Khosla Responds: "Imagining the Future of Gasoline: Reality or Blue-sky Dreaming?"

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[editor's note, by Prof. Goose] *forget not the reddit and digg buttons...*
[editor's note by Super G] Previous posts on Khosla are here.

One thing I strongly believe in is the issue of fairness. I enjoy a good scientific debate, and I find that the best debates are those in which opposing sides are honestly presented. With this in mind, below I present Vinod Khosla's vision of our energy future. If you are like me, you will find aspects of agreement, and aspects of disagreement, and perhaps even strong disagreement. But it would benefit all parties to have a good debate on the technical merits of the issues.

Mr. Khosla is to be commended for presenting his ideas to what I expect will be a relatively hostile audience. So let's be respectful, and if you have criticisms, please make them constructive criticisms. Mr. Khosla has heard my specific objections on several occasions, so I won't reiterate them here. But I have assured him that readers of The Oil Drum are a sharp group of people with diverse backgrounds, and this will be a good place not only to present his vision to people concerned about energy policy, but also to get some good technical criticisms of his proposals. Mr. Khosla will be reading responses, so be sure to present your criticisms, praise, suggestions, or ideas with this in mind. Many of us wish to influence the direction of energy policy in this country. This discourse with Mr. Khosla is a golden opportunity.

Without further ado, I present the following guest post written by Vinod Khosla:

Imagining the Future of Gasoline: Reality or Blue-sky Dreaming?

I recently received the following email: "I find it distressing and bothersome to see ..... how often people assume that we need to find a single silver bullet for our looming oil and/or natural gas challenges, as opposed to relying on a collection of smaller solutions--what I've been calling the "silver BB's" approach.... I'm convinced that we do indeed face a set of harrowing challenges on the energy and environmental fronts, and that they will require all the ingenuity, flexibility, and collective effort (from public policy to large commercial companies to the emergent properties of mainstream consumers embracing conservation) we can muster." I agree.

If you are one of the people who think modern civilization is on the verge of collapse, stop reading. If you think all rich people are bad or everyone has evil or self-interest as their only goal, stop reading. People do care and while there are many people, and especially large corporations, who only care about their self-interest, there are people and corporations (large and small) who care about what happens on this planet. Also stop reading if you believe in massive conspiracies, want to revolutionize the world with rebellion, change the consumption pattern (4% of world population

consuming 25% of its resources- I hate it too but don't count on it changing) overnight, dramatically change behavior like getting Americans to drive less(lots of idealized solutions I can think of but it won't happen except through legislation like higher CAFE; or higher gasoline prices, and most such legislation is politically infeasible).

I support increased CAFE;, free markets (I am not a fan of ethanol subsidies or import tariffs in today's environment and have proposed politically feasible compromises to reduce both: "A Near Term Energy Solution" at www.khoslaventures.com/resources.html) as long as we ensure a level playing field which we don't have in the gasoline market today. I don't believe all oil executives are bad and I don't bash them just to get votes for our ballot initiative in California, but because the oil interests are misleading voters in California and in general often slowing the adoption of alternatives to gasoline, using the massive financial power they have to hire hordes of consultants to spread mis-information (like the royalty fee is a tax that will be passed on to consumers when the California Attorney General says it cannot be passed along and market forces will ensure that this pass-thru wont happen - www.yeson87.com). Vote YESON87 if you are a California voter.

I am working with certain oil companies that are looking beyond the California ballot initiative to find and evaluate new businesses. The single biggest thing we can do to help climate change is a carbon tax (worldwide) or a "cap & trade" system, but I don't think it is politically feasible in the US today. Its time will hopefully come soon, probably in the next decade. I would also like to see much broader energy efficiency legislation but I suspect that is harder and will happen in pockets and spread slowly (I am optimistic about the latest CAFE proposals). I would love for us to bias towards public transportation (even with subsidies) but I suspect that will not happen easily and is not an effective use of my time.

The personal automobile is here to stay. Finally I believe that the problem of stationary power (electricity) and mobile power (mostly transportation) are different and can be addressed separately. So let's not confuse the two problems. I even separate the heavy (diesel) transportation from cars and light trucks (gasoline). I believe we need liquid fuels for transportation and have to live with coal for electricity for a while, even though I would love to see a greater emphasis on nuclear, wind and solar. Without a material breakthrough in storage technologies, wind and solar combined will be no greater than 20% of our electric power needs because of base load issues.

First, what am I invested in? One corn ethanol venture, one corn plus cellulosic ethanol venture, three cellulosic (only) ethanol ventures (all very different approaches), three non-ethanol liquid fuel ventures (next generation fuels to replace ethanol we hope), two gasification ventures (one for coal to natural gas and one for biomass), one solar, one high efficiency lighting (LED - very high risk project), one new high efficiency engine venture, one sugarcane venture, one low impact very low cost housing venture ($5000 homes), a few microfinance institutions and a few others. Battery technologies are among my highest priorities. Many of these are very high risk science projects and will fail but many will succeed too. So I don't have a particular perspective or bias other than the fact that alternatives to dirty coal and oil have an important role to play in our planets evolution.

We have to find solutions and only the ones that are economically driven will achieve substantial scale. To balance the large ongoing investments in oil, the only solutions that can compete effectively are ones that leverage Wall Street. I like solutions that the average American can be coaxed into adopting, not the ones the 5% who care most will adopt. The 5% fringe play a valuable role in buying early, demonstrating feasibility, establishing markets, but in the end impact happens when the average American adopts something. New businesses happen when Wall

Street gets excited about a new market or technology.

What have I done in my personal life? A solution I believe many if not most Americans would adopt more easily than buying a Prius- every car I buy gets a sticker to be a 100% carbon neutral from www.terrapass.com and the rest of my life is carbon neutral by buying carbon credits on the Chicago climate exchange or from www.carbonfund.org. But I am not spending my time convincing most Americans to bicycle to work or drop their personal automobile. Why?

On the public debate, why have I chosen to speak mostly about ethanol? I do support solar, wind, biodiesel, and many other alternative technologies. First, I am only focusing (for now) on gasoline, not all petroleum. Yes, later diesel, plastics etc will also have to be addressed but I handle "material but manageable" problems one at a time. That is my nature. It does not say that others should not address other problems or that I don't care about other problems. I spend my time where I am most effective per hour spent. That means that some even more critical problems are left to others. For example, if I had an equally effective solution for stationary power generation (yes I am invested in that too - solid oxide fuel cells for greater efficiency) I would spend more time there. I do recognize it as an even bigger problem than gasoline replacement, especially as it pertains to green house gases. But since I see an easy path I can believe in, ethanol (really biohols which include all liquid fuels from the same feedstocks and same ICE engines - some of these are my other liquid fuel investments), I choose to spend my time there.

I do not focus on peak oil as much but that does not mean I don't recognize it as a potential problem. I do think we will probably (nothing is certain) run out of air to put the oil emissions into before we run out of oil. I am personally not excited about coal to liquids technology because of its greenhouse gas implications which I consider a bigger issue than the peak oil issue. But given I see no easy solutions to the stationary power from coal problem (especially in India and China, I am very interested in clean coal technologies for stationary power.

But the reason to support ethanol in public policy debates for me is the feeling that I can really make a visible difference and it will lead to more than a marginal change. But the real answer is my belief that it has the lowest risk strategy to impact peak oil, green house emissions, energy security and independence, while having huge collateral benefits like sustaining farm incomes, rural employment, and reducing worldwide poverty. Ethanol has the best TRAJECTORY! There are other options like coal to liquids and natural gas which are also reasonable options if one is not looking for a trajectory that leads to a 100% renewable source. Others, especially the oil companies are working on some of these.

It is all about the trajectory! The factors that matter are TRAJECTORY, TRAJECTORY, & TRAJECTORY.

There's a huge difference between people who focus on "what is", and people who focus on "what can be". Ten years ago nobody in the established telecommunication world believed in the internet because the "what was" was not as good as an alternative technology called ATM. Every telecom carrier said, "no way would we ever switch our core network". The state of the internet protocol was so much worse than the alternative ATM for telecom carrier purposes. But "what can be" ended up so much better and so much cheaper because of the trajectory it was on, such that any company not adapting it will over time go out of business.

The difference between what is and what can be has to be reached in an evolutionary not a revolutionary fashion. IP & the web browser had a useful purpose, got deployed, was used and hence attracted both implementation and R&D investments. Next generation stuff was built on top (like better routers, IP management and network software, JAVA, Flash, Dynamic HTML

pages, AJAX, and the semantic web) and is still being pursued because the technology had an incrementally improving path. Both the incremental steps and the long term vision have to be attractive for a technology to cause a revolution. If the two trajectories are in conflict, the incremental path generally wins. It is the road more frequently traveled.

Cell phones have followed the same path, starting from heavy scratchy voice quality devices to being dominant today. How many of you thought twenty years ago that they would mostly surpass land lines? Trajectory often determines where societal choices end up, especially when we cannot or do not legislate the outcome.

What can be with hydrogen is also great, but there is no way to incrementally get there from what is to what can be. The most likely path for hydrogen is co-producing it from ethanol, running it in today's internal combustion engines, getting hydrogen distribution, and then replacing internal combustion engines with higher efficiency fuel cells or improving the internal combustion engines.

A more likely path is ethanol in today's internal combustion engines, followed by better hybrid technology to make hybrids more broadly acceptable, to increasing the amount of battery storage on cars to make them more "plug-in" capable and over time to reduce the size of the ethanol driven internal combustion engine, thereby reducing the amount of liquid fuel we need for our automobiles.

The more we use batteries the cheaper and better they will get, the more investment and R&D interest they will attract, and the faster the cost performance curve will improve. Batteries will get cheaper and we will use more capacity in our cars, enabling longer range, making such cars cheaper and better and driving towards lower percentage use of liquid fuels. If you tell me we should replace today's cars with sixty mile range cars (since that is what most consumers use), I wish you good luck getting in getting it done. And the energy ratio of electricity is far worse than that of corn ethanol. If we get more wind and solar we should be replacing coal plants with that additional capacity, assuming it is cost competitive.

In parallel we will see better liquid fuels, fuels I call biohols. Butanol has already been proposed by BP and DuPont, and other liquid fuels have been discussed among researchers. They are superior to ethanol in many ways but will use the same or similar feedstocks and run interchangeably with gasoline or ethanol in today's engines. Some will require minor engine modifications and others will not. But if we tried to legislate butanol today it probably would not happen.

The bigger the ethanol market, and we must move it from a blend of only fifteen billion gallons a year US market to a primary fuel 200 billion gallons a year market, the more investment and R&D it will attract to reduce cost, improve engine performance to find additives and alternatives like butanol, to make it even better. With ethanol and biohols in general it is very possible to get there incrementally without disturbing a lot of current investment, vested interests (like automakers), and natural market forces.

The oil industry spends hundreds of billions in investments in oil every year and to find a replacement it must attract the same kind of capital. The only source of such capital is Wall Street. If we want to make change happen, make it worthwhile for the entrenched interests without making it easy enough for them to rest on their laurels. Make it attractive for Wall Street. In the end I do believe the oil companies will be big players in the biofuels game.

Why not biodiesel? First, its trajectory does not lead to cellulosic ethanol and other biohols. Most importantly, though I like biodiesel, there is a fundamental difference. Even though biodiesel has a better energy balance than corn ethanol, I don't believe it will scale beyond hundreds of gallons

per acre of land. Ethanol, butanol and any liquid fuel that has a shot at replacing our gasoline needs has to scale up to 2,000-3,000 gallons per acre.

Add some form of increased CAFE; (the current 4% a year increase proposed by Senators Biden & Obama seems good and even politically possible, even a 2% per year compromise would be great), better engines (we hope our startup in the area is successful and gets to fuel cell efficiency in an ICE engine but if not there are at least a dozen other ICE engine efficiency startups), 3,000 gallons per acre results in some part of our export crop lands and CRP lands being sufficient to replace all our gasoline needs (my current best guess for 2030 - see Appendix A in "Is Ethanol Controversial?" at www.khoslaventures.com/resources.html). This involves improved yields of energy crops, cellulosic ethanol optimization but does not assume alternative biohols (something that is very likely - butanol could reduce gallons of fuel needed by 25%), improved engines (easy to get even ethanol mileage per gallon close to that of gasoline, not 33% lower as is assumed by many who base it strictly on energy content), higher CAFÉ standards (likely by 2030 - even a 2% per year increase in CAFE cuts our gasoline needs in half) and other positive surprises. If all these happen our likely needs will be a third of what we assume today, and we will get there incrementally and in a politically acceptable fashion. But we don't need these "extra" improvements to replace most of our gasoline consumption with ethanol.

And then there are better ethanol and biohols production strategies. I have seen plans (not one I funded) to get 22,000 gallons per acre using current carbon dioxide sources (like power plant exhausts), proposals for ocean based dense algae farms (something that seems like a good idea) that convert algae to biodiesel and ethanol. We need to set a path that leads to revolutionary vision but has short term steps to renovate, innovate, and make money for our scientists, engineers, entrepreneurs and established companies that choose this new path. The steps will be incremental. The bigger the market, the more the attention, the greater the funding for both implementation and R&D, the greater the competition and hence a faster and faster pace of innovation and revolution. This is the trajectory I believe is possible here in the short term.

So am I over promising on cellulosic ethanol? I don't think so but if I am I don't see another viable alternative. What makes me believe in cellulosic ethanol? If the goal is ethanol production costs of $2 per gallon (roughly equal to gasoline at today's prices), we are there already. We have a number of different ways to do it except that no investor is willing to bet on these price points being viable.

So the real question is do we expect cellulosic ethanol production costs to drop sufficiently to be competitive with corn ethanol? The expected dozen or so (I have heard 60+) serious respondents to a recent Department of Energy RFP are willing to invest $60-70m of their own private money on the belief that their particular technology can meet the requirements. They could all be wrong but it is somewhat unlikely that so many different approaches and distinct technology sets will all prove wrong. I have significant funds invested in three such projects and unfortunately those of you who looked at the technology in the public domain will never get to see what private companies are doing. Am I certain this will work? No, but it is very likely that one of the dozen or more projects will achieve the cost target. The risk of a failure is much lower than the risk of a battery breakthrough to make plug-ins economically attractive (in my view).

Further if we did not have corn ethanol priming the pump, helping create a market for ethanol, getting the fuel infrastructure and FFV's lined up, I would not be investing in cellulosic ethanol as the cascade of distribution, market demand and infrastructure risks with the technology risk would make it too risky for me. In fact the corn ethanol investments we have made will make the cellulosic risk smaller as it is likely (but not guaranteed) that the initial cellulosic plants will be

add-ons to today's corn ethanol plants, making them economically viable sooner.

To make this future happen this is a pretty modest risk to take compared to the risks we are taking with oil today, shipping lanes, supply, and geopolitics. We have a climate crisis and energy crisis. We have a terrorism crisis and a foreign policy crisis and all of them are linked to oil. Ethanol is a risk worth taking. And it takes us down a path that can lead to revolution through a series of evolutionary steps, at little cost to government, consumers or US automakers. Little cost, lots of upside - what is there not to like. I don't buy the argument that this will lull us into not pursuing other solutions (like increased CAFE;, better batteries) in parallel.

To address the issues we disagree on according to Mr. Rapier, on corn ethanol most of the community does not get the questions right. EROIE is not relevant (By the way, the fossil energy ratio of electricity today is four times worse than corn ethanol according to the Argonne National Labs GREET model!). What is only the "somewhat wrong" question is the "fossil energy ratio" - fossil energy in to total energy out. Renewable energy like solar is free, if one can take care of land conservation (addressed later). Otherwise a 15% efficient solar cell would have an energy ratio of 0.15! And nobody thinks that is bad.

Here, more accurate than the fossil energy ratio is the fossil energy used per mile driven (to take the differential mileage actually or potentially achieved into account), COMPARED TO GASOLINE. Even better is to directly measure our goals -(i) how much petroleum do we displace and (2) greenhouse gas reductions. So what is the trick? Most of the fossil energy used in corn ethanol production is natural gas, not petroleum so for peak oil fans, the typical US corn ethanol plant reduces petroleum use dramatically, according to the NRDC and Dr Wang at Argonne National Labs (90% or more reduction)! That addresses peak oil and energy security issues even if it does not address the green house gas issues. (2) We get moderate,(roughly 20% depending on production methodology for corn ethanol plants) green house gas reductions but as we try and reduce cost of production and make the process more energy efficient we can get 5X the fossil energy balance (www.e3biofuels.com) as verified by the National Commission on Energy Policy (personal communications)even with corn ethanol.

As explained above, in my view the only solution we can implement rapidly will have to fit in today's engines and we should chart a path for improving engines and improving fuels in smaller manageable steps without a dramatic big-step change. If we require a big step we know it won't happen. Pragmatics is what rules doability in my view. Others are welcome to disagree and spend their time trying to make it happen. I won't spend my time on it but I will sincerely hope they are successful. As described above it will probably (but not certainly) lead to the same place.

Corn ethanol will lead to other fuels but will it be completely displaced? I don't know the answer but probably not. I do think it will become an immaterial part of our liquid fuel infrastructure because of its inherent limited capacity (15 billion gallons per year). Biofuels in the US will be a 100-200 billion gallons per year market and if we have excess capacity (something I think is likely) excess capacity will be applied to bioplastics, stationary power and other applications. Compared to what we are likely to pick as politically acceptable options, the consequences of failure are small. I don't know a pragmatic solution that will get past the various interest groups that I can advocate.

All electric cars in one step is not something I can believe in. Despite incentives it has already failed and I don't see a smooth path to massive adoption, except as described above. If others are more successful with electric then nothing I am proposing will be in conflict. We will get to oil independence sooner as electrics catch on rapidly. I do hope they are successful. Personally I believe running electric cars off wind power or off hydrogen generated from wind power is an

unrealistic pie-in-the-sky idea from academics who have no understanding of the politics of change and have not participated in real change. Theory and practice are often different. But I wish them well.

Having dismissed energy ratios as mostly irrelevant I want to stress that even corn ethanol from a typical natural gas powered corn ethanol plant today has almost twice the energy balance of petroleum. Apples to apples a unit of fossil energy will deliver between 1.3 to 1.8 units of liquid fuel energy out in corn ethanol and 0.8 units of energy out for gasoline per Dr. Wang at the Argonne National Labs and the GREET simulation model. There is additional renewable energy going into corn ethanol production, mostly solar energy, but that is in my view free. Otherwise solar cells would make no sense and would have a terrible energy ratio. This fact is the subject of much confusion. And this energy, being of higher octane can be used more efficiently than gasoline -some where between 10-30% more efficiently depending upon the engine. With 33% less energy mileage with ethanol is between 5-25% lower in most cases (the 5% case is hypothetical but feasible as real engines in the SAAB 9-5 Biopower car gets 18% less mileage but about 20% more horsepower. If it was sized to give the rated 150hp it gets on gasoline, mileage would improve substantially).

Even better, the ethanol production uses about 90% less petroleum so for peak oil enthusiasts it is by far the best and easiest solution. It will result in a 10-30% lower green house gases per mile driven for environmentalists. The plants one of my investments (Cilion) is building do not dry the distillers grain, cutting the energy use substantially and hence are much greener. Later they will replace the rest of the natural gas by utilizing the manure from local cattle feedlots (they are mostly building plants near cattle feedlots).
The following graph illustrates that even for standard corn ethanol plants ethanol comes out way ahead when evaluating (1) the amount of fossil energy needed or (2) the amount of petroleum energy needed.

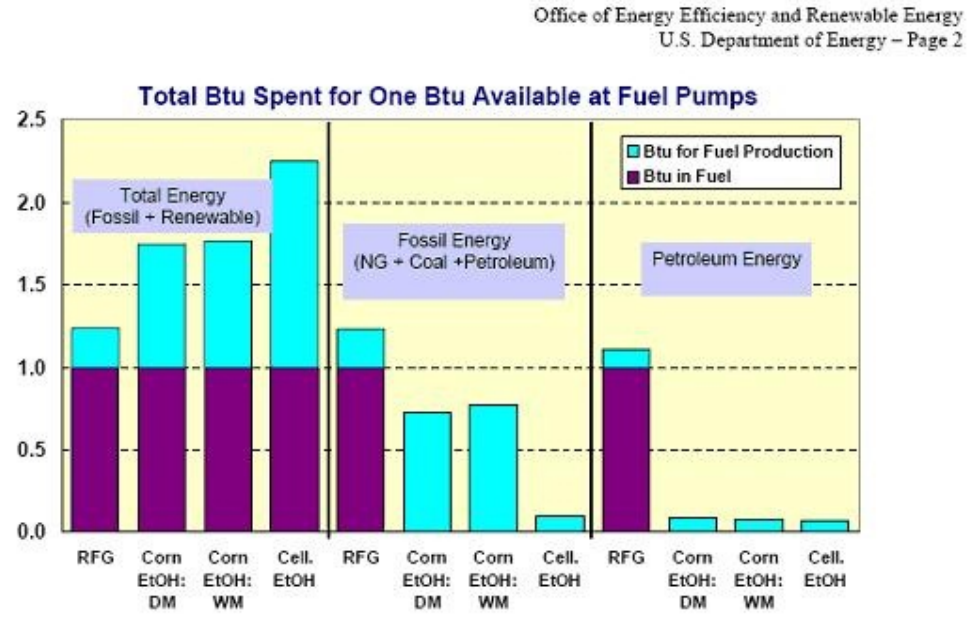

Fig 1: BTUs Spent per BTUs Available Source: DOE

The following NRDC chart shows green house gas emission per mile driven for various ways to

produce corn ethanol. E3 Biofuels corn ethanol and cellulosic ethanol are dramatically better than corn ethanol but traditional corn ethanol is good enough on all counts and we should not let perfect be the enemy of the good.

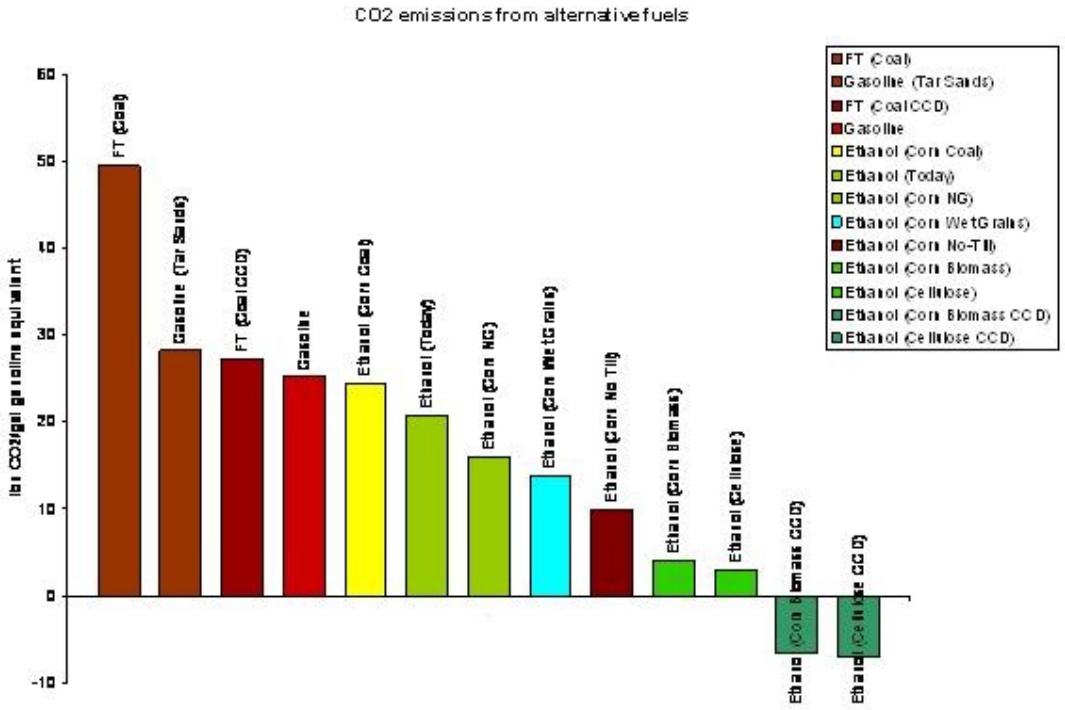

Fig 2: Carbon Dioxide Emissions of various fuels Source: NRDC

Ethanol is clearly going down the right trajectory, even without other biohols like butanol which will improve the potential of this trajectory further.

The there is the food versus fuel controversy. Why have the developing countries been fighting so hard to eliminate the food subsidies? Because with cheap western food exports their farmers cannot generate enough income to sell their own crops or generate enough income to feed their families. There is no scarcity of food but rather a scarcity of income to buy it for the poorest of the poor. The current Doha round of talks on international trade broke down mostly over this issue. Developing liquid fuels based on biomass to replace gasoline is among the best things we could do to alleviate poverty and increase the value of lands in Africa, Latin America and other parts of the poverty belt. Temporarily food prices in America may go up but long term this will be a boon to farmers and consumers in America and around the world. Incidentally, we devote 250 million acres to animal feed in this country and it takes 15 ponds of corn to produce a pound of beef/pork/poultry today! Beef use has been declining in favor of poultry and if that trend continues, we will use only 10 pounds of feedstock to generate a pound of meat, freeing up 33% of the land currently used for meat production (and lots of water).

If you see anybody extrapolating corn ethanol use to meet all of our gasoline replacement needs, you are seeing a person with an agenda. Nobody in their right mind is proposing we meet more than a small fraction of our gasoline needs from corn. Are there issues with ethanol? Sure. Today it is less than perfect. Corn uses more water and fertilizer than I like (E3 Biofuels corn uses far less). With all factors like fermentation emissions, crop growing and transportation etc it reduces green house gases only about 20% (actually between 10-30% generally but getting better every day). I would like to see much higher numbers on green house gas reductions and less intensive crop cultivations.

Cellulosic will make all these issues much less critical - *Miscanthus* will use a lot less water and almost no fertilizer (after the growing season it sends its nutrients back to the root system (stored in rhizomes for the winter) which is not harvested, almost no tillage, richer soil because it actually fixes carbon into the soil (hence the negative carbon per mile driven in the NRDC charts), and much greater biodiversity. We will still have to do grass cocktails to avoid monoculture, probably more complex crop rotation schemes and better management of the land. Unexpected problems with agriculture will crop up and will need to be managed.

Likely we will have mixed species of C4 photosynthetic grasslands. Highly diverse native hay meadows, mowed annually, were once an important part of the Oklahoma landscape and should serve as models. They can provide carbohydrates to convert into liquid fuels for our cars and remnant proteins to turn into animal feed protein. It is not only unlikely that we will not get our gasoline replacement from corn; it is also unlikely that economics will support our getting the biomass from byproducts of today's annual crops like corn stover. Economics will dictate biomass density of atleast 6-8 tons per acre initially and 15+ tons per acre later to keep the collection radius small (below 30 miles probably) and delivered cost of biomass below $40 per dry ton (or about $0.40 per gallon of fuel). This will dictate energy crops like *Miscanthus*. We will probably design higher energy density fuels with even higher octane ratings and higher burn efficiency, higher compression ratios before knock occurs and more.

Finally on the issue of subsidies, we force the cheapest oil in the world from Saudi Arabia to compete with expensive US ethanol, while keeping out cheap ethanol from Brazil. In addition there are plenty of direct and indirect subsidies for oil. Keep in mind that oil is an even more potent political force than the ethanol interests and has many different subsidies, direct and indirect, that it receives. A recent General Accounting Office of the Federal government listed a few of direct and directly measurable subsidies. Something esoterically called the "Excess of Percentage over cost depletion" has been a $82 billion dollar subsidy to oil. Expensing of exploration and development cost was listed as another $42 billion subsidy. Add on alternative fuel production credit (read oil shales, tar sands etc), oil and gas exception from passive loss limitation, credit for enhanced oil recovery costs, expensing of tertiary injectants, and other esoteric tools the oil lobby has inserted into various pieces of legislation, (including shameless attempts to get royalty relief from Katrina related legislation to the tune of $7b). And none of this includes any of the indirect subsidies. They have been variously estimated at from a few tens of cents to many dollars per gallon once one includes indirect costs like military costs. We spend over $50 b per year defending the sea lanes through which oil passes!

But does ethanol need a subsidy to survive? NO. It may get subsidies but it doesn't need them to be competitive with gasoline at any projected price of oil within the next twenty five years (Energy Information Administration projections, 2006). But the ethanol interest group is a potent political force and if it is getting subsidies, it won't give it up easily. But getting it does not mean they need it. We have a subsidy for ethanol but we also have a tariff of $0.54 per gallon, making expensive ethanol from the US compete with the least expensive oil in the world (Saudi oil), while keeping out Brazilian ethanol.

Today, even if ethanol prices were cut in half or more to $1.40 a gallon wholesale, corn ethanol producers would make adequate margins of profit. If we did not have a tariff or a subsidy ethanol would compete extremely well with oil. And while we are at it, I should point out that cost and price are different things. E85 market pricing would be much lower in a stable market because production costs are so much lower than gasoline. If production costs are half of gasoline why shouldn't it sell for half of gasoline? Answer: because of distortion and mismanagement. Frankly it is in the interest of the oil companies to keep ethanol prices high so as a primary fuel it doesn't

start to replace gasoline. In the end for any commodity, price will be related to production costs but the oil companies are in no hurry to see rapid change happen here. If we ever get a real cap and trade system like we should have it will make ethanol more competitive. In some sense I view the current subsidy on ethanol as just offsetting the current subsidies to oil and in the future to substitute for what will be a cap and trade credit.

How much biomass can we produce?

We can only go by current data points and the realization that corn yields have increased by 7X and are still increasing (expected to go from 140 bushels per acre average currently to about 200 bushels per acre by 2015). We assume only a modest 60% increase above experimental *Miscanthus* yields in our model after twenty five years (2030) of development and optimization using plant breeding and genetic engineering. In the only side-by-side comparison of switchgrass and *Miscanthus* undertaken to date in the U.S., *Miscanthus* averaged 16.5 dry tons/acre/year whereas switchgrass averaged 4.6 dry tons/acre/year for three Illinois sites with data taken over two years (Heaton and Long, in preparation). The fact that a well-controlled study showed a 3-fold productivity increase relative to the cellulosic energy crop most widely-studied in the United States is indicative of the nascent status of the field. At the best of three sites in the best of two years, a yield of 25 dry tons per acre per year was realized. We assume this best yield will become the average yield after twenty five years, across 40-60 million acres of good cropland that is currently used for export oriented crops. The maximum potential yield of switchgrass - based on simulations founded on plausible physics, biochemistry, and physiology of the crop in its normal growing environment - is estimated by McLaughlin et al. at 21 dry tons/acre/year.

New tools for plant breeding are available that are expected to foster fast gains. These include marker-assisted breeding, which do not result in GMO plants, as well as development of transgenic plants (McGlaughlin and Kszos, 2005). Sugar cane experts (Frikkie Botha, South Africa Sugar Research Institute; Fernando Reinach, Allelyx and Votorantim New Business) project that breeding and cultivation of cane with the goal of maximizing total biomass yield can likely result in about 25 dry tons of harvestable biomass per acre per year in the relatively near term. Megaflora corp. has measured productivities of 28 dry tons per acre per year from crossing North American Hardwoods with the polonia tree (Ray Allen, personal communication). Ceres, a leading plant biotechnology company, has concluded that available information "strongly suggest[s] that over the next decade or so the deployment of modern breeding technologies will result in average energy yields of at least 15 tons per acre, and that these averages can be sustained across a broad range of geographic and environmental conditions, including the approximately 75 million acres of crop and pasture land in the United States that could easily be converted to their cultivation without impacting domestic food production." (Richard Hamilton, Personal Communication).

Many researchers, especially in the environmental community assume that energy crops will not use genetic engineering while we continue to use these techniques for row crops. They further assume we will use marginal lands or get our biomass as a byproduct of crops on currently managed lands. The DOE estimates that this scenario of collection of existing biomass with only small change in agricultural practices could generate 1.3 billion tons of biomass in the US. We personally believe that it is likely we will use dedicated energy crops (cocktails of C4 photosynthetic grasses like *Miscanthus*) on lands that are currently used to produce export crops and 40-60 million acres of this land will be sufficient to meet most of our gasoline needs. Quoting form the 2005 DOE study's conclusion "In the context of the time required to scale up to a large-scale biorefinery industry, an annual biomass supply of more than 1.3 billion dry tons can be accomplished with relatively modest changes in land use and agricultural and forestry practices"

(Technical Feasibility of a Billion-Ton Annual Supply, US Department of Energy Report, April 2005). At an average of 100 gallons per ton, that should be a130 billion gallons of ethanol. We use 140 billion gallons of gasoline today.

And how much land could we use?

We have over 120 million acres of CRP and export crop lands. Our default assumption is that we will use some fraction of these lands to eliminate our oil imports for gasoline and then go on to replace even domestic oil used for gasoline. It is also worth contemplating that harvested land has stayed constant as the US population has tripled and the per capita calorie consumption has gone up. Further, in the US approximately 250 million acres of cropland are devoted to animal feed production (including forage crops) and pasture for meat production, essentially all of which could be used to produce energy crops. In addition, about 350 million acres are devoted to range land, of which some but not all could be used to produce energy crops.

In 2005, 75.1 million acres of corn grain were harvested in the U.S., about 80% of which was feed to livestock (~60 MM acres;); 71.4 million acres of soybeans were harvested, with 70% going to feed animals (~50 million acres); and 61.6 million acres of hay were harvested. In 2002, 62 million acres of cropland were used as pastureland. An estimated 20% of the 50 million harvested acres of wheat are used to feed livestock (~10 million acres). Additional crops that are primarily fed to animals include sorghum (6 million), oats (2 million), and barley (3 million). The total allocation for animal feed production, therefore, is an estimated 255 million acres, not including other crops commonly feed to livestock (e.g. millet, rye, peas, beans, lentils). Crop acreages from NASS, 2006. Pasture acreage from USDA, 2006. Corn grain and soybeans allocated to animal feed from Etherton et al., 2003. Wheat allocated to animal feed based on FAO, 2006.

Table 3. Feed conversion efficiencies for major animal food types.

	Feed Conversion	
Food Type	(kg feed/kg edible weight)	(kcal feed/kcal edible weight)
Beef	25.0	31.4
Pork	9.4	9.1
Chicken	4.5	7.7
Eggs	4.2	29.5
Fish	2.3	6.6
Milk	0.7	4.3

Mass conversions from Smil, 2000, assuming feed is corn; corresponding caloric values from USDA National Nutrient Database for Standard Reference

Changes in the relative proportions of various kinds of meat also have large potential impacts on land availability. In 2000, relative consumption of beef, pork, and poultry was as follows: 41% beef, 27% pork, and 32% poultry. Using these values and the data in Table 2, a weighted average of 14.3 kg feed per kg edible animal product can be calculated. Per capita meat consumption changed significantly throughout the 20th century however, and there would seem little reason to assume that it will remain constant in the future. Between the mid seventies and 2000, for example, beef consumption fell by 19%, pork consumption remained essentially constant, and poultry consumption increased by 92%.

For a hypothetical future scenario in which beef and pork accounted for 25% of meat consumption and poultry accounted for 50% - which would not seem unreasonable given recent trends - a weighted average of 10.85 kg feed per kg is calculated; a 24% change relative to the situation

2000. Devoting 24% less cropland to animal feed production would make available very roughly 50 million acres. We will also see the emergence of new practices. For example, Sweet sorghum, (currently being studied in India for fuel production) can make an excellent and cheaper substitute for corn in ethanol plants and can be grown on marginal lands with less little water and fertilizer.

Failure to look at these possibilities is a failure of imagination. We need to thread the needle between the "what is... and let's extrapolate today's corn ethanol production" tunnel vision crowd (generally done with an agenda - The American Petroleum Institute is concerned enough about world food supply and our welfare to have issued press releases on it!) and the "pie-in-the-sky academics who will dream up "what can be" without consideration for the path dependence of the choices we make and the pragmatics of how business works and what is needed to make a revolutionary future happen through a series of evolutionary steps. We should take our lesson from nature - from single celled amoeba to complex humans was an evolutionary process. It is the only way we can get billions of dollars deployed to make this alternative future happen.