Curbing the Fossil Fuel Dependency

Confluence of Agri-biotech, Nanotechnology & Nuclear Fusion as a Bridge to the Hydrogen Supply Chain

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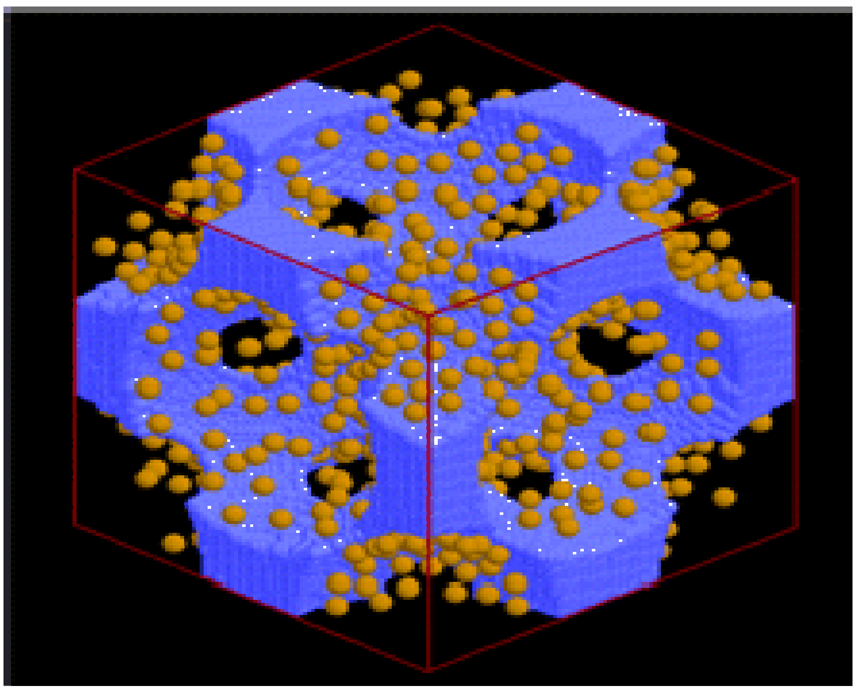
Molecular Simulation of Novel Carbonaceous Materials for Hydrogen Storage



Snapshot of hydrogen molecules adsorbed in the GCIO porous material. Carbonaceous material in blue and yellow spheres represent Hydrogen.

http://pubs.acs.org/cgi-bin/article.cgi/nalefd/2004/4/i08/pdf/nl0491475.pdf

1.0 Energy Economy

In 2003, when General Motors (GM) demonstrated HydroGen3 at the Tokyo auto show, the $1M price tag for the minivan may have evoked nostalgia in those old enough to remember that DEC priced its desktop computer, PDP-1 at $120,000 in 1960. Michael Ramage, former Executive VP of ExxonMobil Research and Engineering commented that, "we face a chicken and egg problem that will be difficult to overcome." Bernard Bulkin, former Chief Scientist at BP echoes the 'chicken and egg problem' as the "need for a massive new hydrogen infrastructure to deliver the goods."

In other words, the pipe dream about filling stations and fueling services – the bread and butter (with jam) for the global petro merchants. Perhaps the latter may explain, in part, the tone from US National Academy of Science (NAS) and American Physical Society (APS) reports that the hydrogen economy challenges are enormous and "the transition to a hydrogen economy, if it comes at all, will not happen soon." Predictions are difficult to make, especially about the future, but the recent report (chaired by Michael Ramage of ExxonMobil) from NAS, an august society of thinkers, stopped short of declaring it is impossible. The facts may be genuine but one must wonder about the quality of vision of the leadership that is bound to retard the progress toward the economic prospects and environmental benefits from use of hydrogen as a fuel, albeit, in the future that one may not map with accuracy.

Today, the world uses about 13 terawatts of power, of which, approximately 80% is derived from carbon dioxide emitting fossil fuel. To keep the Earth's average temperature low enough to prevent eventual sea level increases (projected to be from 8 metres to 35 metres) and sustain 3% annual economic growth, we will need between 10 and 30 terawatts of new carbon-free power by 2050.[1]

For fossil fuel enthusiasts, the Middle East spells doom not only because it fails to contain its metaphysical zeal but also because it cannot sustain the global demand for oil even if peace was offered a fighting chance in between its many wars. A decade ago economists were confident that demand for oil was stagnating at 70 million barrels per day (bpd). Our current global consumption of about 85 million bpd (US uses 21 million bpd) vastly exceeds such estimates. It is now clear that global growth, especially in India and China, will push demand for oil over the 120 million bpd mark by 2030, according to the International Energy Agency (IEA). For such demand to be met, one assumes "boundless Middle East oil" output to grow by more than 30 million bpd. Saudi Arabia's comforting "trust me" statements about its oil reserves (jumped to 280 billion barrels in 1988 from 110 billion barrels in 1978) and production capacity (expects to sustain 10-15 million bpd for at least another half century) are highly suspect since these numbers have never been subject to any third party audit or any report on how the reserves stack up on a field-by-field basis. In 2000, 90% of Saudi Aramco's oil was produced from 6 fields. The three most important fields producing 80% of Saudi oil (total production is about 10 million bpd) were discovered in 1940, 1948 and 1951 (Matthew Simmons). In the next 25 years, additional supply of oil may grow at a rate less than the estimated increase in demand (20 million bpd). In other words, oil output of about 100 million bpd may result in oil shortages of about 20% or more by 2030.

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[1] Jim Hansen, Goddard Institute for Space Studies, NASA in MIT Technology Review (07-08/2006)

Discovery teams in search for new resources are accelerating their missions but success is rather scarce and expensive. A bit of hope comes from the oil sands (tar sands) of Fort McMurray (Alberta, Canada) that cover an area of 58,000 square miles. It is expected to yield 174 billion barrels of oil (active through 2025). At the current rate of consumption of oil by the US (21 million barrels per day of which 60% is imported and represents 25% of global demand), the Canadian reserves will be depleted in about 22 years even if Canada chooses to sell every drop of oil from tar sands to its neighbour but none to China.

The discovery of "Tahiti" deep sea oil field by Chevron in the Gulf of Mexico may add about 500 million barrels[2] or a 3 week supply for USA. The Minerals Management Service of the US Government estimates about 44 billion barrels of oil (~5 year supply for US) remain to be discovered in the Gulf of Mexico.

Emergency oil stores are most certainly inconsequential. Rokkasho, an oil-storage site in Honshu holds 30 million barrels of oil. It is barely enough to supply one week's worth of Japanese demand. Rokkasho is also dominated by giant wind-turbines but Rokkasho's fresh sea breeze can operate the turbines 20% of the time and may not produce enough power to make up for the energy consumed in their construction. Japan was keen to invest in yet another hydrogen venture – that of nuclear fusion reactor – in Rokkasho. However, the project (ITER) is now slated to be housed in Grenoble, France. The industrial world is vulnerable to oil supply disruptions in the Middle East. The economic progress in developing countries will be retarded by energy crisis and it will jeopardize the already dubious UN Millennium Development Goals (MDG) to reduce global poverty by half by 2015. The promise of oil from the Middle East and UN's plight to reduce poverty may be utopian dreams unless the vision of hydrogen as a fuel is a part of the answer to global demand for energy.

A report published in 2001 by Sir David King, Chief Scientific Adviser to British PM Tony Blair advocated a fast track for fusion development. Fusion "should not be a place to play short-sighted international politics" says veteran nuclear researcher Tomabechi of Japan and expects "fusion-generated electricity will be sent to the grid within the next 35 years" but admits it will be expensive.

One proposed fusion reactor uses Hydrogen and Boron-11 as fuel. Hydrogen is obtained by electrolysis of water and Boron deposits are plentiful (140 million tons in California, 500 million tons in Turkey). A 100 mega-watt plant would burn 200 grams of Boron a day, as opposed to 700 tons of coal[3] to power a similarly sized coal-burning plant.

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[2] Chevron claims that it could cost $3.5 billion to develop the "Tahiti" oil field that may yield 500 million barrels of crude petroleum. The exploratory vessel, *Deep Seas*, leased from Transocean, costs $250,000 per day (including team of 170 it is $500,000 / day).

[3] The annual amount of carbon dioxide released from burning fossil fuel is projected to increase from 24 billion metric tons in 2002 to 33 billion metric tons in less than 10 years (by 2015). Coal presents the world's single largest opportunity for carbon dioxide mitigation. Coal generates 37% of the global fossil-fuel related emissions, in second place, after oil (42% from oil). In the US, coal contributes 51% of electricity but 81% of carbon dioxide related to power generation. Overall, 40% of global electricity is generated from coal-burning plants that spews twice as much as carbon compared to natural gas (kilowatt for kilowatt). World Coal Institute estimates there are 164 years worth of coal in the ground compared to 40 years store of oil (through 2050). According to the Natural Resources Defense Council, the enthusiastic coal mining countries are US, India and China. More than fourteen hundred 500-megawatt coal powered plants are planned worldwide by 2020, of which 140 are in the US. (Source: MIT Tech Review 07-08/2006)

Better yet, this type of fusion reactor emits no radiation. In addition, because the reactor is safe and clean, it is possible to build small neighborhood power plants or even have a portable domestic fusion reactor right in your back yard, eliminating wasteful long distance electricity transport.

The investment necessary to transform this vision into reality is not quite there, even though evidence suggests billions of dollars worth of government investment in hydrogen fuel projects in US, EU and Japan. A bit of this was spent on perfecting procedures to break down natural gas into hydrogen and carbon dioxide with substantial wastage as heat (~15% of energy). According to Pete Devlin of the US DoE (Department of Energy), it costs $5 to produce the amount of hydrogen that releases as much energy as a gallon of gasoline (assume a modest $2 per gallon but crude is creeping toward the ominous $100 per barrel with continuing Middle East uncertainties). Today, it is increasingly attractive to consider dumpster size conversion equipment costing about $375,000 according to Sandy Thomas of Alexandria (VA, USA) based H2Gen Innovations, manufacturers of hydrogen generators (2004).

Dr Joseph Romm, former Acting Assistant Secretary for Renewable Energy at US Department of Energy (DoE) may have sounded like the doomsday prophet when he told the US Congress (House Science Committee) in March 2004 that, “if we fail to do so because we have bought into the hype about hydrogen’s near-term prospects – we will be making an unforgivable national blunder.” Perhaps Dr Romm had the best intentions of promoting hybrids or alternative fuels such as biomass usage (carbon sequestration) and ethanol. Unfortunately, despite its great potential, we have not yet made any significant strides with ethanol (US annual production is just about 2 billion gallons, mainly from corn) and the same holds for biodiesel and hybrids. JoAnn Miliken, who currently heads the hydrogen storage research for US DoE agrees that hybrids, “can’t solve the problem.”

The gobal hydrogen endeavour is lacking direction and leadership. It is necessary to articulate an unambiguous goal unencumbered by the imminent geo-political ramifications that surround any such profound economic change. Much to the chagrin of the wealthiest industrial nations and energy industry behemoths, hydrogen may be that elusive bridge between the ‘haves and have nots’ which was once conceived to be built bit by bit with information technology. The industrial revolution and the information age provided some incremental quality of life benefits to the developing world but the energy economy increasingly yet silently drains resources and dampens productivity gains. The energy genie is still in the bottle and it has hydrogen written all over it.

1.1 Electrolysis

A simple process that can catapult the hydrogen economy to the forefront of global progress comes from the same man who invented the electric motor, nearly two centuries ago. Michael Faraday, born on 22 September 1791 in Newington, Surrey (England), invented the dynamo in 1831 which led to the invention of the electric motor and the profitable revolution[4] that followed. In 1832, he started work on electrochemistry that led to the discovery of the principle of electrolysis. He lived to see the first isolation of Lithium by electrolysis by his mentor, Humphrey Davy and later in 1855 by Bunsen and Mattiessen. Michael Faraday died on 25 August 1867 in Hampton Court and is buried in the Highgate Cemetery in London. What we should not bury is the idea of generating hydrogen from electrolysis of water, in every garage!

[4] Paul A. David and Gavin Wright (2003) *The Economic Future in Historical Perspective* (Oxford University Press)

It may have intrigued Faraday to see his discovery of electrolysis being practiced safely and successfully since 1875 to remove unwanted hair. Charles Eugene Michel (1833-1913), an ophthalmologist in St. Louis, (Missouri, USA), helped pioneer a technique for removing wild eyelash hairs (cilia) by means of electrolysis. It is the only process that is universally and medically approved, documented and accepted by the US Food and Drug Administration, as a means for permanent hair removal. It is perhaps time to add another universally accepted process to the credit of electrolysis: portable hydrogen generation[5] from water to replenish solid hydrogen storage in automobiles.

Electrolysis of water in your garage to generate hydrogen to replenish hydrogen storage tank in your automobile ("gas tank") could eliminate the trillion dollar investment necessary to re-tool the infrastructure for generation and delivery of hydrogen fuel. If electrolysis is successful and portable hydrogen generators are in every garage, there may not be an "oil industry" or behemoths to reap the financial largesse from the petroleum pool. These behemoths exercise global clout and exert pressure on organizations (governments) that plan and promote the pathways to hydrogen economy. Few, if any, nations of the world have leaders who are willing to lead at the expense of their personal popularity at home and abroad. John F Kennedy, threatened by the Sputnik progress of the then USSR, challenged the nation (USA) to put a 'man on the moon' within a few years. It did happen, soon enough. We lack leaders who can articulate such unambiguous universal agenda to challenge the global research community to concentrate their focus on developing efficient commercial portable electrolyzer compatible with solid hydrogen storage systems for automobiles. If automobile usage, alone, could become independent of fossil fuel, imagine the impact on the global economy, decreasing oil prices and the potential economic boom for the developing nations.

It is often said that we humans are our own worst enemies. The economic revolution possible through the use of hydrogen fuel for automobiles harbours the potential to trigger resistance from the uneducated and uninformed about the source of energy for electrolysis. Renewable energy (solar, wind) systems may supplement a part of the energy required for electrolysis but for commercial uses (car rental agencies, fleet operators) the use of nuclear energy (nuclear fusion?) to run the electrolyzers may be inevitable unless the ethanol economy starts working wonders hitherto unexplored. Some nations (for example, Ireland) have banned the use of nuclear (fission) energy!

Chernobyl has been sensationalized by the media yet the incident-free accidental nuclear (fission) plant meltdown at Three Mile Island (USA) is virtually unknown. Chernobyl did not use the recommended safety precautions but the operation at Three Mile Island nuclear power plant was monitored according to the highest safety standards. Safe nuclear (fission) energy has been a reality for several decades yet the ignorance of the public is still carefully cultivated only to worsen global warming (*The March of Unreason* by Dick Taverne).

UK obtains one fifth of its electricity from nuclear plants and all but one (Sizewell, UK) will be decommissioned by 2023. Sir David King and Mr Tony Blair may no longer stand up for the "green" mirage with North Sea oil reserves declining and greenhouse gas emissions on the rise. Even politicians know that politics may temporarily derail long term vision but long term needs can annihilate political frameworks and fail to protect disingenuous individuals from social wrath.

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[5] Richard Bourgeois and his team at GE Global Research (Niskayuna, NY) has built a low-cost mass-manufacturable electrolyzer using a GE plastic (Noryl) resistant to corrosive electrolytes. The prototype produces hydrogen via electrolysis for $3 per kilogram (functionally equivalent to a gallon of gasoline) which is substantially lower than current estimate of $8 per kilogram.

Cheaper and safer nuclear fusion energy is on its way, too, as discussed earlier and perhaps sooner than expected (*Colliding Beam Fusion Reactor* by N. Rostoker, M. Binderbauer, H. Monkhorst in Science (1997) 278 1419). Are there any national leaders who can promote science literacy to enable the public to evaluate the risk to reward ratio of safe use of nuclear energy (fission and fusion) as one mechanism to declare independence from fossil fuel? The simplest way to usher in the hydrogen economy is not a 'chicken and egg' problem, it is a political problem.

1.2 Scientific Hurdles

Simple ideas are often complex problems and this is not an exception. Several questions need answers through focused research. By using energy (solar, wind, nuclear, hydroelectric, geothermal) we can convert water to yield hydrogen in an electrolyzer and reverse the process in a fuel cell to obtain electrical energy from hydrogen. Energy required to produce hydrogen by electrolysis is 32.9 kWhr/kg. For 1 mole (2g) of hydrogen the energy is (approx) 0.0660 kWhr/mole. For commercial electrolysis systems that operate at 1 A/cm^2, 1.75 volts is required, which translates to 46.8 kWhr/kg and an energy efficiency of 70%. Lowering the voltage for electrolysis, will increase the energy efficiency of the process and is one important area for research. R. P. Viswanath and his team at the Indian Institute of Technology in Madras, claims to split water into hydrogen and oxygen at a lower potential (0.9V) by using a compartmentalized electrolytic cell. Current efficiency works out to 135% (a key advance, if reproducible).

In an ideal case, fuel energy from hydrogen is converted to electrical energy at an efficiency of 80% or more. This is greater than the ideal efficiency of a generating facility which burns hydrogen and uses heat to power generator. Fuel cells currently may not approach >80% efficiency but are still more efficient than electric power plants which burns a fuel. In comparing the fuel cell process to its reverse reaction (electrolysis of water) it is useful to treat the enthalpy change as the overall energy change. Gibbs free energy is necessary to drive the reaction. In electrolysis and fuel cell pair, 237 kJ energy is required to drive electrolysis and the heat from the environment will contribute 48.7 kJ. In the fuel cell, 237 kJ is regained as electrical energy (48.7 kJ escapes as heat but part may be recaptured for use). The benefits from catalysis and search for nano-materials (nano-catalysts with greater surface to volume ratio) that can improve efficiencies in the electrolysis/fuel cell paradigm are key areas for research.

Can we use bio-catalysts for hydrogen generation? John Peters and Lance Seefeldt of Utah described the structure of an enzyme found in the soil microorganism *Clostridium pasteurianum*. CpI is a hydrogenase, which uses iron atoms to catalyze hydrogen (waste) production from protons and electrons. The enzyme active site, tethered to a substrate, may improve hydrogen production efficiencies. Non-platinum catalysts are also of increasing importance (G.W. Huber, J.W. Shabaker and J.A. Dumesic. 2003. Raney Ni-Sn Catalyst for H_2 Production from Biomass-derived Hydrocarbons. *Science* **300** 2075–2077).

Safe, non-toxic, cost-effective on-board solid hydrogen storage solutions are emerging from traditional materials (sodium borohydride) as well as nano-materials (nanotubes). Catalysts (doped nanotubes) that can improve storage capacities above the US DoE recommended 6.5% (storage by weight) will be a boon to this fuel system. Solid sodium borohydride currently can store 10.5% hydrogen[6] by weight.

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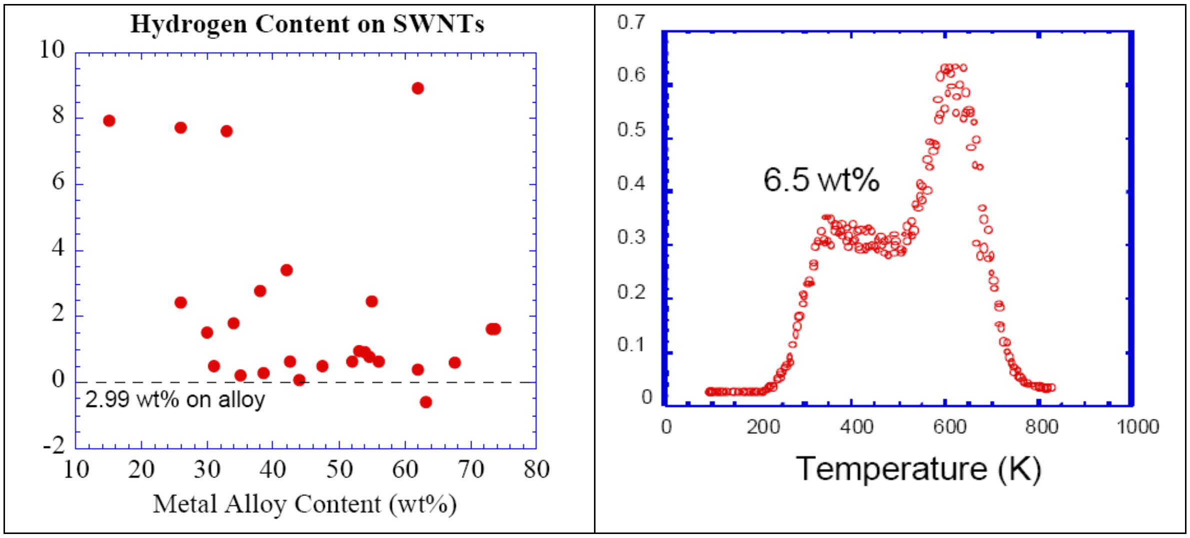
[6] One kg of solid $NaBH_4$ reacted with 950gm of water yields 213.5g of hydrogen gas or 24,230 BTU = 7.1 kWh = 25,560 kJ (1 kg of hydrogen = 119,600 kJ which is a close equivalent to 1 gallon of gasoline = 121,300 kJ).

Carbon single-wall nanotubes (SWNT) and other nano-structure materials exhibit hydrogen storage capacities at room temperatures. Capacity for adsorption of hydrogen by SWNT is about 8% by weight. A method for growing SWNTs by vapor deposition from methane holds promise when scaled-up, to produce SWNTs for $1 per kilogram.



HYDROGEN STORAGE IN CARBON SINGLE-WALL NANOTUBES

Proceedings of the 2002 US DoE Hydrogen Program Review

A.C. Dillon, K.E.H. Gilbert, P.A. Parilla, J.L. Alleman, G.L. Hornyak, K.M. Jones, and M.J. Heben

1.3 The Road Ahead

Except for Iceland with its vast geothermal resources, Hydrogen is the global Holy Grail. Standardization of form for fuel cells and mechanism to replenish with hydrogen from portable electrolyzers may be as simple as inserting a tube to feed hydrogen to adsorbent in the on-board storage tank or solid material that can be stored in the hollow frame of an automobile. When the domestic electrolyzer is not available (while on vacation), electrolyzer outlets may be ubiquitous in stores, grocery chains, restaurants or charged fuel cells can be exchanged just as cooking gas is available in tanks in most corner stores. GPS-RFID-UWB linked hydrogen sensor tagged fuel cells can help track and trace customer issues, inventory, billing operations, as well as monitor fill-status and safety considerations.

Perhaps this discussion about hydrogen as a renewable fuel for the near future focuses disproportionately on fuel consumption as a function of automobiles and transportation. In most industrialized nations, energy consumption in this sector is about 20-25% of total energy. Successful implementation of hydrogen as a fuel reduces need for fossil fuel by the same amount. However, residential and commercial use is another 20-25% while industrial uses claim almost half of the energy output. Fusion reactors are a definitive answer but are still a few decades away. The 'south' nations cannot continue to wade through squalor while scientists develop ways for mass deployment of fusion reactors still decades away (2025-2050). One doesn't need the brilliance of Jeffrey Sachs to grasp that energy is the key that may change the tide for sustainable growth in 'south' nations and lend credibility to Mary Robinson's penchant to pursue ethical globalization. However, politically unpalatable it may be, the 'fast food' model of energy is in demand but of course not in disproportion to global hunger that affects more than a billion, each day.

There may be a “STAR” solution, albeit a partial solution. Sealed, transportable, autonomous reactors (STAR) can generate power from nuclear fission without refueling or maintenance. It is a choice that is available now and those who will keep it out of the hands of those who need it the most may wish to consider the odds. By the time you finish reading the rest of this article, several children will have perished from malaria. In Africa, a child dies every 30 seconds from malaria, alone. Improvements in sewer and sanitation can eliminate this morbid mortality statistic. Lack of energy is the gatekeeper in the ‘south’ nations who are reliant on the proactive benevolence of the ‘north’ even for their very basic survival. Disposable nuclear fission reactors may be an interim answer to this agony.

STAR can meet the immediate energy demands of under-developed and developing countries without the risk of malicious use by disenfranchised individuals to use the by-products for weaponry. Taking a lesson from modern submarines, STAR was developed by the Lawrence Livermore National Laboratory in California, to be transported to a site and generate power for decades (current estimate is 30 years). When the fuel is spent, it can be retrieved from the site and disposed under proper supervision since there is no option in a sealed STAR for recharging the fuel rods depleted of fissile isotopes (usually commercial operators replace fuel rods every few years). The latter coupled with a tamper-proof casket eliminates the risk of extracting fissile material. An even better reason to use STAR in ‘south’ nations is the ability to produce versions capable of generating 100 or 10 megawatts of electricity compared to the conventional nuclear stations that produce about one gigawatt. Without an extensive electricity grid, the output from a conventional nuclear station is wasted or unused due to lack of distribution infrastructure. STAR units producing 100 megawatts may be 15 metres tall, 3 meters in diameter and weigh 500 metric tons. A lighter, 200 metric ton version may produce 10 megawatts of electricity. Nuclear fuel, liquid lead coolant and a steam generator is sealed in the housing along with steam pipes ready to hook up to an external generator turbine.

In the 5th century BC, Herodotus noted in his *History* that every Babylonian was an amateur physician, because the sick were laid out in the street so that any passerby might offer advice for a cure. Nearly 2500 years later, we are all environmentalists offering advice, apostles of platitude without power, uniformly impotent, to cure the energy sickness. Yet the ‘penicillin’ from the mold in Dr. Florey’s coat was gifted as the cure for the energy-addicted world, over half a century ago by Lise Meitner, Otto Hahn and Frederic Joliot-Curie, among other notables.

1.4 One Shoe Fits All ?

Safe use of nuclear fission for energy *cannot* become the ‘one shoe fits all’ solution for the impoverished nations to climb out of their poverty capsules. It is a solution at hand and one that will empower the ‘south’ nations to see some light at the end of the tunnel. It is important that national policies commit to concomitant exploration of other renewable energy sources that can stem the tide of global warming, even if the validity and reliability of such warming trends are often steeped in scientific controversy and subject to incessant political spin through the media.

Encouraging advances include one by UK-based Intelligent Energy and its product – a motorcycle - that runs on hydrogen fuel cells, attains speeds of upto 50 mph and travels for 100 miles before refueling is necessary. Tokyo Gas launched (2005) a residential fuel cell project where a home-owner can lease an unit that extracts hydrogen from natural gas and uses it to generate enough electricity to meet about 60% of the demand for a four-person household. Each unit may reduce a home’s annual greenhouse gas emissions by 40%. A 10 year lease costs JPY 1 million (<$10,000) but the savings from reduced energy usage, today, may not cover the cost of the lease. The annual shortfall is estimated to be about JPY 40,000 (<$400) per home (MIT Technology Review, March 2005).

Developments from super-conductivity research are helping to produce better fuel cells. New thin film solid oxide fuel cells (SOFC) offers catalyst-independent operating temperatures of less than 500^0 C. At less than 1 micron thin and an output of about 1 volt, a stack of SOFC equivalent to two soda cans may produce more than 5 kilowatts (enough to power one or more typical households). Connected to a homeowner's natural gas line, this stack operates at an efficiency of about 65%, a two-fold increase in efficiency over conventional power plants.

Plankton fuel cells, energy from spinach, biodiesel, carbon sequestration (Craig Venter Institute) and natural forces (air, water, solar) to generate energy are all likely to be more or less viable in specific use cases and environments. The latter is demonstrated in part by Costa Rica which claims to derive 92% of its energy from renewable sources. It is vital to pursue these and other emerging 'green' sources of energy while we continue to boldly support options available at hand to immediately provide energy for the emerging economies that are politically responsible. The sooner the impoverished countries are economically mature, the sooner they can contribute to invest in the global plight for alternative 'green' energy to reduce fossil fuel dependency and reduce carbon emissions.

1.5 Manufacturing Energy: Biofuels

With 40% of operating automobiles **<u>not</u>** running on petroleum, Brazil has demonstrated that it is the global leader in the use of ethanol without government subsidies. Alcool (ethanol) as an alternate fuel for cars, buses and other motor vehicles is in use because 75% of all vehicles sold in Brazil are flex fuel vehicles that can run on ethanol or gasoline or a mix. Commencing with ideas and idealism that sprouted during 1970-1975, Brazil now boasts of ***manufacturing energy*** from 5 billion gallons of ethanol per year. Brazil is manufacturing energy from sugar (sugarcane) and pays for plant operation using energy obtained from burning the fiber from sugarcane (biomass). This is a remarkable paradigm shift because till recently energy was traditionally associated with discovery and mining (oil, coal, natural gas). While "sugar farmers" in the EU are sparring over the size of "hand outs" (subsidies), sugar is effectively used as an energy cash-crop in a novel entrepreneurial zeal just a few thousand miles, south.

The necessary detour to use ethanol and others biofuels remain low on the strategic agenda for many nations despite the projections that gallon for gallon ethanol is competitive with gasoline in terms of fuel efficiency even if crude prices drop to $40 per barrel. One wonders why national energy policy wonks are yet to grasp that production of biofuels can be tuned by manufacturing at a cost comparable to or lower than that of gasoline. Agriculture and farming can reinvent its financial lustre from corn, sugarcane, sorghum and the oil-weed, *Jatropha curcas*, to name a few common agricultural raw materials that can be chemically processed (fermentation) to yield energy. Although ethanol does not significantly reduce carbon emissions, if viewed in the narrow sense of emissions alone, it adds little to the *total* carbon in the atmosphere. The carbon dioxide given off while burning a gallon of ethanol is roughly equal to the amount absorbed by the plants to produce the next gallon but biodiesel scores higher on the "green" scale. Biofuels may thus be an interim beacon of hope to wean away the war on peace by reducing our dependency.

Commercially, biofuels may be lucrative. Small, industrially advanced and truly innovative knowledge economies (nations) may now manufacture energy (biofuels). Hence, these countries may sell biofuels plus its associated knowledge services to the fuel-guzzling Dragon (China) and the Elephant (India). It is as simple as manufacturing and selling skyr or pizza or tikka masala or wonton soup!

The commercial chemical appeal cryptic in ethanol may be further stimulated by the understanding that ethanol can be obtained from *any* cellulose source because basic sugars are the key building blocks of cellulose. In practical terms, cellulose is present in all plant materials – wheat and rice straw, switchgrass, paper pulp, agricultural waste, leaves. This fact doubles the potential to squeeze twice as much as fuel from the same unit area of land without decreasing food crop for animal and human consumption. The latter is false perception currently peddled by some.

The convergence of energy scientists with chemists and biologists are likely to unveil new vistas only limited by our imagination. Hydrocarbon chemists are hopeful that the methanol economy (George Olah, USC) may chime in before the ethanol economy gathers steam. For now, the biologists contribution to biofuels and the ethanol economy seems to lead the way. Biologically speaking, converting cellulose to ethanol is a two-step process. First, the long chains of cellulose must be broken down to basic units (glucose, fructose or other sugars) and second, fermenting those sugars into ethanol. In nature, fungi and bacteria secrete enzymes (cellulase) that hydrolyzes cellulose to “free” the sugars. Yeasts ferment the sugars to produce alcohol. With tools available from biochemistry, molecular genetics, recombinant DNA and bio-engineering, it is possible to improve the efficacy of the microorganisms for production of cellulosic ethanol. Genetic engineering to yield strains of yeast (*Saccharomyces cerevisiae*) that tolerate higher concentrations of ethanol[7] in a fermentation reactor and can survive on cellulose alone[8] may be a “disruptive technology” in the ethanol energy economy. The strides made by genomics and proteomics may make it possible to engineer an existing microorganism[9] with an artificial chromosome to harbour genes for the enzymes necessary to direct a high yield manufacturing process to produce ethanol from cellulose by enzyme catalysis.

Manufacturing energy may lend itself to the practices of near-shoring, off-shoring and outsourcing, classical strategies used in global supply chain management. For example, recently Singapore leased an island for 999 years from Indonesia to set up a chemical processing facility. Leasing a few islands from Indonesia may not be an absurd idea given that it is the world's largest archipelago with 13,667 islands nestled between Asia and Australia, spanning 3200 miles along the Equator from east to west (almost the expanse of US) and 1100 miles from north to south. In addition to an abundance of plant (cellulose), these tropical islands are suitable for Jatropha, sugarcane or sorghum. The entrepreneurial and industrialised nations of the world, for example, may off-shore biofuel manufacturing in Indonesia (or partner in India with Bihar, the arid state with vast wastelands) in the true spirit of confluence of globalization and innovation. The potential for significant profits from such investments in biochemical-energy may be only limited by politics and the inefficiencies that often plague the knowledge network of information arbitrage.

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[7] Greg Stephanopoulos of MIT has developed a yeast strain that claims to tolerate 50% more ethanol.

[8] Lee Lund of Mascoma, a start-up in Cambridge, Massachusetts, has engineered a thermophilic bacteria to optimise the kinetics of cellulase and whose only fermentation product is ethanol.

[9] Synthetic Genomics, a start-up in Rockville (Maryland, USA), founded by Craig Venter, is exploring *Mycoplasma genitalium*, a microbe which dwells in the human urinary tract and has the smallest genome (517 genes) of known life form (except viruses), to produce task-specific genetic pathways (for example, the two steps or tasks necessary to breakdown cellulose to produce ethanol) in much the same way that software is loaded on to a computer’s operating system. Instructions from the software could be used to create spread sheets or word processing. Similarly, the “biological software” introduced in the genome of *Mycoplasma genitalium* would instruct the microbe (the cell) to break down cellulose to produce ethanol.

Value Chain: Example of Demand (India)[10]

	Sorghum bicolor (Sweet Sorghum)	*Saccharum officinarum* (Sugarcane)	Corn	Annual Demand India (2004)
Growth Cycle	4-5 months	12-16 months		
Crops / year	2	1		
Water / crop	4,000 m^3	36,000 m^3		
Biomass	70 tons / hectare	90 tons / hectare (TPH)	1.4 – 6.5 TPH	
Ethanol	40 litres / ton	70 litres / ton (LPT)	400 LPT	
Yield / crop	2800 litres / hectare	6300 litres / hectare (LPH)	560-2600 LPH	
Annual Yield	5600 litres / hectare	6300 litres / hectare (LPH)	560-2600 LPH	
Production Cost	USD 0.30 / litre	USD 0.29 / litre	USD 0.37 / litre	
Cost / US Gallon	$1.14 per 3.785 L	$1.10 per 3.785 L	$1.40 per 3.785L	
90EBG*				1 billion litres
95EBD**				3 billion litres
Other				1 billion litres
Production				2 billion litres
Import Potential				3 billion litres
3 billion Litres	1.1 million hectare	0.83 million hectare		

90EBG* = 90% gasoline plus 10% ethanol and 95EBD** = 95% diesel plus 5% ethanol

[10] If my theory of relativity is proven successful, Germany will claim me as a German and France will declare that I am a citizen of the world. Should my theory prove untrue, France will say that I am a German and Germany will declare that I am a Jew.
(ALBERT EINSTEIN, Address at the Sorbonne, 1936)

Illustration 1 – ELECTROLYSIS OF WATER

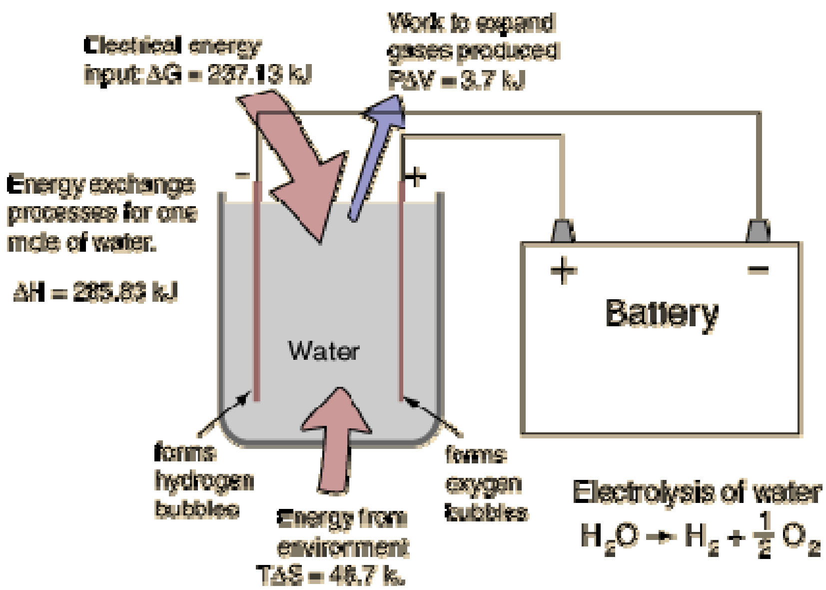
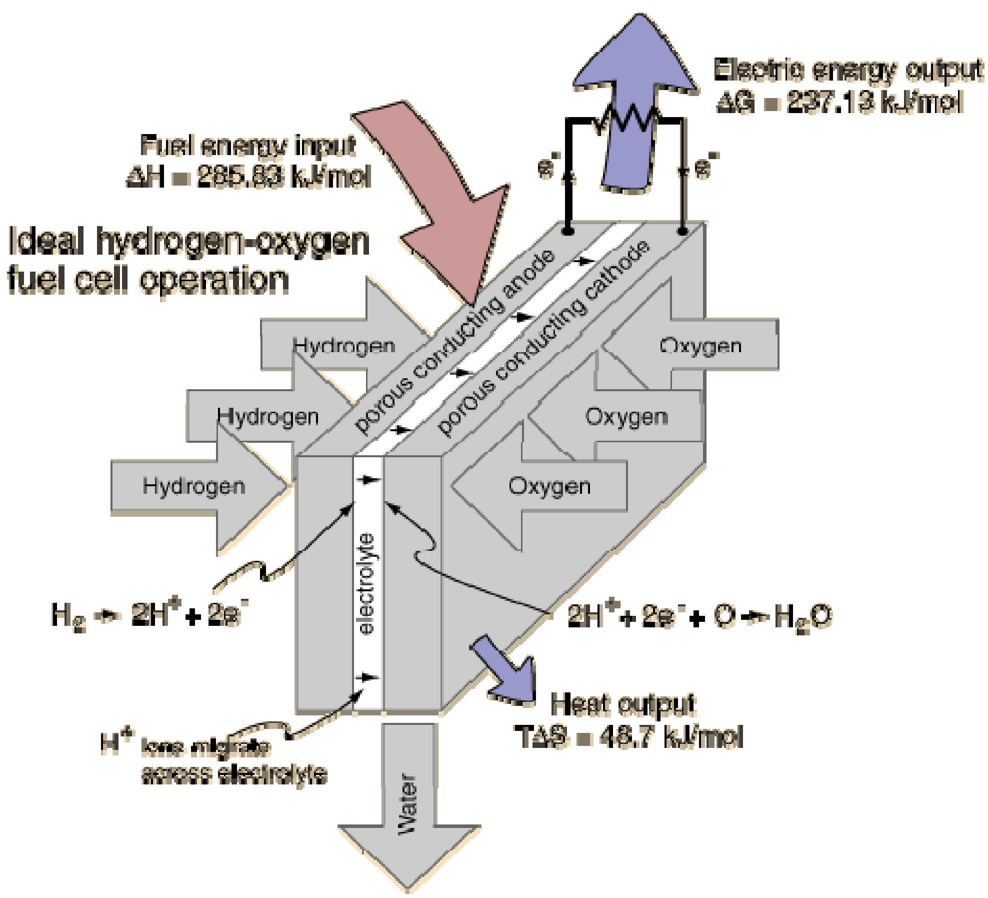


Illustration 2 – REVERSE OF ELECTROLYSIS OF WATER: HYDROGEN FUEL CELL



GM Corn, Sugarcane, Sorghum, Jatropha curcas

USA
>21 million barrels per day or ~8 billion barrels per day (petroleum)
(60% imported) >25% world consumption
Ethanol production ~2 billion gallons

Canada
~170 billion barrels in Fort McMurray (Alberta) active ~25 years (2025)
(<20 years supply for US at current rate of consumption – unrealistic)

Brazil
Ethanol >40% of transportation fuel (current production ~3 billion gallons)

China
Ethanol export negotiations with Brazil
Fort McMurray to Vancouver pipeline negotiations
25% of Russian gas reserves : pipeline negotiated

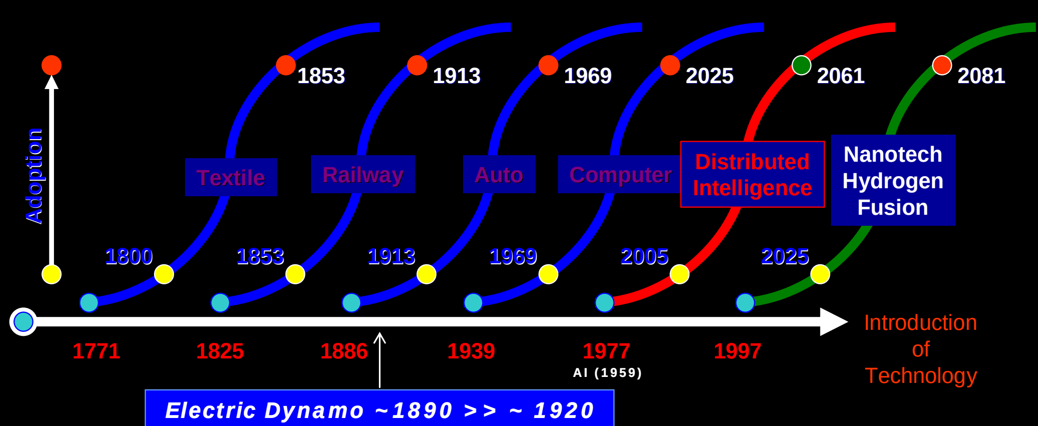
- ***Irrigation & Agriculture***
- ***Production & Distribution***
- ***Automobile Engine Compatibility***

Convergence

Energy Crisis Mitigation Strategy: Saccharomyces cerevisiae?

Economic History from Norman Poire and
Francis T. Evans in *Roads, Railways, and Canals: Technical Choices in 19th century Britain*

Conceptual Advances add to the Wealth of Nations >>> GPT



UK was the first to adopt one standard time. William Hyde Wollaston (1766-1828) suggested the idea and popularized by Abraham Follett Osler (1808-1903). The first railway to adopt London time was the Great Western Railway in November **1840**. On 22 September 1847, Railway Clearing House, recommended GMT at all stations. By 1855 majority of public clocks in UK were set to GMT. Final switch to GMT took effect through the Royal Assent on 2 August **1880** (Statutes Act – Definition of Time). Standard time instituted in US and Canada by the railroads on 18 November **1883**. Detroit kept local time until 1900. Central time adopted by Detroit in 1905, by vote. Standard time zones established in US by the Standard Time Act of 19 March **1918**.

Biofuels: Demand

for

Ethanol and Biodiesel

Example: India

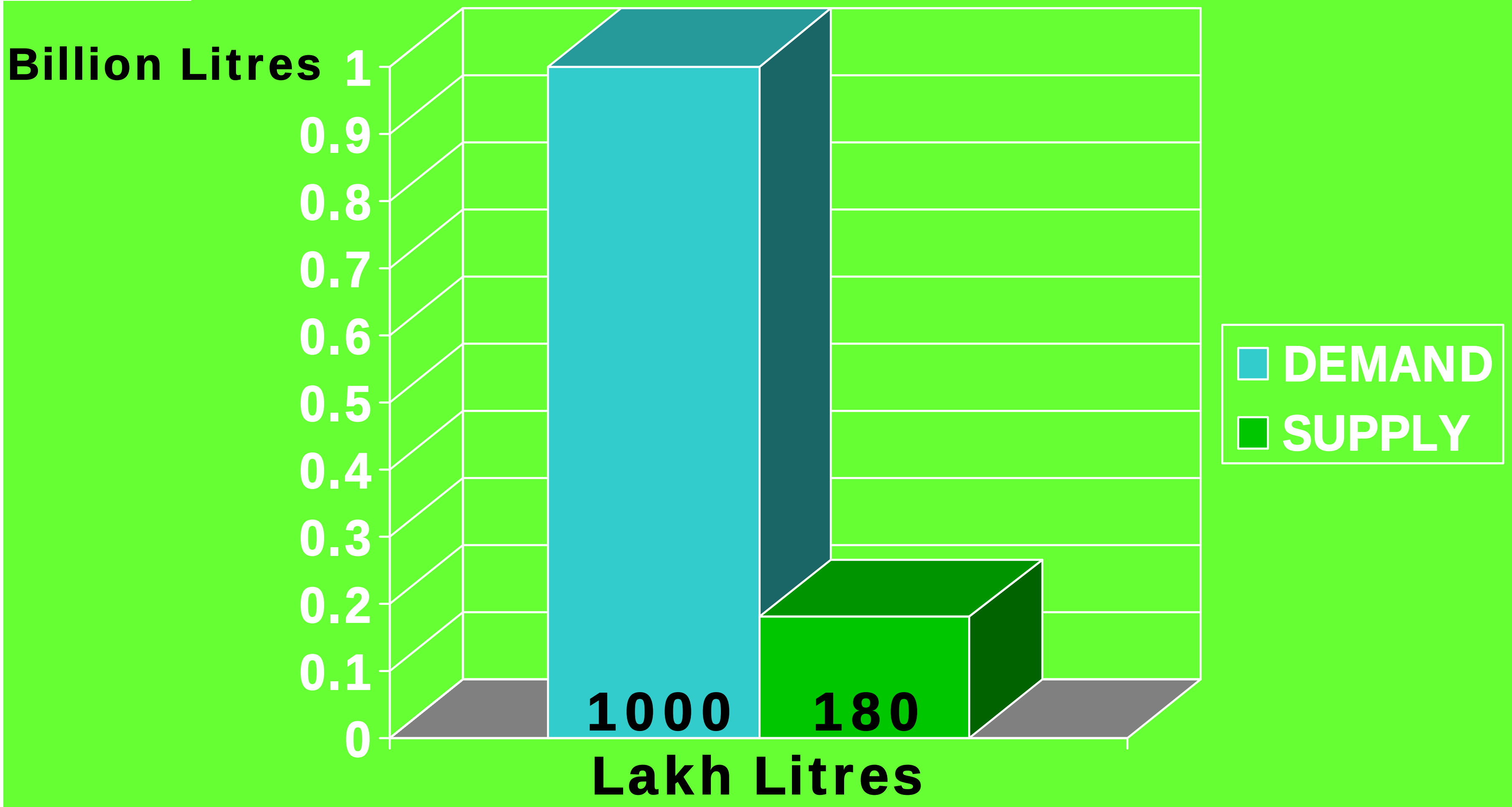
Compiled by
Dr Shoumen Palit Austin Datta
School of Engineering
Massachusetts Institute of Technology

Biofuel Sources

- Ethanol
  - molasses, beet, sweet sorghum, sugarcane
  - cellulosic (wood, grass, biomass residue)

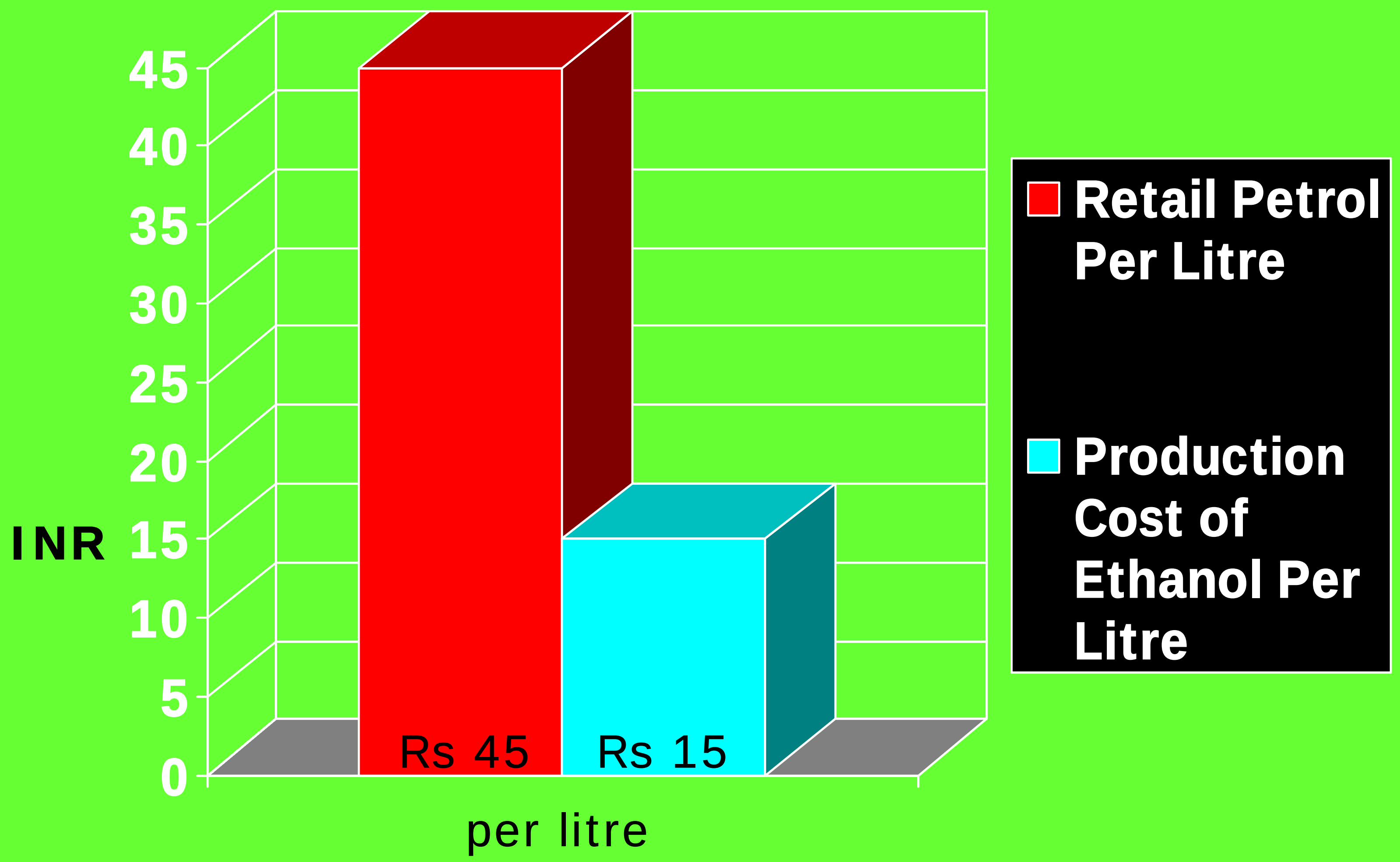
- Vegetable oils (non-edible)
  - Jatropha curcas
  - Karanjia

Ethanol Demand vs Supply



Data per Government of India. According to the US Department of Commerce, the current demand for ethanol in India is 3.6 billion litres or 3,600 lakh litres.

Price of Petrol vs Cost of Ethanol



Biofuels: Bridge to Hydrogen Economy

Number of automobiles 2005 (60% 2-wheelers)	> 60 million
New vehicles registered (50% 2-wheelers)	~ 10,000 per day
Actual Petrol consumed by automobiles	10 billion litres per annum
Total Petroleum consumption in 2006	>130 million tons of crude
Diesel consumption	40 million tons
Imported petroleum	80%
2035: Fuel consumption by on-road automobiles *	60 billion litres
2035: Demand for Ethanol @ 10% (90EBG)	6 billion litres
Biomass residue (cellulose from crops & plantations)	> 500 million tons per year
Potential for Cellulosic Ethanol (200 litres per ton)	> 200 billion litres per year
Potential for power generation from biomass	> 50000 MegaWatts per year

* Projected by the Asian Development Bank

Ethanol Use in India

- **IOC R&D undertaken detailed studies using ethanol blended gasoline (EBG) including 5% (95EGB) and 10% (90EBG) for commercial use.**
- **Ethanol blended gasoline mandatory in many states and 90EBG approved on 1 October 2003**
- **Adequate supply of ethanol is not available**
- **Cellulosic ethanol preferred over grain ethanol**

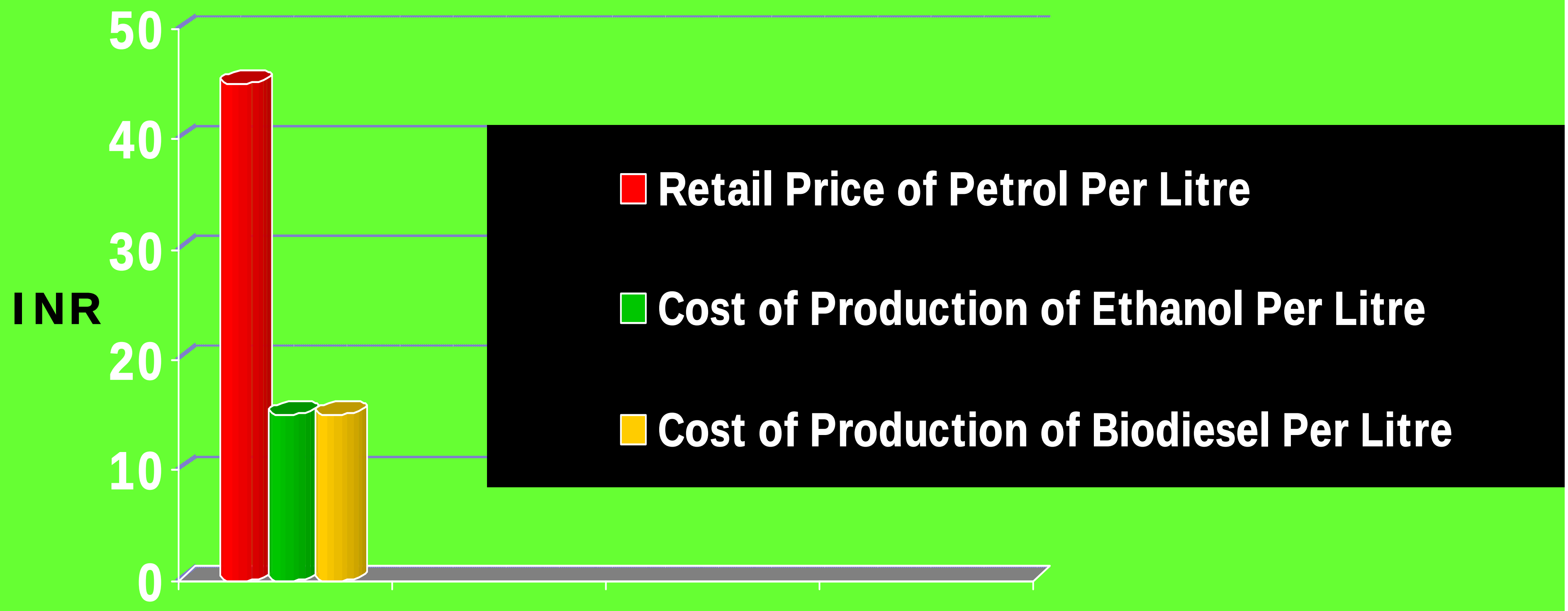
Ethanol Use in Brazil

- 360 million tons sugarcane from 5 million hectares producing 500,000 jobs on plantations and 500,000 jobs in production
- 25,000 petrol pumps dispensing Gasoline, EBG and Ethanol (Alcool)
- VW and GM flex-fuel vehicles (FFV) can run on any fuel or any blended fuel (mixtures)
- Brazil-India cooperation MOU signed in 2001

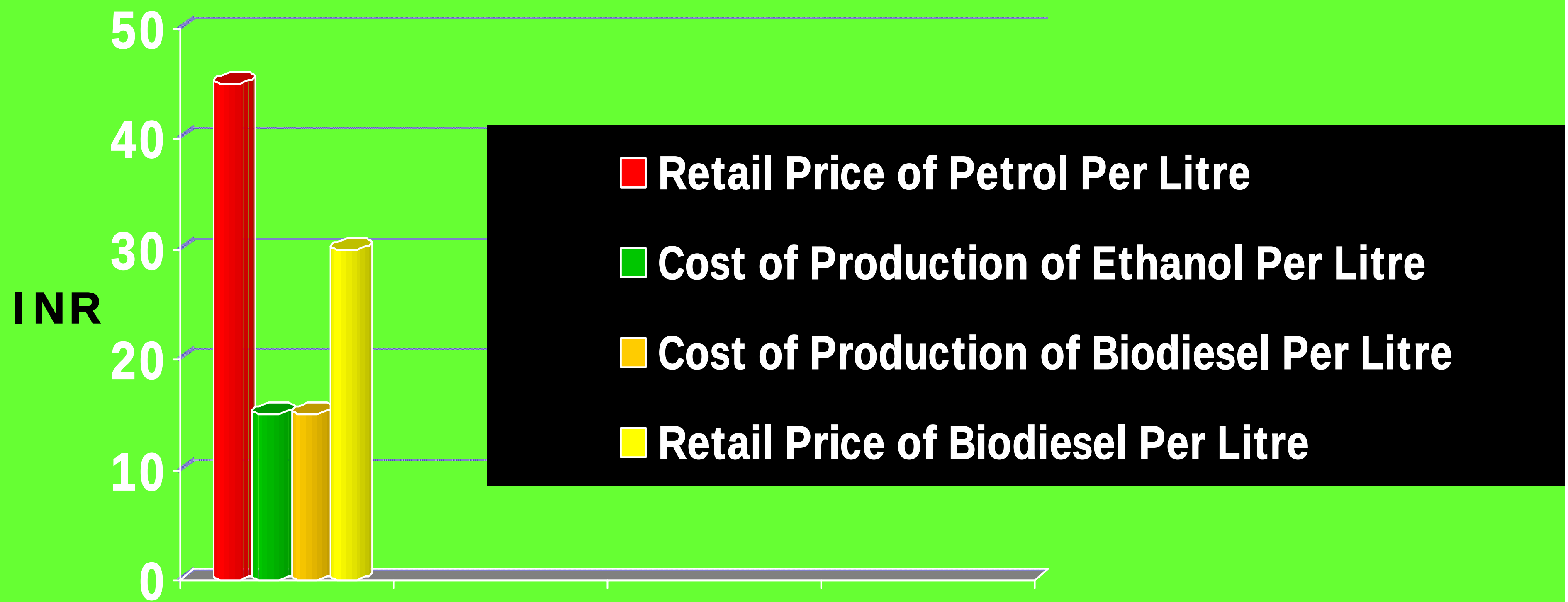
Biodiesel

- Renewable, non-toxic, biodegradable, non-edible vegetable oil
- Lower emissions compared to diesel (zero sulphur, 78% reduction of CO_2 and 50% reduction of CO)
- Better fuel properties (cetane number, lubricity, flash point)
- Daimler Chrysler India successfully tested cars running on 100% biofuel extracted from Jatropha curcas
- 11 million hectares of wasteland suitable for Jatropha cultivation
- 126,000 hectares adjacent to railway tracks owned by Indian Rail

Price of Petrol vs Cost of Biofuels



Rs 30/L **Biodiesel: Profit / Hectare ~ Rs 25,000**



Biodiesel: Profit & Jobs

Lifecycle of plant	50 years
Oil content of seed	35%
Oil yield / kg of seed	250 ml
Plants / hectare	2,500
Job creation / hectare	0.25 FTE
Cost of maintenance / hectare / year	INR 20,000
Seed yield / hectare / year	7 tons
Oil yield / hectare / year	1750 litres
Cost of oil production / litre	INR 15
Cost of oil transport to Europe / litre	INR 5
Cost of oil production / hectare	INR 26,250
Pressed seedcake / hectare	4.5 tons
Selling price of seedcake / ton	INR 4,000
Cost of oil production & maintenance / hectare	INR 46,250
Sales of oil @ INR 30/L and seedcake / hectare	INR 70,500
Gross earnings from biodiesel / hectare	INR 24,250
Area adjacent to railway tracks (hectare)	126,000
Earnings from biodiesel from 126,000 hectares	INR 30 CRORES
New job creation from use of 126,000 hectares	30,000
Wasteland	10 million hectares
Earnings from biodiesel per million hectare	INR 2,425 CRORES
New job creation per million hectare	250,000
Potential for new job creation from Wasteland	25 LAKHS **

** 1 LAKH = 100,000

IOC, Indian Railways, Tata & Other Initiatives

- Trans-esterification, process optimization and commercialization
- Testing of locomotive engines with biodiesel (B100) and blends
- Vehicle performance and emission studies (Escorts, Tata, M&M)
- Field trials with buses in Gujarat
- Jatropha plantation on 70 hectares adjacent to rail tracks
- Studies on 16 cylinder engine (3100 hp) with B5, B10 and B20
- Shatabdi & Jan Shatabadi Train trial runs
- Trains through Lucknow using bio-diesel (B10) from June 2006
- Evaluation of B20 for 4 passenger cars and 2 commercial vehicles
- Tata Motors employee buses using B10 in Pune
- Haryana Roadways converts entire (Gurgaon) bus depot to use B5

Biodiesel Purchase Policy (9 October 2005)

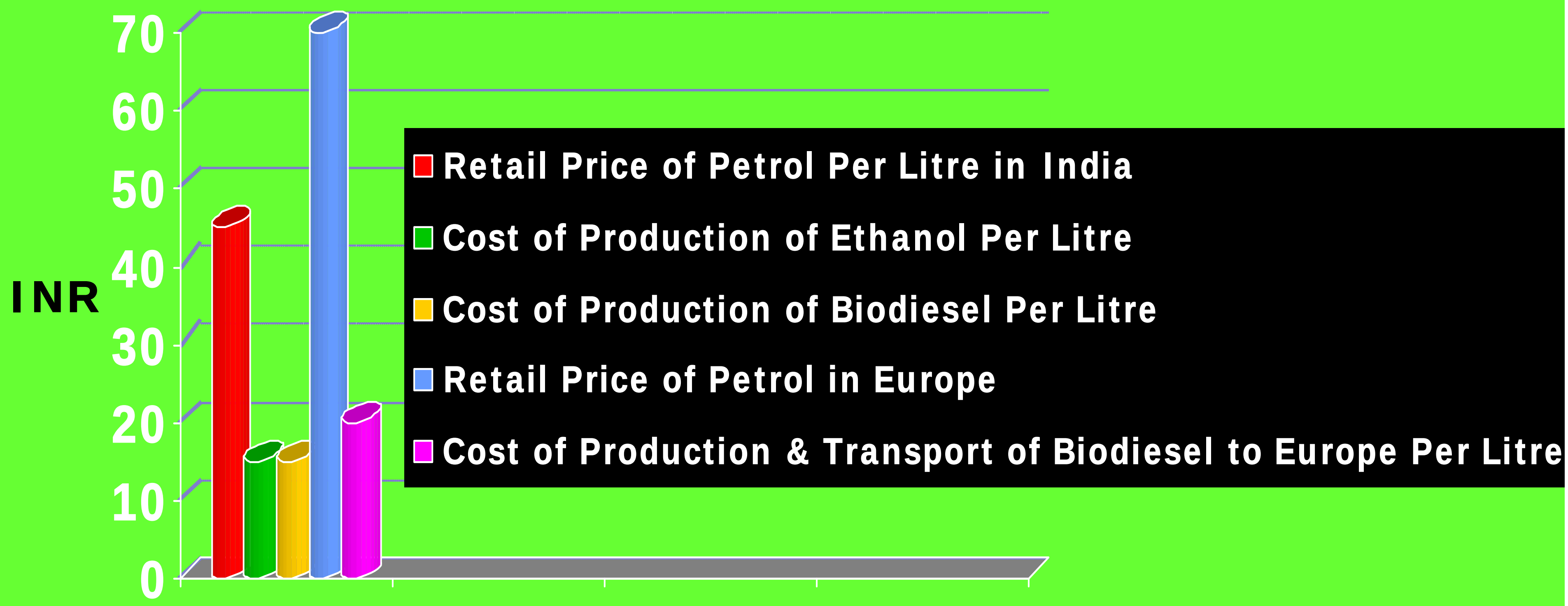
- Biodiesel policy involves PRIs for Jatropha plantations and oil extractions by establishing Rural Business Hubs

- OMC purchase price INR 25 per litre.

- Assistance for Jatropha plantation and oil extraction.

- IOC R&D to increase biodiesel content from 5% to 20%

Profit from Export of Biodiesel



February 2006:
BP invests $9.4 million in India for Jatropha biodiesel.

China: Biofuel Boom

- **13 million hectares for Jatropha plantation**
- **200,000 tons of biodiesel by 2010**
- **1 billion litres of Ethanol produced in 2006**
- **Production cost for cellulosic ethanol $0.25 / L**

Biofuels in India: Potentially Profitable

- **Significant profit from ethanol and biodiesel**
- **Export potential for higher profitability**
- **Ethanol-resistant yeast to improve yield**
- **Enzyme-catalysis for cellulosic ethanol**
- **Creates new jobs even in wastelands**
- **Implementable with minimal time**
- **Foreigners ready to grab market**

Strengths	Increasing Demand ROI 15% of Capital INR 20000 / ton capacity Robust supply chain Distribution Channels Job creation in wasteland No new carbon addition	Decrease fossil fuel use Reduce carbon emissions Oil crisis mitigation Government regulation European distribution Worldwide awareness	**Opportunities**
Weaknesses	Does not eliminate carbon emissions completely In the very long run may be more expensive than hydrogen via electrolysis Existing engine conversion	US / EU investors Slow pace of bureaucracy MNCs land lease venture Failure to use new tools Lethargic approach Paralysis from analysis	**Threats**

Power in Every Garage

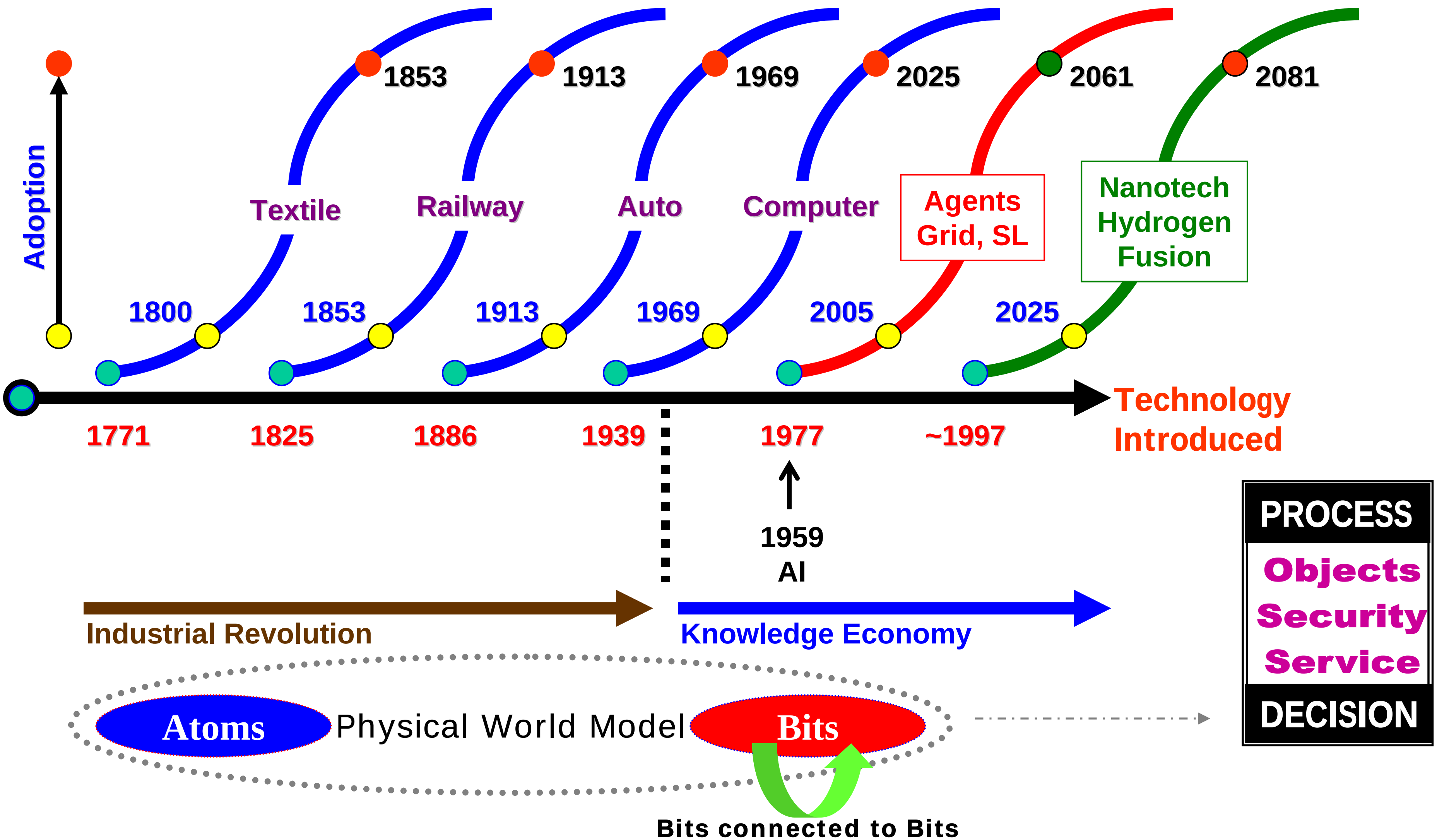
pH ●→ The Power of Hydrogen

A chicken in every pot and a car in every garage!

Herbert Hoover 1928 (1929-1933) 31st POTUS

Shoumen Datta, School of Engineering, Massachusetts Institute of Technology <shoumen@mit.edu>

Conceptual Advances (*add to the Wealth of Nations but "Adam Smith was wrong!"*)



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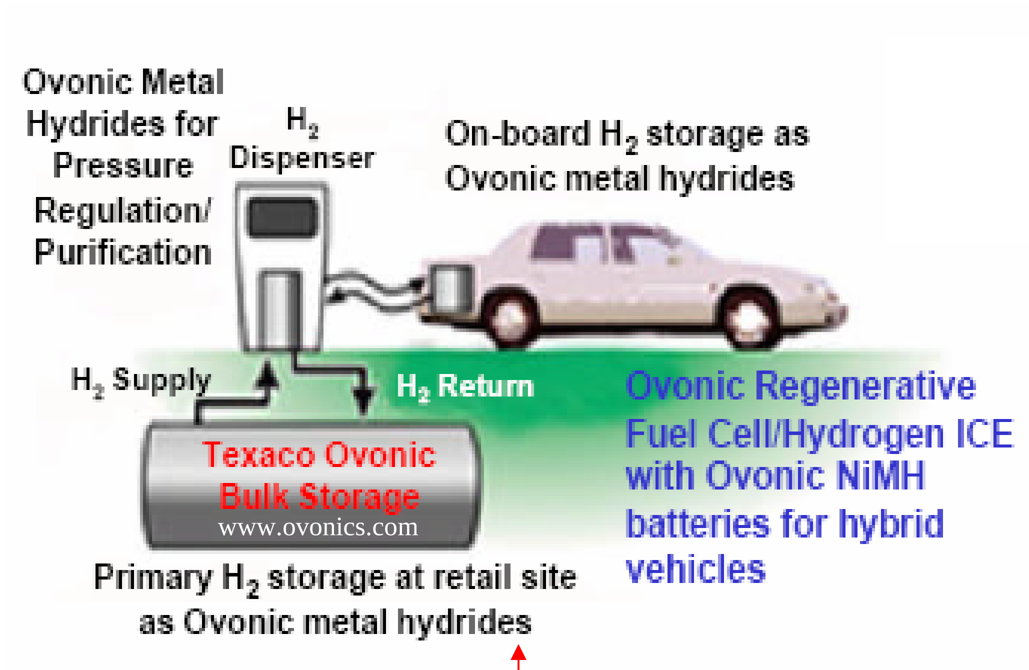
Pipe Dreams ?



173,000 petrol pumps in US
Motorists stopped a total of 11 billion times in 2002
Station refuels 175 cars/day

Source: www.auto.com/industry/hfuel5_20030305.htm

www.auto.com/industry/hfuel5_20030305.htm

US$ 400 Billion

Re-tool pump infrastructure and pipeline in US

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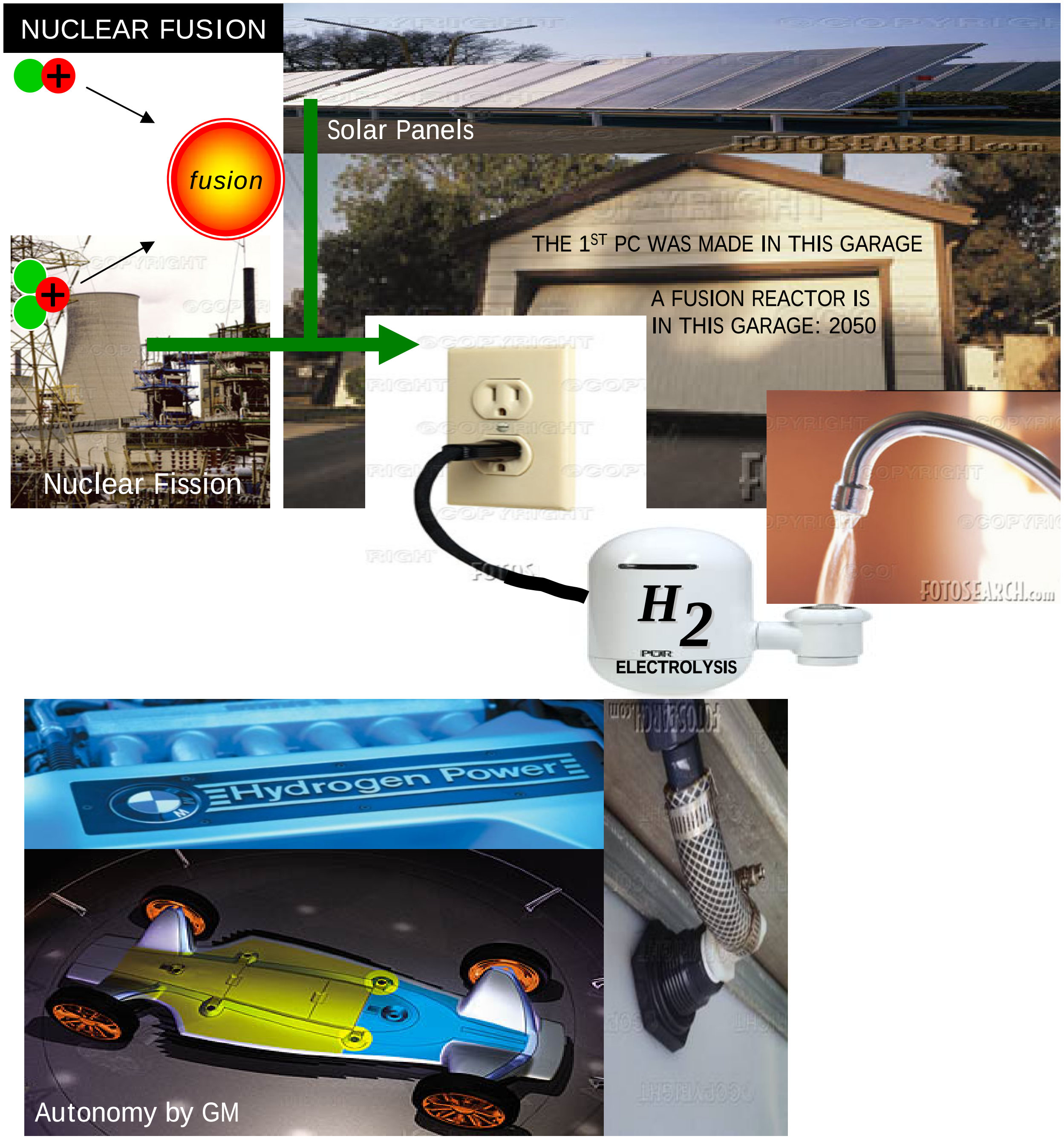

pH: Power of Hydrogen

Power in your Garage

Future

2025 - 2050

Open Air Museum of Fossil Fuel

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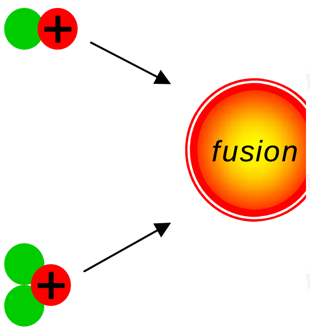
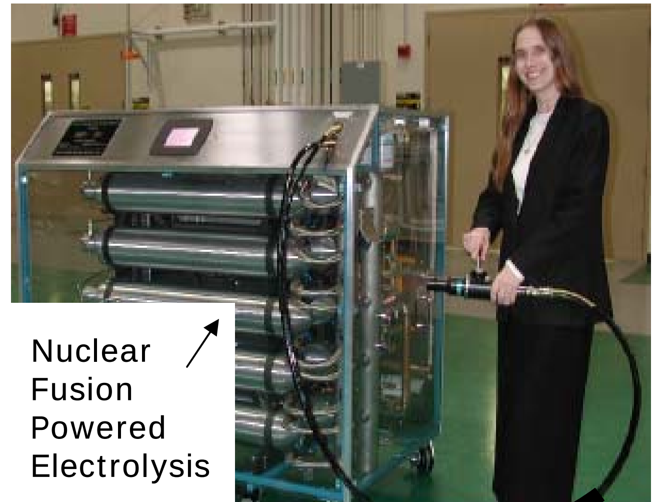
pH: Power of Hydrogen

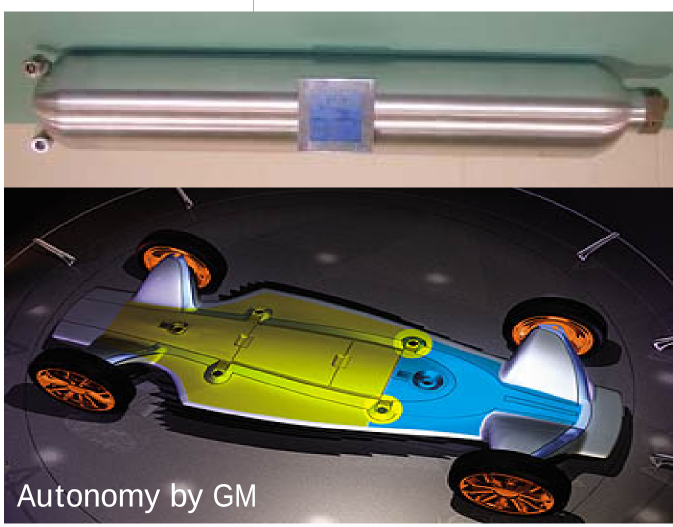


Power in your Garage



Nuclear Fusion Powered Electrolysis

Cartoons: Ovonics



Autonomy by GM

Ubiquitous Hydrogen on Demand

GPS-UWB linked hydrogen sensor tagged Hydrogen Power Cells for sale in restaurants and grocery stores to replenish fuel, anytime.

Create that, not which is acceptable, but what will become accepted.

pH is Unstoppable for Sustainable Economic Growth

1960	2005	2025	2050
VCR* $ 50,000 →	$ 50		Portable Domestic Fusion Reactor
PC* $ 120,000 →	$ 500	$ 50	
pH	$ 375,000* →	$ 2000	

Energy Plant in Every House

* Cost of semi-portable Hydrogen generator from natural gas (www.auto.com/industry/hfuel5_20030305.htm)

* VCR manufactured by AMPEX Corporation; * Desktop PC model PDP-1 manufactured by DEC

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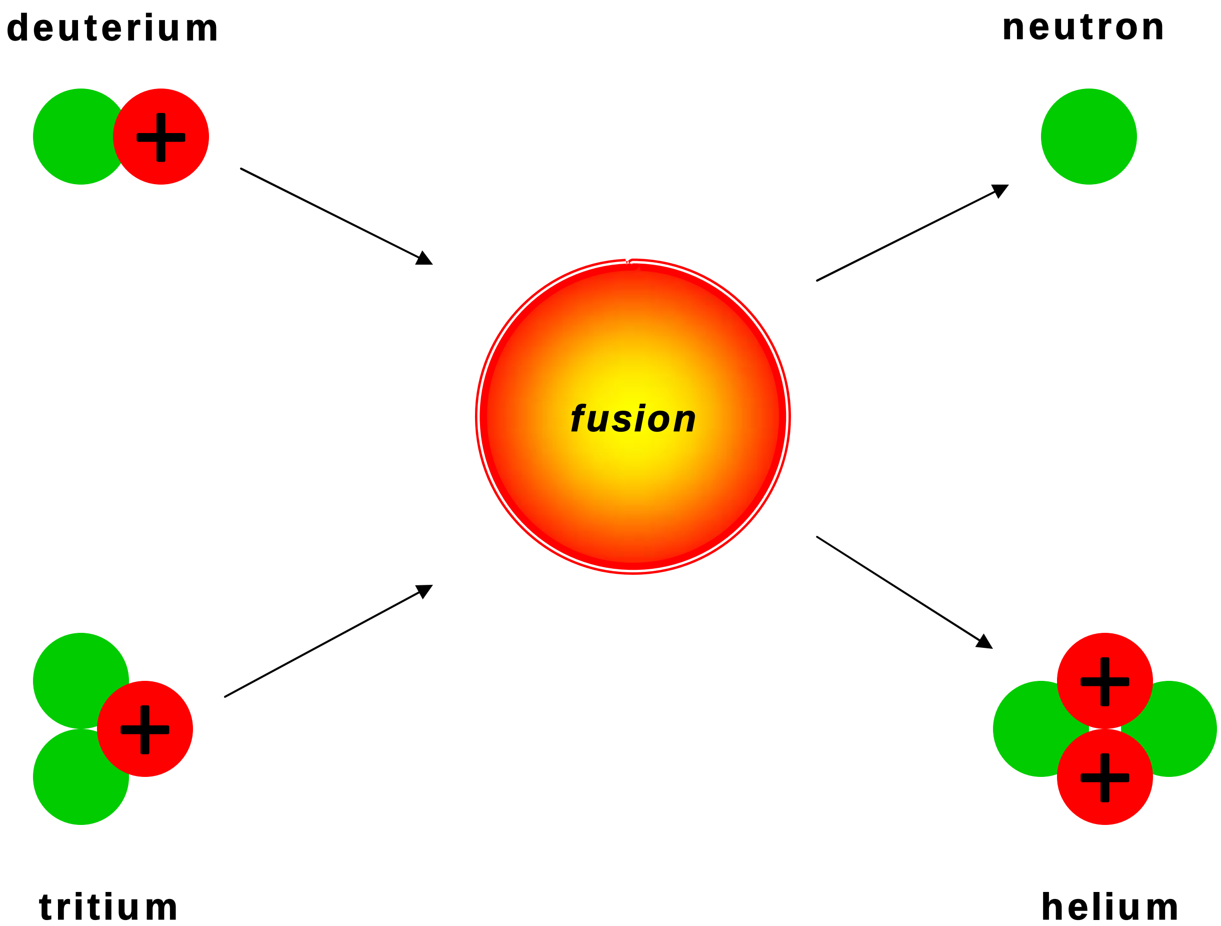
FUSION REACTION

Heavy Hydrogen in one can of sea water provides about as much energy as one tanker truck of gasoline (petrol).



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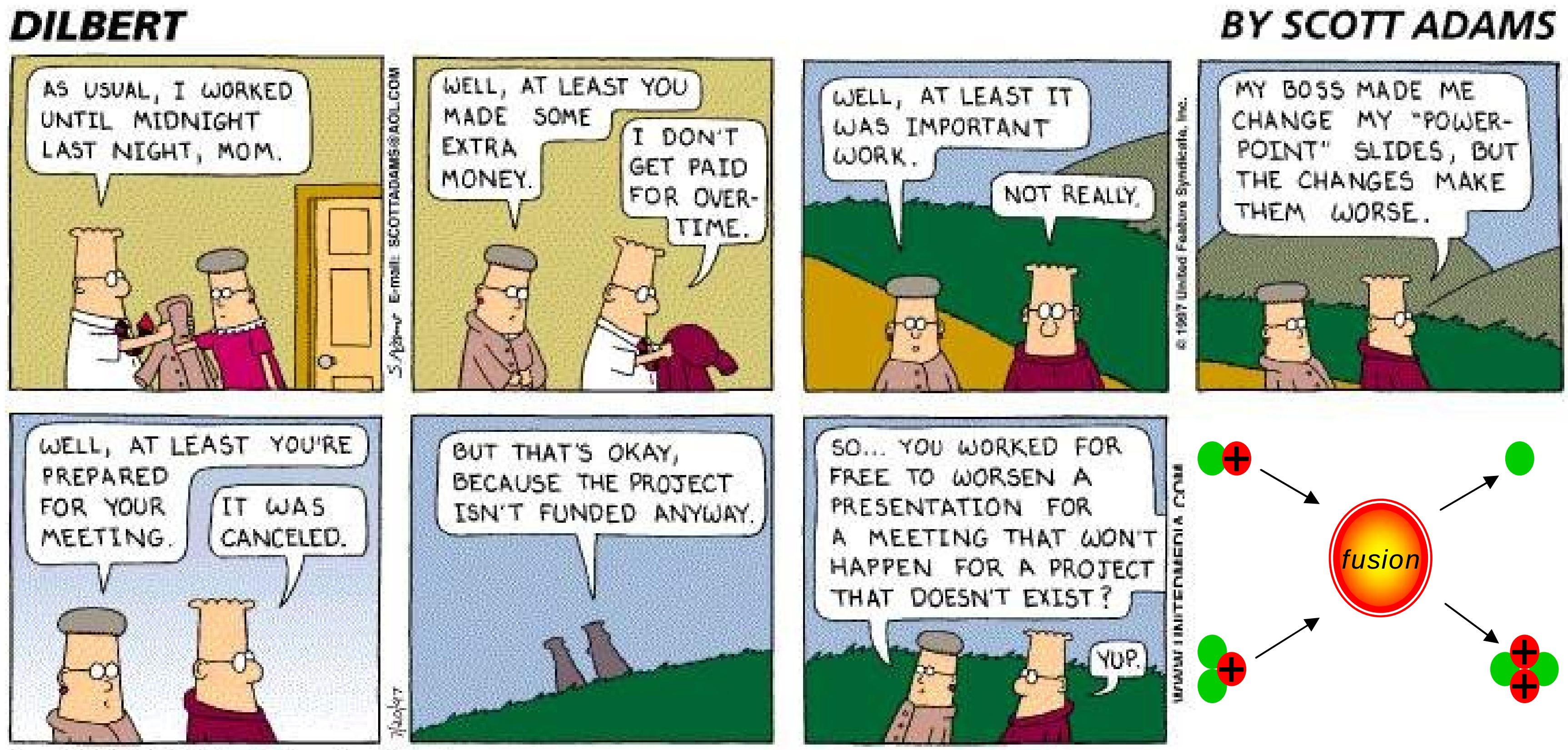

DILBERT
BY SCOTT ADAMS
AS USUAL, I WORKED UNTIL MIDNIGHT LAST NIGHT, MOM.
E-mail: SCOTTADAMS@AOL.COM
WELL, AT LEAST YOU MADE SOME EXTRA MONEY.
I DON'T GET PAID FOR OVER-TIME.
WELL, AT LEAST IT WAS IMPORTANT WORK.
NOT REALLY.
© 1997 United Feature Syndicate, Inc.
MY BOSS MADE ME CHANGE MY "POWER-POINT" SLIDES, BUT THE CHANGES MAKE THEM WORSE.
WELL, AT LEAST YOU'RE PREPARED FOR YOUR MEETING.
IT WAS CANCELED.
BUT THAT'S OKAY, BECAUSE THE PROJECT ISN'T FUNDED ANYWAY.
SO... YOU WORKED FOR FREE TO WORSEN A PRESENTATION FOR A MEETING THAT WON'T HAPPEN FOR A PROJECT THAT DOESN'T EXIST?
YUP.
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