Pragmentalists vs. Environmentalists (Part I): Prius: Green or Greenwash?

By Vinod Khosla

What is the actual impact of hybrids? In this paper, we are will analyze hybrids, ranging from the conventional Toyota Prius to fashionable plug-in hybrids. Our focus here is on highlighting the actual carbon emission reduction of hybrids (particularly vis-à-vis biofuels), and discussing the best possible solutions to reduce these emissions at a reasonable cost both in the near and long-term. We object to greenwashing (powered by large marketing machines) that obfuscate the facts that suggest hybrids can solve our problems. Corn ethanol, which has been heavily maligned in the mainstream media, reduces carbon emissions (on a per mile driven basis) by almost the same amount as today's typical hybrid. Despite the similar environmental profiles – one is a media darling, and the other is maligned despite its much more competitive economics (not that we are advocating corn ethanol). We believe that corn ethanol is paving the way for cellulosic ethanol, which will prove to be a cleaner and cheaper source of our transportation fuel needs for the foreseeable future – the table below provides a quick summary of our in-class comparisons (more detail later in the paper). In the long run, we don't need to worry about corn ethanol – cellulosic ethanol will be cheaper within a few years and will replace it (and other food based fuels like classic biodiesel).

2017

Car	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)
Toyota Prius - (1.6kwh, $21,200)	238	$490
Toyota Corolla -(Hypothetical FFV ,Cellul E85, $14,500)	88	$355
Honda Civic Hybrid - (On Gasoline, $22,600)	260	$524
Honda Civic - (FFV – On Cellulosic E85, , $15,110)	94	$372
GM Volt (16kwh, $30,000) - Electricity	144	$623
GM Volt - (16kwh, $30,000) - Cellulosic E85	55	$641
Public Transportation – US "Heavy Rail" (Subway) System	157	N/A

My main complaint has been the lack of critical analysis in this space because corn ethanol (which we don't believe is a long term solution) has been positioned by the oil companies marketing machine and farm policy critics, and impractical environmentalists (the NRDC and Sierra Club support corn ethanol's transition role as we do, subject to certain constraints) and the Prius and hybrids have been positioned by Toyota's marketing machine. The key questions from a public policy perspective are

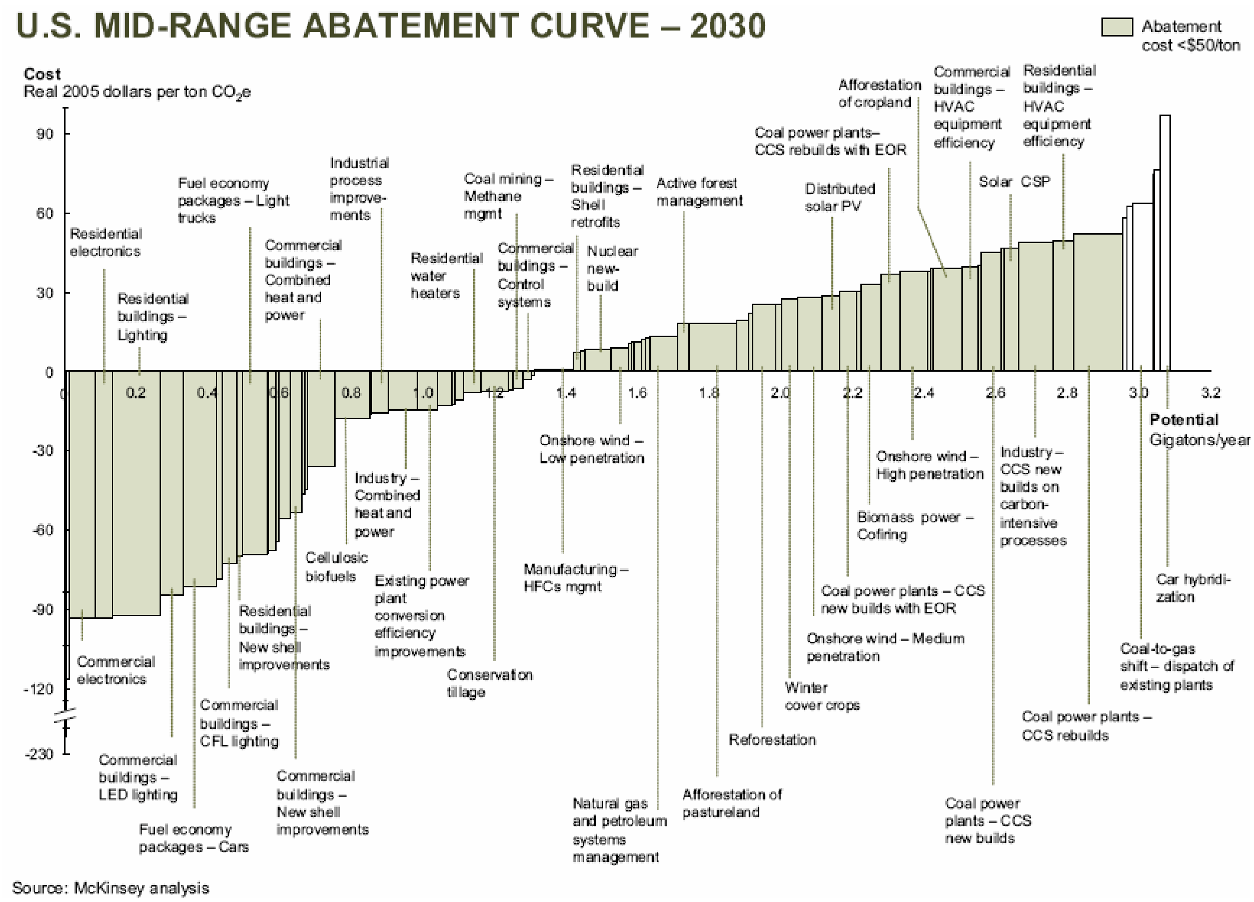
(1) What can technologies can realistically penetrate at least 500M to 800M of the billion cars we will ship worldwide in the next 15 years? Another way to reframe the question from a policy perspective is "what is the cheapest way in dollars per ton to reduce carbon emissions from automobiles?"

(2) What is the cost of carbon reduction per ton of the various technologies?

(3) Practically and politically, which strategies result in the smallest infrastructure investment and highest leverage for the existing automotive supply chain (in order to make the probability of success higher)?

When answering these questions, we have to accept the basic market constraint - expected consumer behavior worldwide, especially in India and China. Our analysis shows that hybrids, plug-ins and electric cars are probably not material climate change solutions with technology developments that are visible today. Nonetheless, we are aggressively investing in, the area and will continue to do so - we are confident that this is an enormous market.. Morgan Stanley[i] estimates total US hybrid demand at 1.2M in 2015 (ranging from 0.8M in the pessimistic case to 2.1M in the optimistic one), with plug-in hybrids (like the Volt) accounting for 250K in sales (325K worldwide). By 2020, their base US projection has sales of 1.9M hybrids, of which a majority (1M) are plug-in hybrids. Other experts are similarly optimistic. Nonetheless, hybridization at this scale is still not large enough to be a climate change solution, but we're hopeful that technological breakthroughs can reduce automobile emissions to the point where the impact is material.

The public is gullible. A JD Power and Associates representative (quoted in a recent Businessweek article) note that "consumers on average expect to get an 18.5-mpg improvement in fuel economy and to pay about $2,500 extra for a hybrid. In reality, they'll pay a premium closer to $5,000 and get improvement of about 9 mpg"[ii] We are open and hopeful, especially longer term, on serial plug-in hybrids, especially in small battery configurations geared towards engine efficiency (a point we address in Part III). Price still remains a major issue. Even for serial hybrids cars, the ability to keep cost, or atleast monthly payments, close to that of a regular ICE (internal combustion engine) car is unclear. The critical question remains: what is the likely trajectory of plug-in serial hybrid costs (say with a typical 40 mile "battery range") or a small battery pack (1.5KWH) "non plug-in" serial hybrid (a configuration we are most optimistic about) ? We are clear that a Prius is the corn ethanol of hybrid cars and we should recognize that. It has increased investment in battery development but beyond that it is no different than Gucci bags, a branding luxury for a few to indulge in who want the "cool eco" branding (70%+ of Prius buyers make more than $100k per year). The December 2007 graph below (from McKinsey)[iii] highlights the relative costs (at $ per ton of carbon dioxide emissions) of potential carbon abatement options– and car hybridization is projected as the most expensive method available. The Royal Society's recent report on sustainable biofuels noted that "
the development and widespread use of full hybrid vehicles by 2030 will only reduce world demand for transport fuel by 10%" and suggests the petrol hybridization offers limited CO2 emissions reduction (about 20%) for relatively high costs (over 100 dollars per ton of CO2 avoided).[iv] Why do environmentalists love hybridization and electric vehicles? Because the vast majority are not pragmentalists – cost does not matter to them. **Public policy does not have this luxury – cost of carbon reduction needs to be a primary consideration.**



In this paper, we will try to lay out our views on hybrids as a whole: what I believe hybrids are good for and what they are not. The companion paper on Biofuels Pathways and Where Will Biomass Come From delves into the details of the biofuels alternative. The primary question is one of cost – how many people will pay $5,000 more for a hybrid (the hybrid premium typically of many of today's parallel hybrids) that reduces carbon emissions by 25% (minus lifecycle emissions of battery manufacture which are significant but difficult to estimate), versus a flex-fuel car that costs about the same as a regular ICE (internal combustion engine typical of most road transportation) engine car and can reduce emissions by 75% or more when run on cellulosic biofuels? The Prius is selling well as a car model (so are Gucci bags) but in irrelevant numbers as a percentage of worldwide new car sales. It and its cohort hybrids are unlikely to make 50% penetration of the new car sales worldwide (or US) anytime soon. Flex-fuel cars went from under 5% of new car sales in Brazil to over 75% in less than three years because they don't cost any more than a regular car. They are projected to be 50% of GM, Ford, and Chrysler's new car sales by 2012 in the US.

Serial or parallel hybrids, plug-in hybrids or electric vehicles (EV's) are unlikely to achieve these kind of penetration numbers anytime in the next twenty years. A plug-in, serial hybrid (with sufficient driving range to get consumer acceptance, based on automotive folks we have talked to) powered mostly by electricity would cost at least $5,000 more (probably $10,000 more) for the average buyer (the GM Volt is rumored to have a price point of "less than $30,000" – we suspect EV's with "sufficient" range of around 150 miles would be atleast $15,000 more) and would reduce carbon emissions by a questionable percentage today – the exact percentage is dependant upon the location and source of your electricity (how much fossil fuel is used in your power grid). Total carbon dioxide emissions from power generation might one day reach 0% in the grid (when we have all renewable power in a region and all cars are fully plug-in with large batteries) - but when might that happen? Even if we reached a point where 50% of the cars of the US fleet were Prius like hybrids, emissions reductions would be an inadequate 10-15%! Serial hybrid carbon reductions are estimated in Part II.

Could we get people in India and China (the fastest growing car markets) to ante up this much additional money, when the biggest thrust in volume cars in India is to reduce the cost of the whole car to $2500 (Tata Nano)? Our goal has to be solving the global problem in carbon emissions, and we need to pick technologies that will be adopted by market forces worldwide. There are about a billion cars on the world's roads and likely we will produce another billion or so in the next 15-20 years. We will need cost points for low carbon emission cars such that 50-80% of the car buyers worldwide adopt these new "low carbon" technology automobiles (in each market - market conditions and price points vary widely form the US to India) to make a material difference. We believe that battery costs will decline and performance increases will continue, but my review of the technology suggests that the upside with known chemistries is limited to maybe 2-4x change in cost per kwh of capacity – a significant improvement to be sure, but not nearly enough to change the hybrid or plug-in hybrid cost dynamic.

That being said, we at Khosla Ventures are investing in batteries and other technologies to try and enable breakthroughs that can beat this 2-4X barrier, hopefully to 5-10X. Ecomotors' (one of our investments) uniquely designed engine can generate significantly more "bang for the buck" than conventional engines, and will be used to power serial plug-in hybrids. Seeo is working on polymers that allow them to develop batteries with high energy density and high cyclability. We keep looking for more innovative technologies that might invalidate the assumptions in this paper. Other technologists are doing the same, but the outcomes look very uncertain at this point and, more importantly in our opinion, far less predictable than $1.00 per gallon production cost, 75-90%

carbon reduction capable cellulosic biofuels. Others may differ with our assessment but we base it on the status of technologies we see under confidentiality obligations. Furthermore, we should note that it takes approximately fifteen years for the automotive fleet to turn over in the US - any impact will be gradual, not instantaneous. What is the "adoption" cost point and timeline for these technologies, when the fifteen year fleet turnover period can start? We suspect it is when the additional up-front cost of hybrids is paid-back (through lower fuel costs) within 3-4 years. Today, Edmunds.com estimated that a hybrid Camry (with an estimated $2,000 to $3,800 price premium) can take anywhere from three-and-a-half to eight years to payback the initial upfront costs through reduced gas usage; a parallel hybrid with a typical $5,000 premium would take even longer.[v] The financing of batteries or extra costs are just schemes to make cost perceptions comparable, and another way to look at the same metric is total monthly payments at commercial interest rates, for upfront car and monthly fuel costs (See Part II for estimates). When will that happen in the US? In the world? In the long term, we still believe we can reach this laudable, primarily clean electricity goal driven transportation goal but probably not in the next decade or even two (more calculations on carbon emissions per mile later)! We do believe that fifty years from now we will probably be running an all electric fleet for transportation (be it personal cars or public transportation).

The topic of public transportation is another one to consider. For some idealists, eliminating cars (or sharply curtailing them) is the step needed to reduce carbon emissions significantly. We agree public transportation is desirable for a multitude of reasons, but with almost a billion cars on the road today (and the number set to increase as Chinese/Indian consumers buy many more), eliminating cars is simply not a feasible or pragmatic solution. Some preliminary analysis of public transportation suggests that while it is a notable improvement over conventional gasoline powered automobiles, the impact is limited. Our analysis below suggests that the national heavy rail (essentially subway) system actually gets similar (to a Volt) mileage/kwh on a per-capita basis. The numbers (from the American Public Transport Association): nationally, 3.68 billion KWh of electricity was used for 14.3 billion passenger miles[vi], with effective mileage of about 3.89 miles/kwh), and electricity carbon emissions of approximately 1.35 lbs per KWh (as per the EIA) – using that, we get per-capita emissions of 157 grams per mile. Furthermore, most of our automotive data (covered in the next section) assumes one passenger per car - in practice, that number is almost certainly higher, reducing per capita data, probably by another 10%. Public transportation clearly has an important role to play and it can make a material impact on carbon emissions reduction, but not as much as cellulosic biofuels. A complete turnabout in consumer preferences for vehicles is simply not a practical assumption, and the impact of that change on carbon emissions is not that huge. A billion cars are likely to be built in the next 15-20 years. Should they be hybrids or something else to impact carbon emissions the most? What will be affordable? **What will people actually buy that can reduce carbon emissions?**

Pragmentalists vs. Environmentalists: (Part II): Hybrid Emissions -Facts & Numbers

Having laid out my views in part I, let's look at the actual data on hybrids – both from an environmental and economic perspective. How do carbon emissions per mile driven for the various cars compare? The General Motors Volt is expected to be "less than $30,000" with a 1.0L engine, compared to the Toyota Corolla with a 1.8Lengine (peak hp of 126; 31 mpg) and a price of $14,400. Its worth noting that this in the optimistic, no-gasoline use scenario for the Volt is computed below along with carbon emissions for it running on cellulosic ethanol, gasoline and emissions for comparable sized ICE cars. Questions on the Volt's actual usage patterns remain: how many people will recharge everyday? What % of total miles will be on the grid and what % on gasoline?

	2010		**2017**		**2017 (with a 50% increase in ICE mpg)**	
Car	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)
Toyota Prius - (1.6kwh) (Price - $21,200)	238	$490	238	$490	159	$468
Toyota Corolla (ICE - Gasoline) (Price - $14,400)	353	$385	353	$385	235	$353
Toyota Corolla (Hypothetical FFV version) (Price - $14,500)	282 (Corn E85)	$387	88 (Cellul. E85)	$355	58 (Cellul. E85)	$334
Toyota Corolla (Hypothetical 1.6kwh Hybrid) (Price - $18,400)	274	$444	274	$444	182	$419
GM Volt - (16kwh) On Electricity Only (Price - $30,000)	144	$623	144	$623	144	$623
GM Volt - (16kwh) Cellul. E85 (Price - $30,000)	-	-	55	$641	37	$628

GM Volt - (16kwh) Gasoline Only (Price - $30,000)	219	$661	219	$661	146	$641
GM Volt - (16kwh) Gas + Electricity (1:1) (Price - $30,000)	182	$642	181	$642	145	$632

Notes: A hypothetical "plug-in Prius" with a Volt sized 16kwh battery would probably cost more than the Volt. Hence the above comparison of a plug-in Volt vs a hybrid Prius is unfair to the GM Volt. The hypothetical Hybrid Corolla in this example is calculated by adding $4,000 (the additional estimated cost of a Prius drivetrain with a 1.6kwh battery) to the cost of a Corolla, and assuming 40 MPG. The monthly cost includes the monthly amortized cost of purchase (7.5% loan – completely financed over 5 years) + cost of fuel (1,000 miles/month). Battery cost of $7,600 (at $400Kwh + $1,200 control) in 2010 and $4,000 ($200Kwh + $800 control) in 2017 is included in the Volt purchase price of $30,000 – these battery cost estimates are 40-60% lower than current estimates of $700-1000KWh[vii] and automaker margin is not included. Fuel cost assumptions of $0.11c/KWh electricity (US average per EIA) and 5 miles per kwh for the Volt, $3.00 gasoline cost to consumers (roughly just the material cost of "oil" in gasoline at $100 oil price, before taxes- actual costs likely to be higher for consumers if oil prices stay high), $2.25 per gallon corn E85 to consumers before taxes ($1.75 production cost per gallon), and $1.50 per gallon cellulosic E85 (based on $1.00 production cost before taxes) in 2017. A 25% mileage discount is used with ethanol (equal to current average EPA de-rating for E85). Does not include expected improvement on E85 mileage relative to gasoline or the carbon emissions from battery manufacturing which are likely to make electric vehicle and battery numbers about 10-20% worse on carbon emissions. None of the costs account for subsides or taxes which we assume will be zero/equal for all technologies by 2017. No vehicle attribute changes are assumed (e.g size, weight, drag). The electricity cost assumption is for the current coal fired grid. A clean grid with renewable power is likely to be more expensive and is not included here. A hypothetical Corolla with a Prius like 1.6kwh battery and drivetrain would cost an estimated $4000 mile and get a guestimated 40mpg (it has higher drag than the Prius accounting for its lower estimated mileage).

In Class Comparisons

Some of the criticism we have received has suggested that comparing a Prius to a Corolla is not an fair comparison – they are different vehicles, aimed at different segments of the market. In order to provide a more equivalent comparison, the table-below compares cars with their direct counterparties, eliminating other cost-distinguishing factors. Our conclusions remain the same – FFV's on cellulosic ethanol offers the most emissions reductions, and (eventually) at lowest cost.

	2010		2017		2017 (with a 50% increase in ICE mpg)	
Car	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)
Honda Civic (On Gasoline) (Price - $15,010)	377	$404	377	$404	252	$370
Honda Civic (FFV – Ethanol) (Price - $15,110)	302 (Corn E85)	$406	94 (Cellul. E85)	$372	63 (Cellul. E85)	$349
Honda Civic Hybrid (On Gasoline) (Price - $22,600)	261	$524	260	$524	174	$500
Saturn Vue (On Gasoline) (Price - $21,875)	497	$575	497	$575	332	$529
Saturn Vue (FFV – Ethanol) (Price - $21,975)	398 (Corn E85)	$577	125 (Cellul. E85)	$531	83 (Cellul. E85)	$501
Saturn Vue Hybrid (On Gasoline) (Price - $24,795)	391	$604	391	$604	261	$568

The numbers are necessarily estimates and apples to apples comparisons are difficult. Notably, they do not include the carbon emissions for battery manufacture amortized over the assumed 100,000 mile life of the battery. In addition, speculation persists that the GM Volt battery will be leased to consumers – and that the $30,000 price-tag is not inclusive of any leasing costs. We suspect these errors are material and make the electric numbers look better than they are. The assumptions behind this table are as follows: the Volt gets 5 miles/kwh - given US electrical grid emissions of approximately 1.35lbs per KWh (EIA estimates) that gives us a per-mile emissions level of roughly 0.32 lbs / mile (after adjusting for an electrical roundtrip storage efficiency at 85% for the battery, and assuming it is running on battery alone) or about 144 grams of carbon dioxide per mile. On gasoline alone (assuming no battery charging from electricity) the same car's emissions would be 219 grams pre mile. Using only cellulosic ethanol, the same car would have 75% lower emissions or 55 grams per mile (assuming trucks etc supplying biomass, and transportation still run on fossil fuel). We have modeled gasoline emissions for tank to wheels to be 80% of that from well to wheels emissions (roughly what the EIA uses.

What are the emissions associated with battery production? While there is a lack of literature on a full "dust-to-dust" analysis, it is clear that manufacturing hybrids consume more energy than regular gasoline vehicles – Toyota's own analysis confirms this.[viii] Other sources suggest similar results– analysis by Pablo Paster (using the GREET model developed by Argonne National Lab) notes that a 2,632 pound HEV requires 101.726 mmBTU to produce, or about 38,650 BTU /lb; a regular 3,201 pound gasoline vehicle uses 100.391 mmBTU, or about 31,362 BTU /lb – a 23% increase on a per-pound basis for the HEV. While further research on the lifecycle emissions of hybrid batteries is needed (especially on a post-life basis – the nickel in a battery is significantly harder to recycle than the metals in a standard ICE), it is clear these emissions detract from the overall environmental impact of HEV's (and eventually PHEV's) as a class.

The percentage of coal in the US grid is expected to go up, not down. Contrary to most forecasts, we think we can do better than that and limit coal-powered electricity to the point where it's percentage will decline (we have investments to make renewable grid electricity at similar costs to next generation IGCC coal plants), but the decline will be gradual given typical power plant lifespans. Despite what we might wish for on driving on solar or wind power, the reality is likely to be different. McKinsey's analysis [ix] is below – in the reference case, coal usage increases by 140GW, and becomes a larger percentage of our power supply. While we are optimistic that a scenario similar to their abatement result is viable, they do note that this will require an investment of $1.1 trillion over the period.

POWER SECTOR

Gigawatts	2005	2030	*Change*
Coal-fired capacity*	306	446	*140*
Nuclear power	100	113	*13*
Renewables **	32	49	*17*

For those of you who want to compute solar PV panels on your roof, its effective cost is between $0.25 (low cost panels in sunny Arizona?) to $0.50(foggy Seattle?) per kwh depending upon the cost of the panels and their location. In a few locations wind might be cost effective but that would be for a small minority of car owners.

What about the cost of driving a mile? When we get to the incremental clean grid costs, renewable electricity is expected to cost about $0.10-0.15c/kwh (prior to taxes; $0.06-0.10 /kwh delivered to utilities) delivered to the consumer at any large scale (or $0.20-$0.30 Kwh for distributed rooftop generation), or about $0.02-0.03 per mile for a vehicle of the Volt class. In favor of plug-in hybrids, they are more likely to be recharged at night, when electricity costs are significant lower. The Morgan Stanley report notes that "that several electric utilities are actively supporting and financially contributing to PHEV R&D" and that "Overnight charging for PHEVs, in fact, is expected to improve the efficiency of existing power plants by increasing loads during off-peak hours." A production cost of $1.00 per gallon biofuel (we suspect lower costs are likely in 10-15 years) will likely result in a $1.50 consumer price point (prior to any taxes, which vary by state), so one would have to get 50mpg (very doable; essentially the GM Volt gasoline only mileage) in a flex-fuel car to get a similar variable cost per mile driven. Yes, we do expect within the decade, a good flex-fuel engine to get the same mileage on biofuels as they do on gasoline (for example an ethanol capable engine running at a compression ratio of 16 – ethanol's higher octane rating means that today's engines are not optimized for it) which will increase ethanol mileage by another 25% that is not figured into our monthly cost reduction calculations. We should be clear that all numbers are necessarily approximations; probably to within 25%.

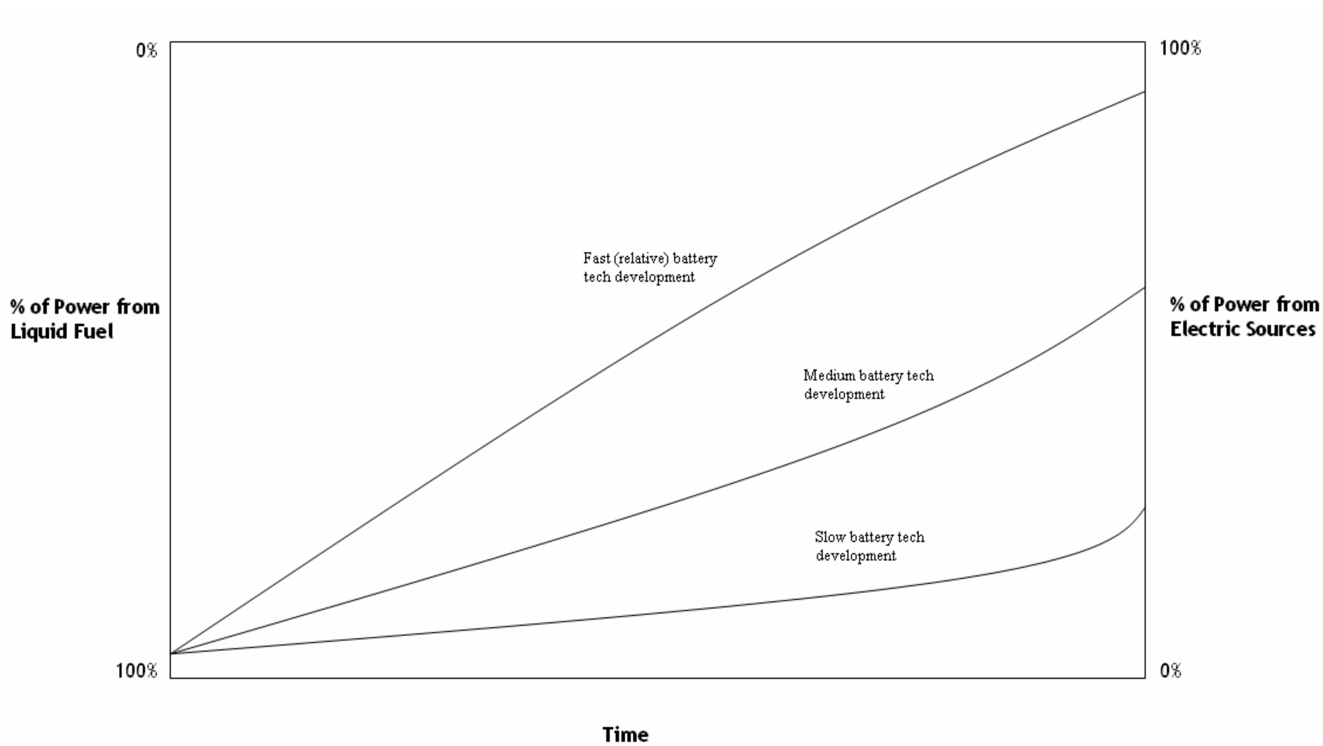
Pragmentalists vs. Environmentalists (Part III): Hybrids & Bioufels -The Road Ahead

Many people make the mistake of comparing apples to oranges. One has to compare futures to futures and current status to current status. All technologies improve but some improve more than others. The Prius gets 46 mpg, while a similar sized Toyota Corolla gets 31 mpg. One of our investments (Transonic) is trying to make it such that a Prius without the hybrid engine but fitted with a Transonic engine (if it works!) that will have lower carbon emissions than the hybrid Prius (so will the Toyota Corolla) at below $1,000 in marginal cost. Other efficient engine efforts abound. If battery technology efforts like Seeo (one of our investments), EEstor, silicon nanowire batteries (or similar efforts that others have funded and many that we are evaluating) are successful we will get the same effect (better petroleum mpg) with a plug-in IF we can also clean up our grid at the same time!

From our perspective, if we have to pick between a 5-10X lower cost/performance battery AND a cleaned up electrical grid in the next 5-10 years (or even 20-25 years) or pick cellulosic fuels in 50% more efficient ICE engines, we consider the latter lower risk and significantly more probable. We are confident that cellulosic biofuels without significant land use impact or biodiversity impact can achieve costs of $1.25 per gallon in less than five years and below $1.00 per gallon in 10years (more details on that, especially land use/biodiversity and sources of biomass, in our Where Will Biomass Come From paper). At this price point the technology will be adopted broadly worldwide and rapidly, even if oil prices decline substantially.

If hybrids and clean electricity make progress faster or biofuels progress slower than we believe, then we will get electricity powering the cars of tomorrow much faster. Within 25-50 years, we may well see a transition to an all-electric propulsion fleet, depending on the relative technical progress on battery, fuel and engine efficiency technology. But one has to guess at the probability and expected value (cost) of such uncertain outcomes, Nonetheless it appears to us that biofuels are likely to be a significant source of our "non-oil" transportation energy needs in the next few decades. The extent to which we use them is going to be a function of the cost of oil, the cost of biofuels, the cost of battery technology, and the scalability of the technologies – as addressed in the chart below.

Powering the Automotive Fleet for the Future (from our 2007 paper "Biofuel Pathways")



Essentially, we think replacing coal based electricity plants (50 year typical life) is a much longer tougher slog than replacing oil with biofuels (fifteen year car life). The average power plant lasts 50 years and no one will dispose of old plants. Incrementally, we will start adding new cleaner plants (we do believe renewable power plants will take a large share of new plant construction quickly – see my “Coal” paper) but it will take a long time to clean up the US (and especially the worldwide) grid. As our whitepapers make clear, we do consider hybrids and biofuels as complementary strategies – biofuels are a broad, large-scale technology that can reduce costs for all consumers, while hybrids can offer cost benefits to those on the higher end of the income spectrum (there higher upfront costs are likely to limit their penetration amongst lower-income consumers, especially in India/China). In the long run, we expect this penetration to increase as costs decline, to the point where we can may eventually get an-all hybrid fleet (by 2050?). Incidentally, the GM Volt serial plug-in hybrid is rumored to be a flex fuel car (very much like the kind of car we talked about last year). Its evolution, and that of its cohorts, will depend upon the relative progress of the technologies. As ICE engine efficiency, biofuels carbon content, battery cost/performance, electric grid carbon content progress at different rates, and the relative percentage of the cars “power” form each of these sources will change. Meanwhile we continue to invest in breakthrough engines, batteries, and biofuels and hope that all progress rapidly.

Where do we see hope for hybrids (besides if unforecasted battery breakthroughs happen)? We are cautiously bullish on serial hybrids which can run on the battery but offer gasoline as a “backup” fuel - always available in the tank if the battery runs out. Configurations that, like the Prius, use small amounts of battery capacity (1.6kwh Prius vs. 16kwh rumored for the GM Volt) but in serial hybrid configurations like the Volt are promising as they help engine management and hence engine efficiency. As discussed in Part II, the GM Volt has a 40 mile range with a 16kwh pack. Earlier, we laid out our cost estimates for the battery pack of $7,600 @$400/kwh plus $1200 for the battery control module (not including manufacturer and dealer margins) which optimistically could get to $4,000 in the future ($200/kwh plus $800 control module) - though we assume that battery costs are included in the $30,000 purchase price. Estimates from a recent Morgan Stanley report[x] suggest a Li-Ion battery could cost around $5,000-$8,000 in 2010, declining to $3,000-$5,000 in the long run; they also cite a recent California Air Resources Board study which estimates that a PHEV-40, 14Kwh battery would cost around $8,350 at 20,000 units of production and $5,585 at 100,000 units of production. The Volt also has a peak hp of 160 from battery but about 70hp estimated when running off generator (curb weight unknown today) and 50mpg mileage when sustaining charge (essentially its ICE efficiency). In the hypothetical scenario where the GM Volt runs only on its battery power (40 miles per day max, 8Kwh daily charge, 85% electrical round trip storage efficiency for the battery – 12,000 miles per year; average carbon emissions of 1.35 lbs per KWh for electricity before efficiency), it will have carbon dioxide emissions of 3,812 lbs (or about 1.7 metric tons) per year (for the typical US user where the grid is 50% coal powered; emissions in China and India will be higher). In contrast, a 2008 Toyota Corolla driving the same distance per year would expect to emit 4.2 metric tons per year.

We have chosen to ignore the expensive cars like the $100,000 Tesla or the Audi plug-in even though they are potentially successful cars – at that price, they aren't likely to impact the worldwide adoption of very low carbon cars. We have also chosen to ignore the folks who rant at SUV buyers. As one blogger said: "Why are you telling other people what *they* value? What does what you value have to do with what others value?" We can't change consumer preferences as a fix-all; rather we need to have technologies change to meet consumer and society's needs while reducing CO2 emissions as much as possible.

For the record, we are fans of much higher CAFE standards because it makes sense as national and global policy (the recently passed bill was a start). With regards to public funding, we are not fans of continuing any subsidies for hybrids, biofuels, solar power, wind etc beyond the first 5-7 years of their market introduction – aid ought to be developmental, and not never-ending (for example, large oil subsidies and nuclear subsidies still continue). We have helped all clean and not so clean technologies (e.g. nuclear with over a $100b in cumulative subsidies; currently subsidizing IGCC coal + carbon capture & sequestration) get started. It is somewhat ridiculous that we still have massive subsidies (and much larger than renewables) for fossil fuels such as coal, oil (as well as non-fossil fuels like nuclear power)….. One potential worry for me is a scenario where battery costs actually rise if 50-80% of the world's car fleet is running on batteries, and the raw materials start to escalate in cost (as happened to corn, silicon and other commodities; biomass is unlikely to suffer from this for reasons explained in an upcoming paper). Cost and sustainability at scale matters more than anything else – as the summary table below reiterates, the cost and environmental benefits of cellulosic ethanol are significantly greater than that of the viable alternatives.

Car	CO2 emissions – grams/ mile	Monthly Cost (Car+Fuel)
Toyota Prius - (1.6kwh, $21,200)	238	$490
Toyota Corolla -(Hypothetical FFV ,Cellul E85, $14,500)	88	$355
Honda Civic Hybrid - (On Gasoline, $22,600)	260	$524
Honda Civic - (FFV – On Cellulosic E85, , $15,110)	94	$372
GM Volt (16kwh, $30,000) - Electricity	144	$623
GM Volt - (16kwh, $30,000) - Cellulosic E85	55	$641
Public Transportation – US "Heavy Rail" (Subway) System	157	N/A

But as Alan Kay said "the best way to predict the future is to invent it". Our goal is to back entrepreneurs who are doing just that, be they ethanol, butanol, cellulosic gasoline or cellulosic diesel (we are not fans of "classic" biodiesel), solar, wind, batteries, higher efficiency lights, cars, pumps, homes, appliances and more. We have invested in all of these areas as detailed in my Green Investing paper. We believe, as our papers detail, we can get most gasoline replaced within 25 years by biofuels that reduce carbon emissions by 75-85% and have 75% or more of the world's car fleet capable of these fuels within ten years. That market penetration, infrastructure switchover, consumer acceptance and cost effectiveness is unlikely to happen (though possible with breakthroughs we hope happen but am not currently seeing) with any other technology. We're out trying to find these alternatives right now. Some of you will surely find nits, even errors in our calculations or disagree with the numbers (all corrections are welcome) but we doubt if any of them will change the fundamental conclusions. If they do, you will see a new direction from us.

PS: GM unveiled a V6 flex-fuel Hummer and a partnership with Coskata that produces cellulosic ethanol. A Prius running on gasoline would have twice the carbon emissions per mile compared to this 16mpg (estimated) Hummer V6 running on Coskata's ethanol. Papers on renewable electric power/coal/nuclear, biodiesel, biomass, Biofuels Pathways, Food vs Fuel, and Green Investing as well as our portfolio are available at http://www.khoslaventures.com/resources.html

[i] "Autos & Auto-Related: Plug-in Hybrids: The Next Automotive Revolution" ", Morgan Stanley, March 11, 2008
[ii] http://www.businessweek.com/bwdaily/dnflash/content/mar2008/db20080321_748642.htm
[iii] "Reducing U.S Greenhouse Gas Emissions: How Much at What Cost?", McKinsey – December 2007
[iv] "Sustainable Biofuels: Prospects and Challenges", Royal Society, Jan 2008
[v] http://www.businessweek.com/bwdaily/dnflash/content/mar2008/db20080321_748642_page_2.htm
[vi] http://apta.com/research/stats/rail/hrsum.cfm
[vii] "Battery Technology and Markets", EPRI, November 20, 2007
[viii] http://www.toyota.co.jp/en/k_forum/tenji/pdf/pgr_e.pdf
[ix] "Reducing U.S Greenhouse Gas Emissions: How Much at What Cost?", McKinsey – December 2007
[x] "Autos & Auto-Related: Plug-in Hybrids: The Next Automotive Revolution" ", Morgan Stanley, March 11, 2008