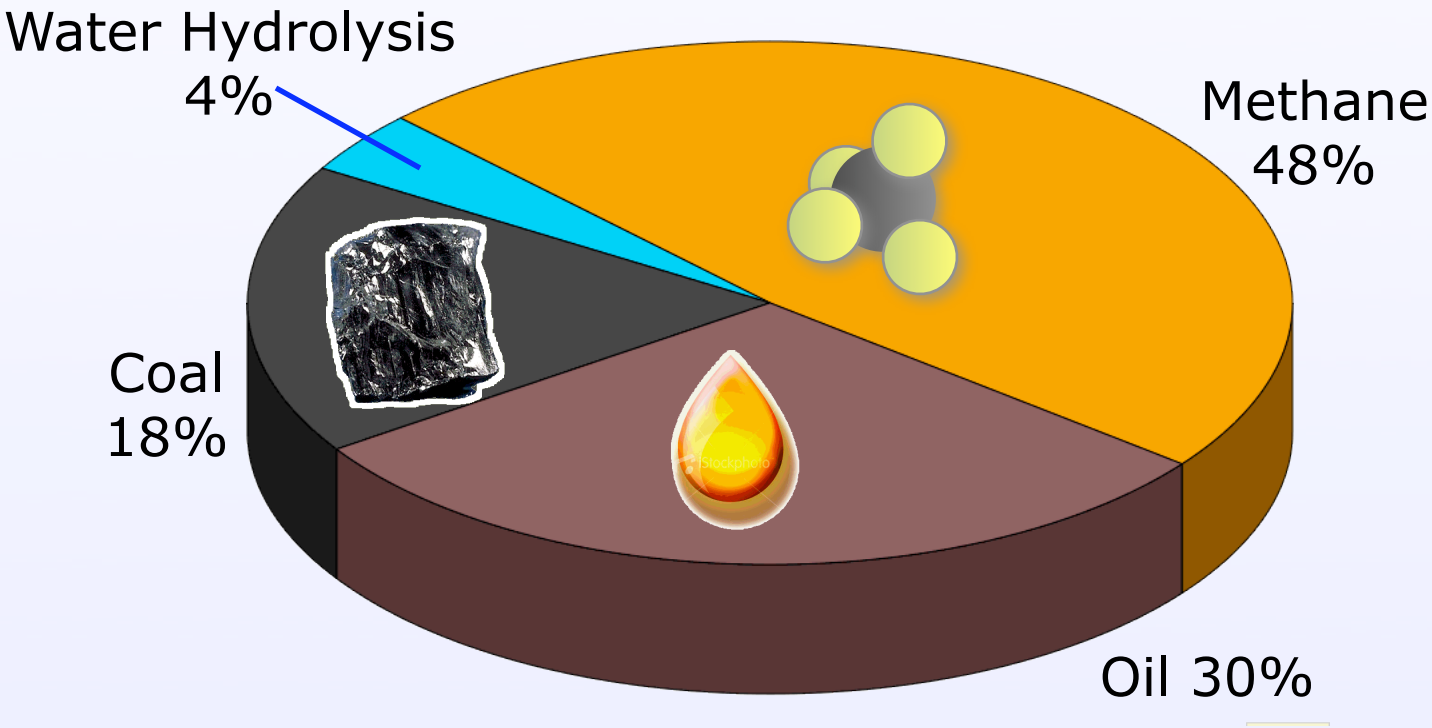


Manufacturing Inefficiency

- Manufacturing hydrogen has to obey the First and Second Laws of Thermodynamics
  1. You can't win.
  2. You can't even break even.
- Steam reformation of methane is about 70% efficient… other reactions are worse.
- Energy input comes from somewhere—fossil fuel, nuclear, hydroelectric…
  - Solar and wind power are rounding errors.
  - Just shifting environmental impact from tailpipe to somewhere else!

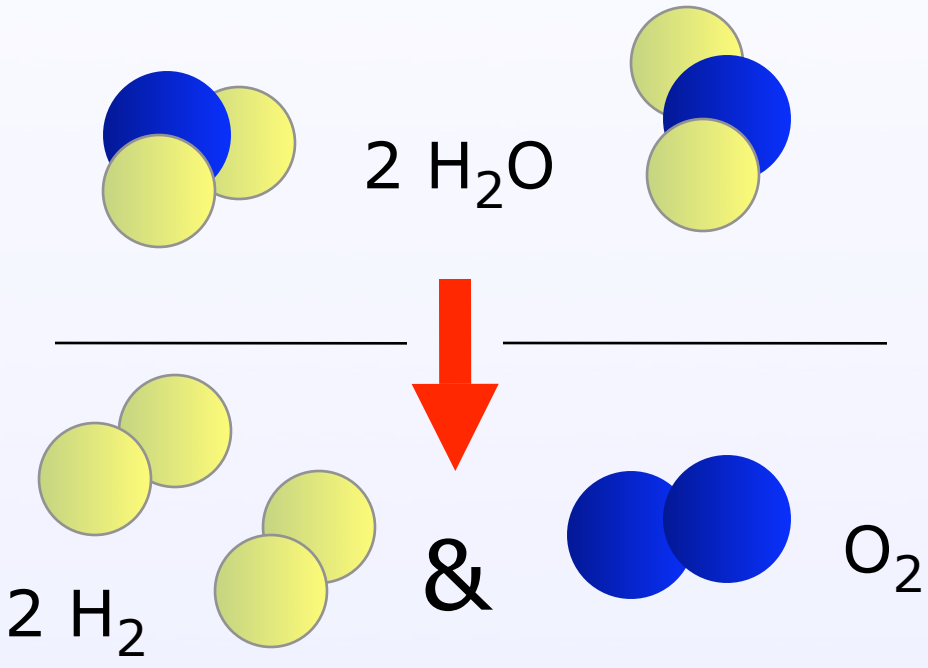
Hydrogen Manufacturing

- Most other processes have the same basic equation… converting fossil fuels to hydrogen releases carbon dioxide.



Why Not Electrolysis?

- Cracking water into hydrogen and oxygen
- Lovely in theory
- Stubbornly expensive in practice
  - Breaking up those chemical bonds takes *serious* energy
  - Approx. 4x cost of methane reformation



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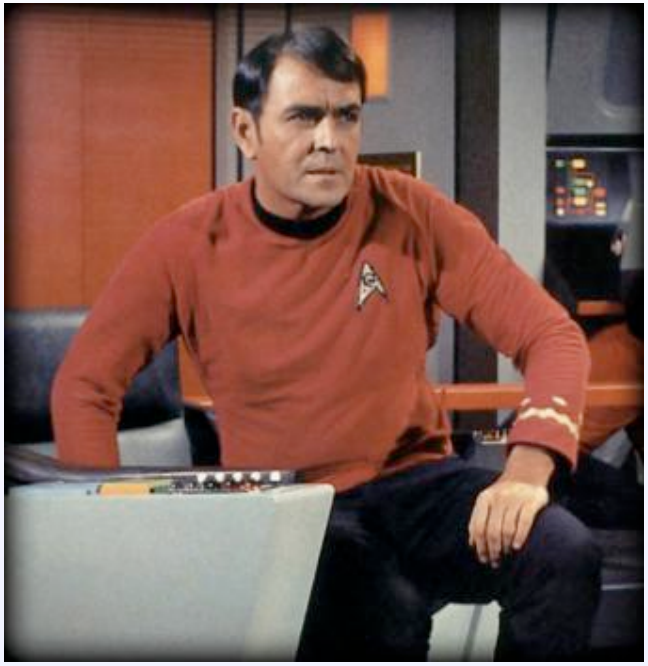

"Captain, I canna change the laws of physics!"

To be effective, electrolysis requires ample clean, non-polluting electricity. Did someone say "nuclear"?

Hydrogen Logistics

- So you've decided to manufacture hydrogen. Then what?

Production	70% efficient
Liquefaction or Compression	80% efficient
Transportation	90% efficient (Boil-off, leaks)
Fuel cell conversion	45% efficient
Net Efficiency	*Only 23%!*

Oh, and did I mention that it all boils off from your fuel tank in two weeks if you don't drive the car???

Hydrogen Infrastructure

- Hydrogen pipelines would be expensive!
  - Insulated for cryogenic temperatures
  - Exotic valves, fittings, other materials
  - Frequent inspection due to embrittlement

Hydrogen Infrastructure

- New production facilities, new pipelines, new tankage, new fueling stations, new pumps…
- How much?
  - Speculation on the cost of implementing a national hydrogen infrastructure is in the hundreds of billions of dollars, perhaps well over one trillion dollars.

Damn. That'd buy a lot of plug-in hybrids…

Energy Conversion

- *Design decision:* Liquid-hydrogen internal combustion engines, or fuel cells?
- BMW is using a hydrogen ICE in trials.
- Fuel cells offer promise of higher efficiency, with less pollution.
  - *Problem:* We don't know how to make them in volume yet. And when we do, they're going to be stuffed with exotic and expensive catalysts (platinum-group metals, etc.).

Fuel Cells

Energy Conversion Mechanism	Year of Invention	Common Application
Fuel cell	1837	?
Rechargeable battery	1859	
Otto-cycle internal combustion engine	1866	
Gas turbine	1906	

So why are we still waiting for a workable fuel cell?

Smart People

"As far as I know, no one who is technically literate is an enthusiastic supporter of fuel-cell-powered vehicles"

– *Donald R. Sadoway, professor of materials engineering, MIT*

Smart People

"Don't hold your breath on fuel cells. Every 10 years they say commercial deployment is only 10 years away. We're still not seeing any real fuel cells that can run, say, a car."

– *Robert Lifton, chief executive of Medis Technologies*

Smart People

In response to "When will fuel-cell cars replace gasoline-powered or hybrid cars?"

"If I told you 'never,' would you be upset?"

– *Bill Reinert, national manager, Toyota USA Advanced Technology Group*

Smart People

"Neither government policy nor business investment should be based on the belief that hydrogen cars will have meaningful commercial success in the near or medium term."

– *Joseph J. Romm, acting Assistant Secretary of Energy under Bill Clinton*

Smart People

"There certainly will not be an overabundance of clean energy to squander on an inefficient hydrogen loop, particularly when the same tasks can be accomplished directly with the original electricity. Not even nuclear energy can turn hydrogen into a winner."

– *David Barber, Nuclear Programs, Idaho National Laboratory*

Smart People

"Forget hydrogen, forget hydrogen, forget hydrogen."

– *James Woolsey, energy security analyst; former Director of the CIA under Bill Clinton*

Types of Challenges

Resource-Constrained

- We know how to do it, it's just expensive.
- *Examples:*
  - Apollo Project
  - Ending illiteracy
  - Building 1000 new nuclear power plants
  - Mining the asteroids

Knowledge-Constrained

- We don't know how to do it, or even if it can be done at all.
- *Examples:*
  - Curing cancer
  - Extreme longevity
  - Faster-than-light travel
  - "Hydrogen economy"

I *hope* all these knowledge-constrained challenges are solvable. But "hope" is not a good basis for investment decisions or public policy.

For Further Information

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