
5/24/7: We all know that our growing NEED to import oil from unstable parts of the world are a central challenge to US national security. If world dependency on those regions continues to grow at the present rate, in 20-30 years the costs and the dangers could grow to be ten times as large as they are now. Clearly we need to take very strong action, if we have any hope at all of changing these trends. It is a matter of life and death.

Today I will talk about serious ways that we might change these trends. I will be presenting a strategy for zeroing out our NEED to use gasoline, as soon as possible. This is also an essential part of a larger strategy for how to zero out world emissions of CO2 as soon as possible. Notice that the goal here is not to minimize *actual gasoline consumption* in 5-10 years; rather, it is to build up an ability for the US to survive a worst-case scenario, 10-20 years from now. Survival under the worst case scenario is a matter of national security, a legitimate area for strong US government action.

I am employed by the National Science Foundation, and my co-author – Dr. James Momoh – recently ran the Electric Power activity at NSF. But today, we will mainly give our personal views of what could be done to achieve a dramatic reduction in energy dependency in the 20-30 years we have left to do so. Our views on these issues have also been shaped heavily by what we have learned as active members of the IEEE – the world’s largest professional society, with about 300,000 members all over the world. We are the inheritors of Thomas Edison, and we remember how difficult the changes were – both political and economic – which opened the door to a new technology, and eventually allowed Thomas Edison to “turn on the lights” in New York City. The challenge before us today is to open up the door to turning on the lights again – this time all over the world.

Our views have also been shaped by other important sources of information, such as DOE, NASA, Howard University and the Millennium Project (MP) of the American Council for the United Nations University (www.stateofthefuture.org).


US oil dependency and US $CO_2$ emissions are mainly due to the limitations of the technologies we now depend on. Only by massive changes in technology can we improve the situation enough to really matter. Thus the strategy I discuss will directly address the specific possibilities for technology change that offer real hope here. Brute force carbon taxes may help, someday, in "greasing the skids" for technology change… but there are better and more efficient ways to accelerate technology change, as I will discuss.

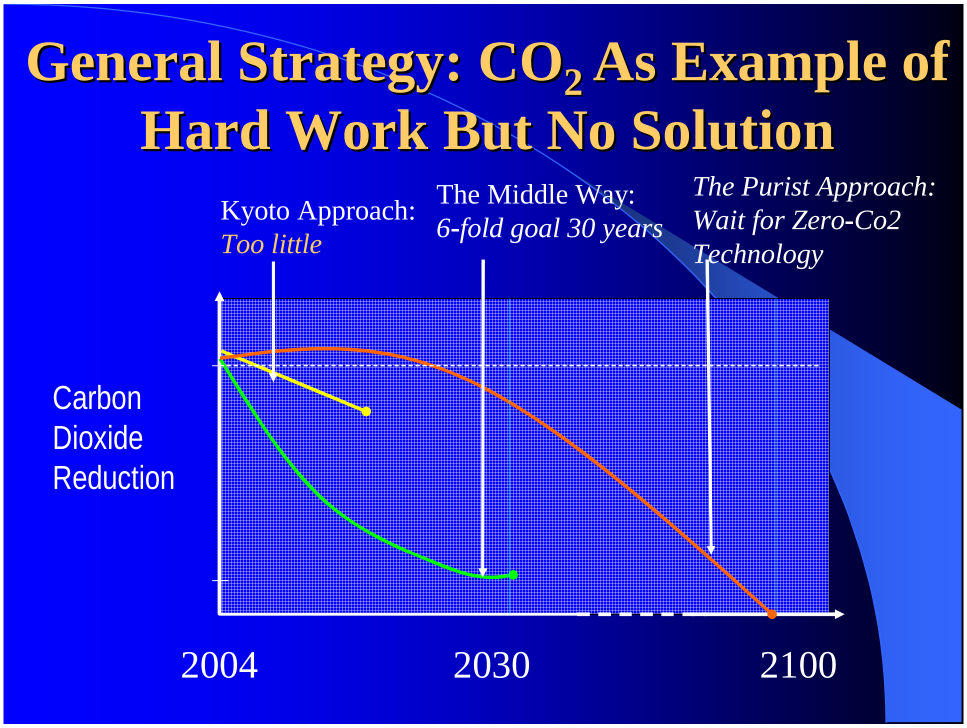
In the end, we have to understand the technologies and what they really offer. The best information on automotive technology is not something you can find in an authoritative hundred-year-old encyclopedia or government agency report. In fact – the engineering community (represented by societies like IEEE, ASME, SAE, etc.) is the best source of front-line current information.

One of my major sources of information here is the Alternate Energy Task Force, whose members are listed here. Nothing I say today will represent the task force as a whole – but people on this task force have been very helpful in keeping me from getting too far off track. For more information on the task force, see: http://ieee-cis.org/isa/alternative/

The people on this list include the world's leaders in intelligent adaptive engine control, one of the two key requirements for maximum fuel flexibility in any kind of car. It is also essential in maximizing fuel efficiency and minimizing pollution.


Today I will mainly talk about car fuel security, for reasons of time. But we cannot really survive as a nation unless we take strong steps to achieve breakthroughs in all THREE areas. The world faces three energy crises, not just one. If we try to "prioritize" here – it's like going to a car dealer who asks you "Which do you want? A car with an engine, a car with wheels, or a car with a body? Choose one…" In fact, if you don't do all three you have nothing.

As an example – if you want to zero out CO2, or cut CO2 enough to really matter, you need to go to zero net CO2 emission from cars and trucks. You need to do that as soon as possible. AT THE SAME TIME, you need to move towards zero CO2 emission in producing electricity as fast as you can – but that's an independent activity. There is no excuse for slowing down either one of these essential activities.




The story of $CO_2$ reduction gives us an excellent example of how well-intentioned policy can spend lots and lots of money and change nothing in the end.

Both for $CO_2$ and for energy dependency, there are lots of laudable things that people can do here and now in the short-term to get useful results. These results are usually very large in dollar terms – but not so large as a share of the global energy system. These short-term things include things like the Kyoto Treaty, the drilling in Anwar, rooftop solar power, wind power, ethanol fuel for cars. I do not plan to pass judgment on all these things today – BUT I DO NOTE THAT they are NOT ENOUGH by themselves, even taken together as a group. For example, the Kyoto Treaty plan, based on aggressive goals for such near-term technologies, simply doesn't do enough to change some of the dire outcomes people are worried about for the coming century. Even when such near-term opportunities are accounted for, oil dependency is projected to grow dangerously by 2030.

On the other hand, the purist approach of just waiting for zero-$CO_2$ technology before doing anything would have us wait too long – maybe forever. Oil dependency and $CO_2$ problems and nuclear proliferation are all growing too fast for comfort, and we need to move as fast as we can towards really big cuts.

But – there is a Middle Way between these extremes, where we don't zero out $CO_2$, but we cut it deeply enough to prevent what the environmentalists fear. We have a real hope – not a guarantee – of very deep cuts in $CO_2$ emissions and oil dependency, soon enough to matter. My goal today is to explain what this Middle Way opportunity is, for energy use in cars and trucks.

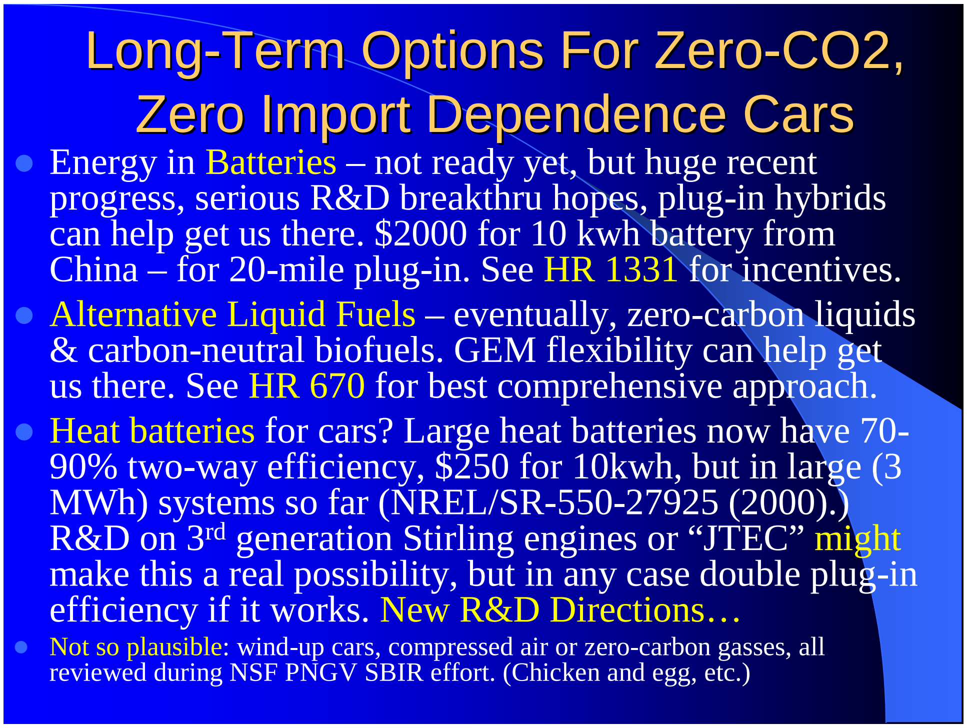

Now back to the core question: what can we do to stop the trend of rising imports?

Twenty years ago, when I was at DOE, we had to explain that the world was not facing a crisis in ENERGY SUPPLY as such. We had plenty of domestic energy – natural gas, coal and electricity. The challenge was how to address the first question: How do we keep our CARS running, when oil from the Middle East becomes too expensive or even cut off? How do we provide more security in case of a sudden cutoff? **Is it possible to change half the new cars in the US in a mere 5 years?**

**It turns out that it is possible** – but only if we have tremendous will power and focus our minds to the utmost, to really solve this problem. What's needed here is not a trillion dollars; it would certainly take some money, but not as much as what the last Energy Bill ended up costing. The critical resource here is brainpower, determination and honesty, not money.

Today I will only have time to talk about oil – but I hope we will have a chance to talk about our sources of electricity as well, as soon as possible. As of now, we are also dependent on imports of Liquefied Natural Gas (LNG) to make electricity. This dependency is small for now, but it could grow to be large over the next 20-30 years if we do not act now to prevent that. Some of the best ways to reduce oil consumption would increase the use of natural gas, and make the problem worse. Unused supplies of conventional natural gas are about the same as unused supplies of oil. We need a strategy for keeping BOTH fuels in balance. Furthermore, we need to work harder and smarter to upgrade the distribution systems – like electric power grid – which are needed to CONNECT new sources of energy to new users.

If we do it all right – we have a serious chance, on the technical level, to reduce our dependency on the Middle East dramatically over the next 20-30 years while paying the world back for the entire cost of the effort and even clearing a profit in the end. But it is only a hope, not a guarantee. If we were venture capitalists, we would say that the new energy technologies are highly risky. But in order to survive, some of us need to think about risk in a different way. From a national or global viewpoint – the most serious risk is what happens if we do nothing. We need to work harder in order to REDUCE the huge risks that we are already facing. We need to ask our R&D review panels to focus discussion on this other kind of risk -- the risk of what we lose by inaction.




HERE IS WHAT WE NEED TO DO, SUMMARIZED IN ONE SLIDE. This is a busy slide. I will give more explanations and details on later slides, but some of you would like to see the whole thing put together on one slide.

There are 3 serious ways to build cars that would emit zero net CO2, and require no fossil fuel at all. None of these are ready for global use by everyone today – but for all three, there are very big near-term opportunities that can improve our situation dramatically, while also putting the whole earth firmly on the path to a secure sustainable future. We need to be moving a whole lot faster than we are today along all three paths, at the same time. Number one on the list is electric cars. You probably all know that Tesla Motors is already mass-marketing an electric car with a good driving range, at a price far lower than it would take for a hydrogen fuel cell car if one were available. It is also far more energy efficient; if electricity generation requires any CO2 at all, per kwh, electric cars would always result in less CO2 emission than the less efficient choices. Most people cannot afford a Tesla – but new batteries have come out which make PLUG-IN hybrid cars within reach for the mass market. New R&D opportunities exist for major breakthroughs here, far more promising than what I have seen with fuel cells lately.

Alternative liquid fuels are a bit riskier for the long-term, but offer huge opportunities in the near term, more than anything else. We need to move much faster on "GEM fuel flexibility," which I will explain. HR 670 is the one bill out so far which would really capture some of the urgent needs here, but in an ideal world we would take even stronger action, as I will explain. To see HR 670 and 1331, look for these bill numbers at http://thomas.loc.gov .

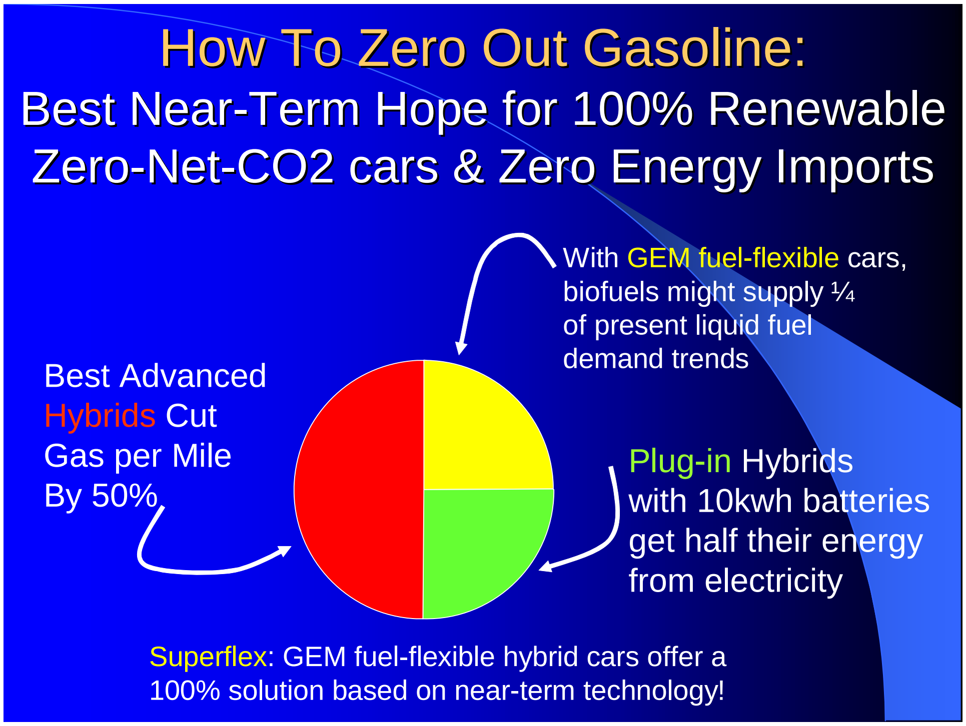
Finally – storing heat on-board cars might ***possibly*** give us a real breakthrough, if we prepared the way through some very promising initial R&D, which would pay off quickly for solar energy. More innovative mid-term R&D is an essential unmet part of this strategy, far more serious and politically difficult than most people realize. The unmet opportunities to solve big problems are huge… but there are also a few directions which seem plausible in principle that do not really look promising now for US use after extensive review, as listed here. (As I submit this, Tata Motors of India is about to mass-produce a small compressed-air car with a 240 km driving range, which can be powered up by a recharger plugged into the power grid – but is far less efficient or grid-friendly than a true electric.)

# Plug-in Hybrids (PHEV) : A Large-Scale Opportunity Here and Now

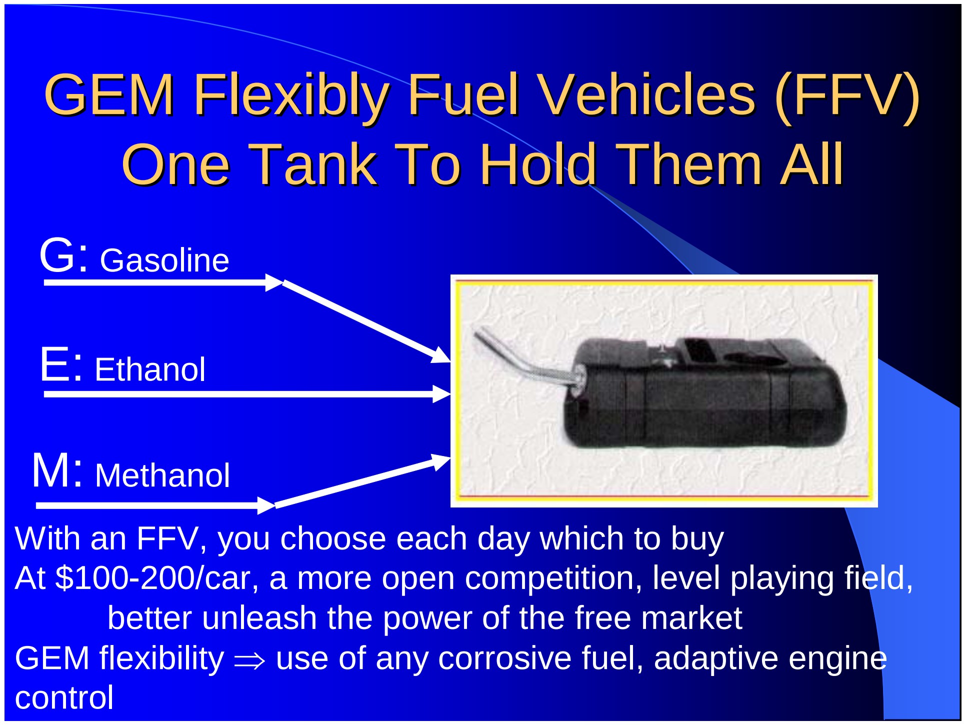
- Hybrids cut liquid fuel use 50% already. Plug-ins cut 50% of that.
  - “Researchers have shown .. (PHEV) offering.. electric range of 32 km will yield… 50% reduction..” (IEEE Spectrum, July/05). Shown in working Prius.

- Battery breakthroughs in China: from 10/07, 10kwh batteries (larger than) cost $2,000. www.thunder-sky.com. Thus an extra $2,000 per car can cut gas dependence in half.
- Gives economic security in case of sudden gasoline cutoff.
- Does not strain grid – actually strengthens it, if done right

This slide is self-explanatory (I hope).
This is a real picture of a real working plug-in hybrid Prius, published in IEEE Spectrum – the flagship magazine of IEEE, the world’s largest engineering society. (Over 300,000 members.) Much of what I have learned about these technologies comes from meetings of IEEE technical societies; I serve on the governing boards (“AdComs”) of two of them, and have worked a lot with others. This is real stuff, not advocacy politics.
Plug-ins are real today – but not cheap today, and not yet mass-produced (though I hope we may be close). The biggest technical problem is the cost of the batteries. In fact, Toyota now says that supplies of state-of-the-art batteries are the main factor limiting their sales of hybrid cars (which have been doubling every year for some time, with lots of people in line to try to buy them). DOE and the US auto industry almost gave up on developing breakthrough batteries decades ago – but the electronics industry did not give up. Major breakthroughs have been made, mainly by people building laptops and cell phones – but the technology carries over.
However – the core electronics manufacturing centers in the world are no longer in the US, even for US-designed and US-owned products. Most of the engineers are not US born even here. A recent pie chart of lithium battery production shows 46% in Japan and 46% in China and Korea. Batteries are available in China today far beyond what the US makers of plug-ins seem to have access to. They are still not cheap – but with more competition, and a solid need for the product, it is a very important option to push as hard as we can.




This slide mainly speaks for itself…
But there is a very important point implicit here. We do not have to CHOOSE between plug-in hybrids and GEM fuel-flexible cars. It is actually easier to provide GEM fuel flexibility in hybrid cars and in plug-ins than it is in conventional cars. It is actually conceivable that in ten years – with the right incentives – the private sector might be able to produce a majority of the cars as GEM-flexible plug-in hybrids.  This is our best hope for absolute gasoline independence and zero net CO2 at the soonest possible time…




The GEM flexibly fueled car is the key to the transition to sustainable car fuel, if we want to get to anything else but a pure electric car. (Even then, hybrid cars can be made flexible.)

The key point is that GEM flexibility is HERE TODAY. It's not mainly a subject for research. It's ready for mass deployment. It is the one and only option we have at hand right now to break the chicken and egg cycle soon enough to deploy advanced independent cars before 2030 in large numbers.

And – it's not very expensive. If you compare the $100-200 per car to achieve "fuel insurance" for the life of a car, that's a whole lot less than what we all pay every year for accident insurance. And maybe for most of us, the chances of a big accident in the next 20 years are less than the chances of some problems in the Middle East. Or, to put it another way, this flexibility would give the car buyer a chance to buy something else besides gasoline on days when the price of gasoline is too high. Many, many Brazilians have been grinning this year about how they didn't have to buy gasoline when the price was rising so much all over the world.

To really accelerate the development of methanol and ethanol fuels, without creating subsidies, we could simply REQUIRE that new gasoline-carrying cars should have GEM flexibility. Yes, this would be a legal intervention – but it would actually STRENGTHEN market forces because it would open the door to more competition. In many ways, it would be like the imposition of common standards for communication interfaces and common carriers; they do require laws, but their EFFECT is to open up more competition. This is a case where more competition may be a life-or-death matter for national security, and we need it as fast as we can get it. GE flexible cars have been penetrating the markets without special laws in Brazil – but we need three-way flexibility, and we cannot afford to wait.

## But How Much Benefit Can We Get From Alcohol Fuels Near-Term?

- The maximum conventional ethanol supply from US corn is only a tiny fraction of US needs, and only a tiny fraction of biofuel potential revenue
- Can we expand it by an order of magnitude?
- Can we find technologies that work off a much wider varieties of plants, more efficiently, at an acceptable price? Can we find technologies well enough proven that they could really scale up fast?


There are lots of people out there who want to spend billions of dollars over a few decades, in order to improve our ability to make pure ethanol from "cellulosic" sources like wood or grass. But why restrict it to pure ethanol? People have known for decades or even centuries how to make MIXED ALCOHOLS or other useful fuels from wood. Ever hear of "wood alcohol?"

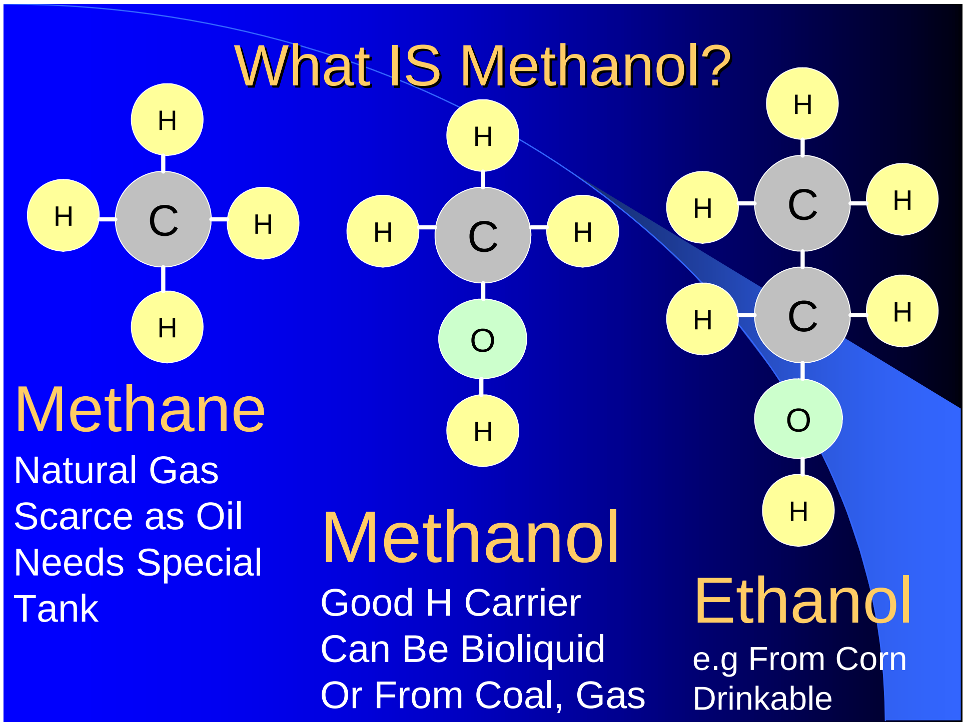
We don't need to wait decades for a technology to make wood alcohol. It's already in existence, for decades and decades. What's more – there is a lot more efficiency and a lot less waste when we make the kinds of fuels nature wants us to make, instead of demanding pure ethanol. Farmers can make a lot more money by making and selling these other kinds of fuels, because they can make more fuel per ton of biomass at a lower cost.

What we need is a MARKET for what we already know how to make.

We need cars which can USE these easier types of alcohol and biofuel…

and that turns out to be a whole lot cheaper than doing things the hard way.

CAVEAT: R&D on new, advanced biofuel production technology could be a big help here, IF WE move immediately to open up the market for ALL these alternative liquid fuels, ethanol included. GEM fuel flexibility will do this, because it requires a general ability to handle liquids as corrosive as methanol, and adaptive engine control.



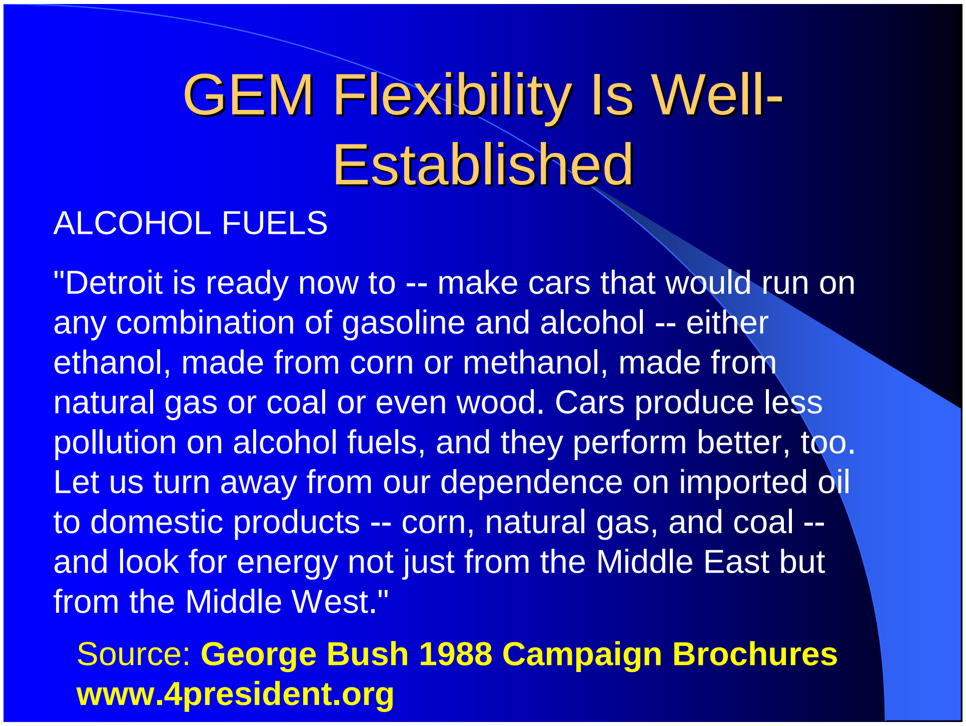

In order to avoid gross mistakes in formulating policy here, it is essential to know about all three of the fuels depicted here – methane, methanol and ethanol. It's very important to keep them straight. All three have important roles to play.

Methane is a gas, but methanol and ethanol are liquids. Therefore, methane needs special tanks to hold it – but usually we only see it coming it out of a pipe, like the pipe going to our stoves. It's basically the same as natural gas, and we need to be careful in using it.

Methanol and ethanol are two different types of alcohol. Ethanol is not enough to meet more than 10 percent or so of our needs, but 10 percent is still a lot, and ethanol can be very useful when linked to methanol as part of a strategy for energy independence. Like methanol, it deserves the right to more of a level-playing field in the market for automotive fuel. It is said that a third to a half of all car fuel in Brazil is coming from ethanol (as part of a fuel mix). But methanol, unlike ethanol, is an excellent and proven hydrogen carrier. Unlike ethanol, it could solve our chicken-and-egg problem with fuel cell cars. Ethanol alone is not enough. The wholesale market for methanol is already large and well-established.

More precisely – if we create a market for methanol, by deploying conventional cars which are flexible enough to use gasoline, ethanol OR methanol, then the free market will have an incentive to build up supplies of BOTH alcohols. And then, after methanol is widely available, it will be possible to mass-market methanol fuel cell cars, without doing undue violence to the market. Some people would say:"This shows that the fastest path between two points is not always a straight line, when you're trying to get through high mountains."

Methanol can be made from MANY sources. The potential supply really might be large enough to meet all of our needs. Fortunately, the government does not have to decide WHICH of these many sources the market will choose, IF the market for methanol is created.



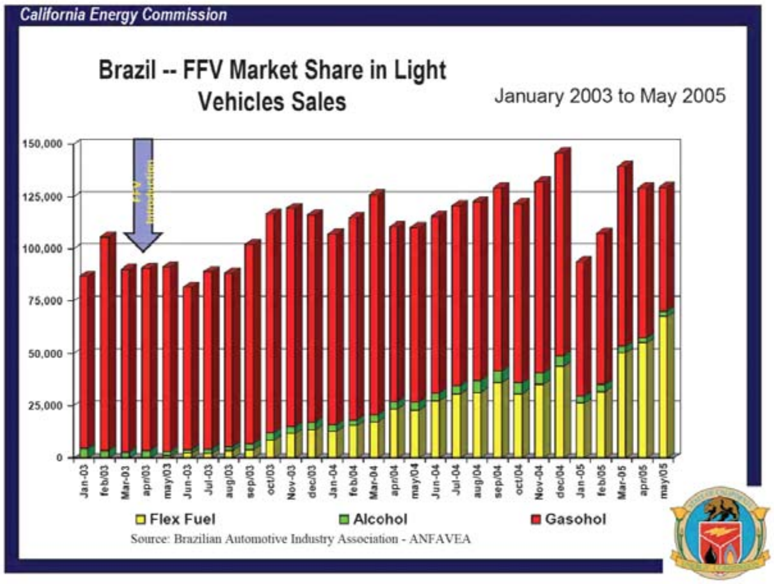

This slide does not represent the official views of NSF any more than the next one does, but it certainly shows that I am not the only person who believes in fuel flexibility.

The views of George Bush senior in 1988 were probably influenced a lot by analysis from Ford Motor Company, from the group run at the time by Roberta Nichols. See Roberta Nichols, The Methanol Story: A Sustainable Fuel for the Future, Journal of Scientific and Industrial Research, Vol. 26, Jan-Feb 2003, p.97-105. Back in the 1980's, Ford sold thousands of GEM-flexible Ford Tauruses in California. They projected it would cost $300 per car to provide that flexibility nationwide – IF it were done at the factory.

Retrofits for GEM flexibility would not make sense; it has to be done in new cars, and that's why it's urgent that we get started NOW.

Nichol's paper is posted, with permission from the journal, at www.werbos.com/energy.htm

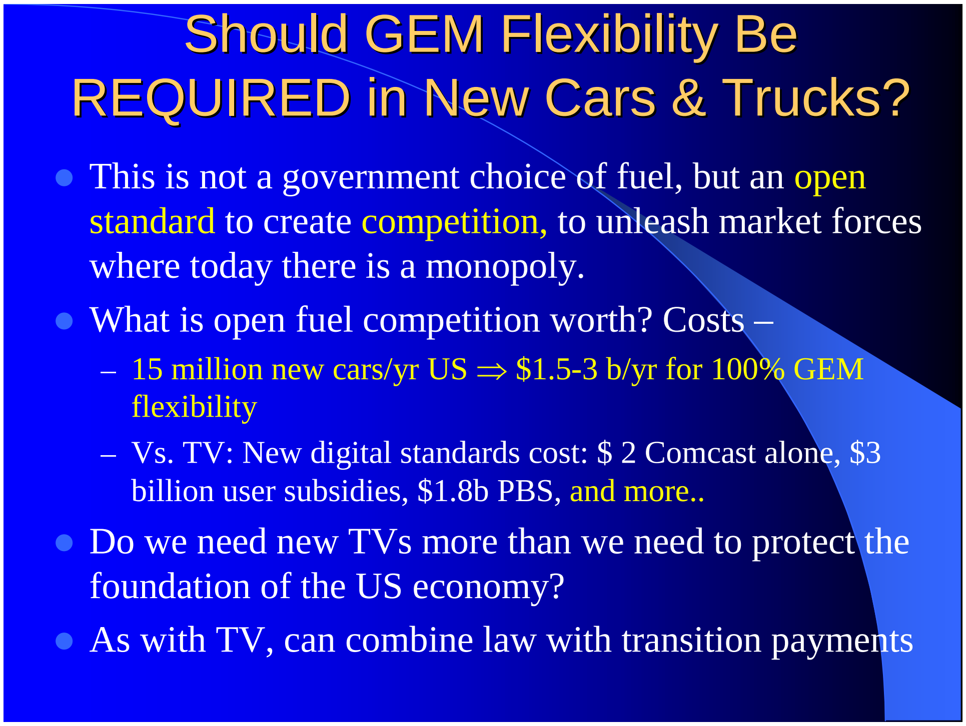
Fuel flexibility can be brought online very quickly, much faster than hybrids merely doubling every year!




All major manufacturers which sell in US have sold such cars in Brazil!!

The flexible cars deployed in Brazil so far have possessed gasoline/ethanol (GE) flexibility, not GEM (gasoline/ethanol/methanol). Even so, GEM flexibility is a relatively simple extension of the same basic technology – use of known corrosion-resistant materials and adaptive engine control. Prof. Paul of Princeton has even tabulated specific part numbers for suitable hoses and gaskets available from Dupont today.

For this figure, thanks to:
http://www.energy.ca.gov/2005publications/CEC-999-2005-024/CEC-999-2005-024.PDF

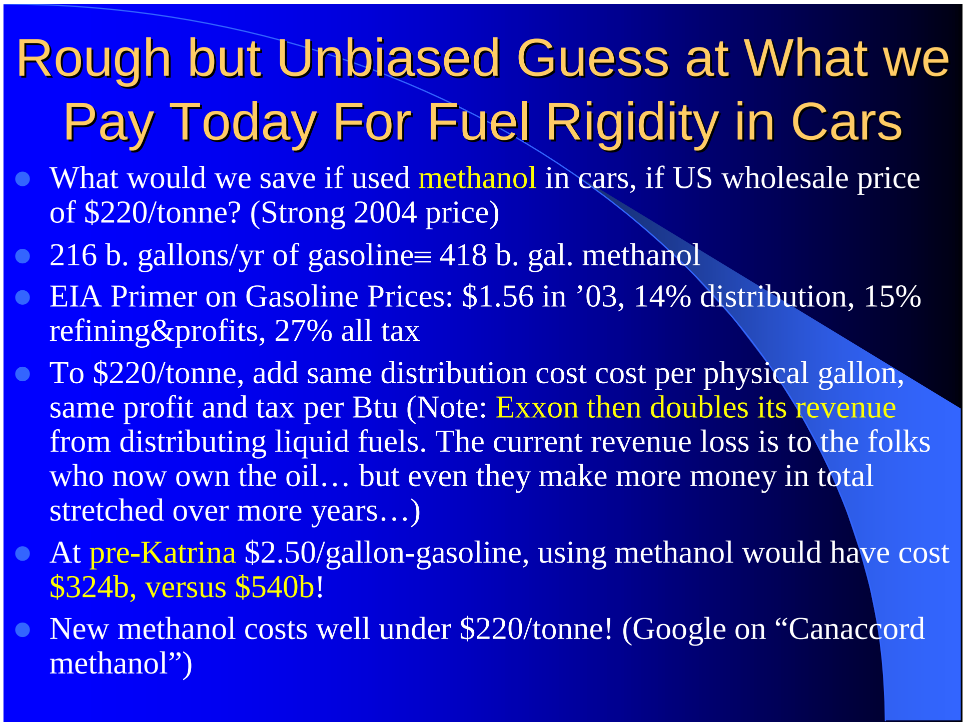



In my personal view, the rational policy is to MANDATE GEM fuel flexibility in all new cars and trucks and tanks at gas stations, starting in 2 to 4 years. As with the new standards we have for televisions, we should probably COMBINE this requirement with incentive or subsidy payments, to help with the cost of the transition and to provide some equity – but we really cannot afford to wait here. We will be living until 2025 with the cars which come on the road in 2010, and we need them to have the most flexibility we can arrange.

Some folks in the oil patch would have a strong knee jerk reaction to the "government mandate" I have proposed here. But this is NOT a mandate to use a specific fuel. This is a mandate for open standards for competition, to allow other fuels to compete with gasoline. The goal is to unleash the forces of the marketplace, and to break a pre-existing monopoly.

People in the electronics industry have learned very well how open standards and competition can be of great value to an industry, and to the nation as a whole. The US has recently enacted new standards for digital television which are MORE of a government mandate than what I am proposing – and which cost a lot more. Yet we recognize the need for technology change and progress in that sector. We certainly ought to be able to afford new open standards for fuel competition in cars and trucks as well – wher it costs more, and is far more essential to national security.

By the way – you may note my estimate of $100-$200 per car for GEM fuel flexibility, if inserted at the factory.  This is less than what Nichols estimated in the 1980's, mainly because of new technology and other changes. For example, because of rules related to evaporative emissions, new cars already use more corrosion-resistant fuel tanks. Also – cars have new computer chips which make it far easier to implement adaptive algorithms.




The sooner we have GEM fuel flexibility in cars, trucks and gas stations, the sooner we save money.

Sources for the calculation:

a. 216 billion gallons comes from EIA/DOE data of 27004 trillion Btu of petroleum in transportation, converted at their Appendix A 5.253 million Btu per barrel of conventional gasoline, 42 barrels per gallon. This was not all cars, but cost per Btu in other motor vehicles would be similar, and most of them can also be made fuel-flexible.
b. $220 per metric tonne (1000 kilograms) from Marathon oil web page, which noted that $220 in 2004 was a very strong price, presumably related to immediate demand-supply balances. From Canaccord, one can find new remote gas projects paying back well at assumed wholesale price of $164/tonne. This is a short-term guesstimate; flexibility would raise methanol prices in the short term, and elicit many sources of supply, some short-term, some long-term, some cheaper than today’s costs (see IEEE-USA slides!)
c. The assumption of the same tax per Btu may or may not represent today’s laws on methanol fuel. However, it would be grossly irrational to maintain higher taxes per Btu on methanol, if that does exist anywhere, since methanol is less expensive to US national security per Btu than gasoline!

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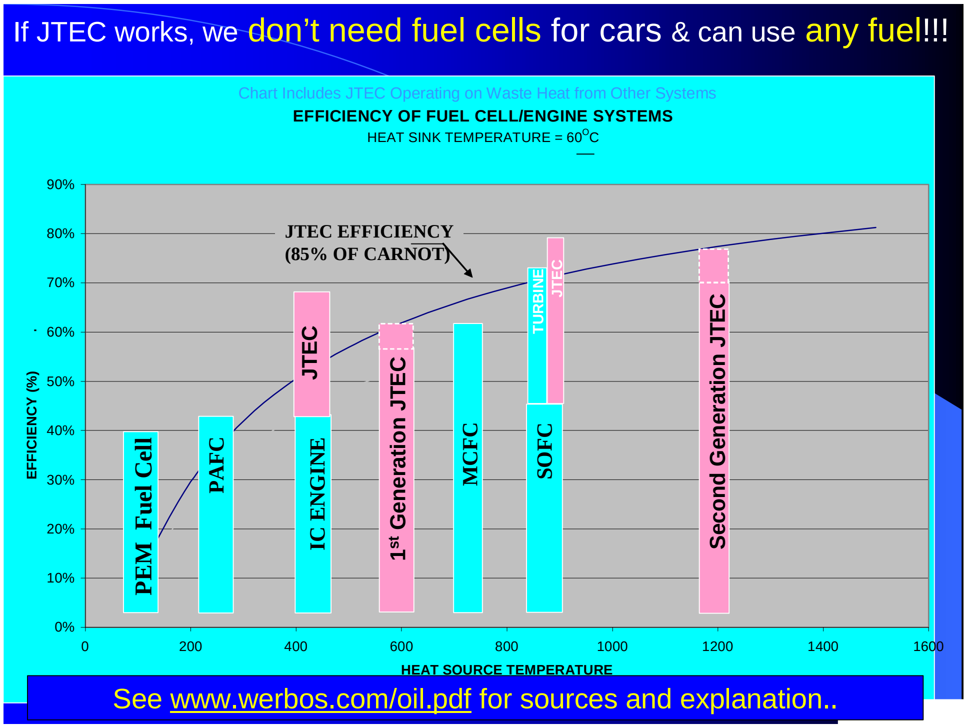
This calculation was done in 2005, but the numbers would look even better today.

There was a time when Exxon got a lot of its profit from the “rent” on cozy contracts with some nations but most such nations now get all the “rent.” Exxon’s gasoline profits now mainly come from distribution and refining; thus I would argue that what’s good for the USA would also be good for Exxon here – but we need to put the USA first. With GEM fuel flexibility, we would be saving money TODAY – mainly because less money would be flowing to the Middle East this year; however, even they would gain, in the long term, by holding more of their oil for the longer-term future. (Osama Bin Laden himself complains violently that they should not be pumping it so fast, and should not accept Western financial arguments based on unIslamic high interest rates.)




So far, I have only talked about plug-ins as a pathway to electric cars, and GEM flexibility as a pathway to alternative liquid fuels. But in the long-term, it is possible that a third kind of car, using STORED HEAT as the source of energy, might work out better than the other two. For example, plug-ins can help us adjust to shorter driving ranges, if we have to adapt as gasoline becomes more and more expensive and if we don't make as much progress as we hope for with battery R&D. But with new heat-based technology, it is possible that we wouldn't HAVE to adapt to shorter driving ranges, even if we made no new progress with electric batteries.

To make this option real, we first need to fully develop two new technologies for converting heat to electricity or to mechanical motion – third generation Stirling engines, or a new breakthrough technology called JTEC. These technologies should be elevated to one of our nation's top priorities. These technologies will have immediate benefits to low-cost solar energy, first. Then as costs fall, they might be used instead of gasoline or diesel engines in plug-in hybrids, in order to get great efficiency and fuel flexibility. Finally, if suitable heat storage systems can be developed (?), they could replace some of the big electric batteries, to provide greater renewable-based driving ranges.  JTEC still involves some risks, and we are right to have some skepticism. Nevertheless, when I saw this chart at an NSF meeting in Tuskegee last year, I knew it would be grossly irresponsible for me not to investigate the possibilities. After an initial investigation, we found out that this technology is serious enough to be worthy of an initial small grant to investigate further. This effort was successful, as I will discuss.

There is a lot of information on this chart – so much so that I am adding an extra page on the pdf version of these slides to explain more and give some sources.

This chart gives efficiencies of different technologies at their optimal operating point. IC engines in conventional cars are usually run too high or too low – but in hybrid cars, all of these powerplants can be run at close to their optimal power levels. If we build a hybrid car around any one of these technologies, we get more efficiency than a conventional car has. The IC engines in today's hybrids are a bit smaller than the big car engines registered here – thus only 30-34% efficient. The bottom line here is that replacing an IC engine with a second-generation JTEC could possibly ***double the efficiency improvement we already get*** with a conventional hybrid or a conventional plug-in hybrid, and do far better than PEM fuel cell cars.

# Sources and Explanations for the Previous Chart

For the **JTEC numbers –** of course, since it is a heat engine, efficiency is limited by Carnot's laws , as shown by the curves. Efficiency is greater if we can operate at higher temperatures. The more detailed JTEC designs and tests developed under NSF funding fit the second generation concept, based on materials tested at higher temperatures.

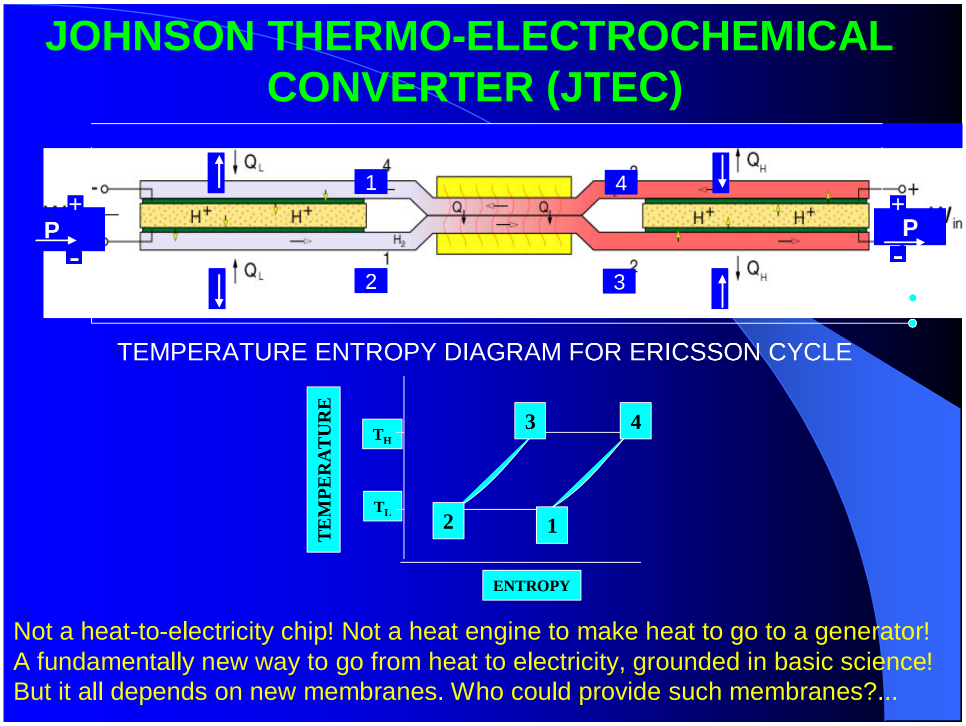
For the number on **ICs at optimal operating point –**
One source:
http://sitemaker.umich.edu/mhross/files/fueleff_physicsautossanders.pdf
"The best thermodynamic efficiency of conventional spark-ignition
gasoline engines is ht » 38%, relative to the lower heating value of
the fuel (or 35% relative to the higher heating value).12"
The original source from Johnson R&D: "I made this presentation to the people at DRS Corp. which is the company that developed the Army's hybrid electric H-HMMWV. They informed me that the H-HMMWV'S engine achieves 38% by operating under optimum conditions." The 37% reported by Wikipedia is close enough…:
http://en.wikipedia.org/wiki/Internal_combustion_engine#Engine_Efficiency.
A confidential DOD discussion list reports: "Another source that I found had the Prius operating at 34% total efficiency in practice at its ideal operating point. In practice it operates at about 30% efficiency (at the Engine Driveline interface)." (An Atkins cycle engine.)

For the numbers on **fuel cells…**

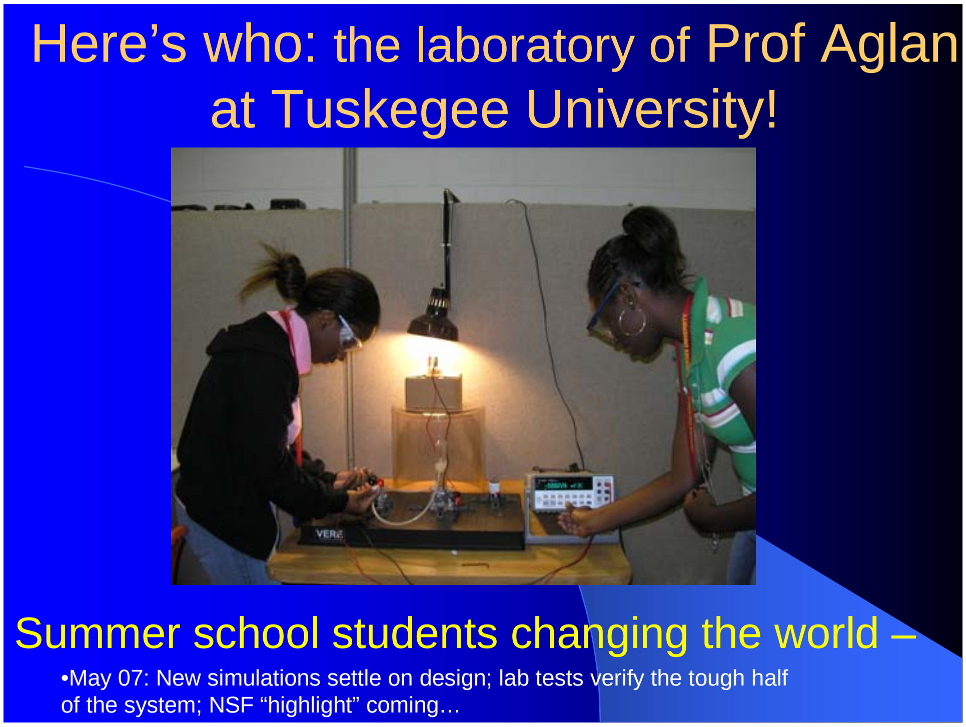
The numbers here were all taken from the Fuel Cell Handbook. But they correspond exactly with what I have seen from other sources. Of the fuel cells shown here, only PEM and SOFC have been investigated for use in cars. Some PEM advocates still talk about a "real" efficiency of 50-58%, versus a "total systems efficiency" of 35-38% (e.g. in the Chevy Synergy); however, the difference between the two is mainly a matter of losses due to peroxide formation and other leaks *within the fuel cell itself*. Thus the comparison here is an honest apples-to-apples comparison. There is another type of fuel cell, the carbon-tolerant alkaline fuel cell, which may be suitable for cars and has shown efficiencies in the 60% range; however, there has been little follow-on to the initial small NSF investment in that area, and the lack of fuel flexibility would make it hard to deploy in any case until and unless methanol fuel becomes widely available for use in more flexible vehicles. (See http://arxiv.org/abs/physics/0504130 for a technical report.)

For the IC+JTEC bar….

You will see a combined efficiency of IC+JTEC which is above the Carnot limit for operation at 400 degrees. But this does not represent an IC engine running at an upper temperature of 400 degrees. It represents an IC engine running at the usual higher temperature, providing waste heat at 400 degrees, which is then used by a low-temperature JTEC system. However, the complexity of this system is greater than that of a second generation JTEC, and it currently seems to offer little if any improvement in efficiency compared to second generation JTEC. It might be worth considering as a possible backup option someday, but for now is premature at best.




JTEC is an all solid state (no mechanical moving parts) heat engine that offers Carnot equivalent efficiency. It includes an MEA stack coupled to a high temperature heat source, QH, a second MEA coupled to a low temperature heat sink, QL, and a recuperative heat exchanger connecting the two MEAs. The Ericsson cycle temperature entropy diagram represents operation of the ideal JTEC heat engine. The Ericsson cycle is Carnot equivalent. The thermodynamic states 1 through 4 are identical at the respective points labeled in both diagrams. Beginning at low temperature and low pressure state 1, electrical energy Win is supplied to the low temperature MEA to pump hydrogen from state 1 to low temperature and high pressure state 2. The temperature of the hydrogen is maintained nearly constant by removing heat QL from the MEA during the compression process. From state 2, the hydrogen passes through the recuperative heat exchanger and is heated under approximately constant pressure to high temperature state 3. The heat needed to elevate the temperature of the hydrogen from state 2 to 3 is transferred from hydrogen flowing in the opposite direction in the heat exchanger. Electrical power is then generated as hydrogen expands across the high temperature MEA from high pressure, high temperature state 3 to high temperature and low pressure state 4. Heat QH is supplied to the MEA and its gas content to maintain a near constant temperature as the hydrogen expands from state 3 to state 4. From state 4 to state 1, hydrogen flows through the recuperative heat exchanger wherein its temperature is lowered by heat transfer to the working fluid passing from state 2 to 3. The hydrogen pumped by the low temperature MEA from state 1 to state 2 maintains low-pressure state 4.




I actually learned about this technology at an NSF outreach conference in Tuskegee, Alabama, in 2006. After we studied and evaluated it further, I realized that this represents a fundamental new approach to converting heat to electricity. When people make great claims of high efficiency using well-known old technologies, the claims usually turn out to be false. But when there is a whole new fundamental principle involved… that's different.

NSF funded a small new grant through me to Tuskegee University with Johnson R&D as a subcontractor, to evaluate this new technology further. Major changes had to be made, when the membranes and other pieces were tested and competing systems designs evaluated. In the end, however, the team has announced to us a concrete design for JTEC proper using well-tested materials. A micro fuel cell was produced and tested, which verifies the most critical part of the design. More R&D is needed… but it is now a very real option, ready for scale-up and for R&D on the larger systems that can use JTEC.

Here is one near-term possibility: since JTEC produces twice as much electricity per unit of heat as the Stirling engines used in the cheapest solar farms today… JTEC could potentially cut the cost of solar farms in half, making them cheaper than daytime electricity from natural gas all across the US. Concretely: many in the engineering world believe that Stirling Energy Systems can afford to charge only 8 cents per kwh for daytime electricity in the long-term, based on first generation Stirling technology. If JTEC allows an upgrade to produce twice as much electricity from the same heat, 4 cents per kwh seems attainable. At that cost, large solar farms could be set up in dry parts of Texas; even adding the 2 cents per kwh transmission costs, solar could beat natural gas for daytime electricity even in the East Coast (PJM) utility market. Even though this is not a VEHICLE application as such – it is the most direct way to get JTEC (or third generation Stirling) available for large-scale use in cars and trucks.

## Batteries Too: Two New Concepts to Use Those Membranes to Outperform Asia on Batteries for Plug-in Hybrids (Maybe Even Affordable True Electrics!)

| | Specific Energy (Wh/kg) | Energy Density (Wh/l) | Discharge Rate (C) | Specific Power (W/kg) | Cycle Life |
|---|---|---|---|---|---|
| Nickel Cadmium | 80 | 150 | 10 | 500 | 800 |
| Nickel Metal Hydride | 150 | 250 | 5 | 200 | 800 |
| Lithium ion | 211 | 577 | 5 | 300 | 500 |
| DMFC | 250 | 75 | 5 | 500 | 500 |
| Johnson Lithium Air | 2000 | 2000 | 5 | 400 | 500 |

This slide mentions some of the work on batteries at Johnson R&D and Tuskegee, which is one of several innovative possibilities for breakthroughs even beyond what we can buy today from China.

Even at less than half of its theoretical energy storage capabilities per unit mass (Wh/kg), lithium air batteries would still be about ten times better than conventional lithium ion batteries, and even better than certain types of fuel cells.

Once again – there are huge unmet opportunities in essential R&D for energy independence far beyond what is being funded by any part of the US government today. Funding is part of the challenge… but the bigger challenge lies in finding a way to fund what is really needed here – to do quality control without being dragged down by old technologies and vested interests (and the legitimate need to preserve existing parts of the US technology infrastructure which are now under very great pressure).