April 23, 2007

Bob Giebeler
P.O. Box 170624
San Francisco, CA 94117
Phone 415.252.7214

California Energy Commission
Docket Office
Attn: Docket 06-AFP-1
1516 Ninth Street, MS-4
Sacramento, CA 95814-5512

DOCKET
06-AFP-1
DATE APR 2 3 2007
RECD. MAY 0 7 2007

Copy: Robert Sawyer, California Air Resources Board
Michael Jackson, TIAX, LLC

Regarding: Docket 06-AFP-1, Alternative Transportation Fuels Plan Full Fuel Cycle Analysis Workshop

Dear Commissioners and fellow Scientists:

I am honored to have the opportunity to participate with the Commission in reviewing materials from the Alternative Transportation Fuels Plan Full Fuel Cycle Workshop on March 2, 2007. My observations after reviewing the TIAX TTW, WTW, and WTT documents are as follows:

I) Mid-size vehicle mileage efficiency estimates: The comparative efficiency shown in the TIAX report (WTW, 2-9) for conventional versus hybrid cars using the best technology presently available does not reflect the over two-fold hybrid improvement for autos in California. The models used for this estimate should be completely transparent, and should include a driving model tailored specifically to California population centers, including climate and congestion factors. This is a very basic tool necessary for planning all vehicle fuel alternatives, particularly in view of potential major infrastructure changes, and the need to quantify greenhouse gas emissions.

II) Plug-in and EV vehicle mileage efficiency: The TIAX report acknowledges the lack of good comparative data for EV's (TTW, 3-14), again the same issue presented in I).

In addition, the mileage efficiency of a plug-in Hybrid is misrepresented (WTW, 2-9), as the efficiency of electric power production and transmission efficiency is not included. This is critical in view of the high percentage of present and future electric power production using natural gas.

Lastly, analysis the electric power grid and electric vehicles should include the additional and *necessary* daily grid load leveling enhancements such as time dependent rate meters for all users, thermal storage, and solar air conditioning.

III) Natural gas supplies for California: The TIAX report discusses natural gas for production of alternative fuels and electric power (WTT, 3-10 to 13, 7-6 to 11), but offers no analysis of reserves in the US, North America, and the World, including world demand and risks of supply interruption. We have small reserves in North America, and importing LNG from over-seas has at least the same interruption and depletion risk as oil.

IV) Bio-fuels, including ethanol: The quantity of bio-fuels that could be generated in California without significantly affecting food production and water supply in California is not quantified in the TIAX reports.

The escalation of ethanol production in the United States from corn has been linked to a food shortage, which is an unacceptable tradeoff.

In addition, the TIAX analysis of the importation of corn from the Mid-West for ethanol production in California (WTT, 3-44, 7-19) does not appear to consider the energy cost of transportation, critical for a feedstock with a marginal energy return without this cost.

V) Conclusions: It appears much work is needed to finalize a viable vehicle fuel road-map for the future. I would encourage the Commission to prioritize the opportunities for reasonable risk, quantity of energy, expediency, and without compromising food production or water resources in California.

Further details on many of these issues are included in the accompanying report, AB1007.giebeler.hev.apr07.doc

Feel free to contact me regarding any questions you may have.

Sincerely,

Robert H. Giebeler
b.giebeler@IEEE.org

Alternative Transportation Fuels plan Full Fuel Cycle Analysis workshop, docket 06-AFP-1

File AB1007.giebeler.hybrids.Apr24.07.~~pdf~~ doc

Analysis of Hybrid Electric Vehicles, EPA mileage standards, and impacts on Oil and Gas imports in California

By Bob Giebeler

I) Introduction and Executive Summary

The prominent issues about the risks of oil and natural gas imports to the United States, world political stability, and Global Warming present a significant challenge for our Politicians and Scientists. Improved vehicle efficiency could have a large impact on these problems, as 100% of all US oil imports are used for transportation, and 62% of transportation consumption is used for automobiles [3]. The refinement of Hybrid vehicles offers an opportunity to eliminate this dependence. This opportunity is particularly important in view of the present difficulty and uncertainty regarding alternative energy options.

Figures 1 and 2 show an overall energy map and transportation usage [1]:

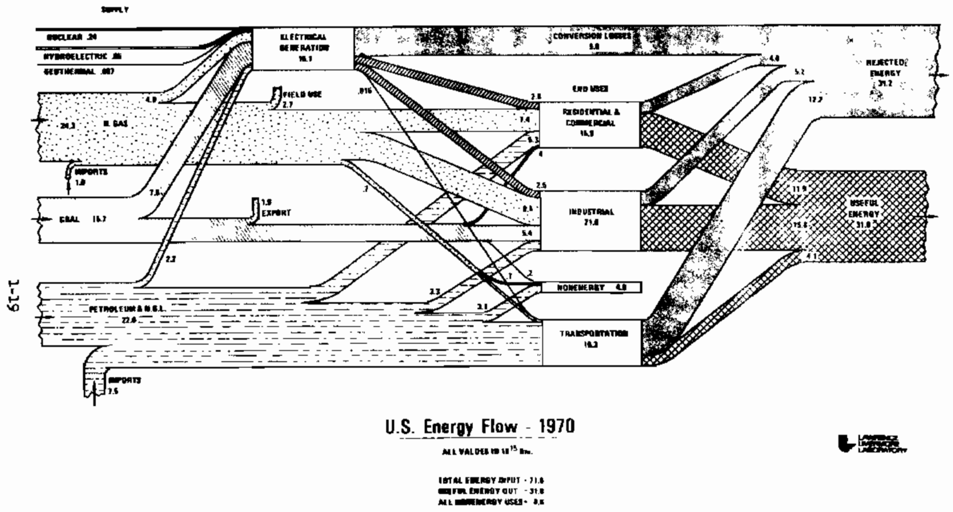


Figure 1

This data is 37 years old, and unfortunately the distribution is still fairly representative. In spite of all the incredible advancements in many technologies in the last four decades, energy technology has not developed significantly, principally because oil remains inexpensive, and there have not been recent political supply interruptions.

Significant changes in the last 37 years include natural gas imports increasing from 4% to 15% [2], which will continue to rise rapidly because of our low reserves, and oil imports increasing from 25% to 55% [3].

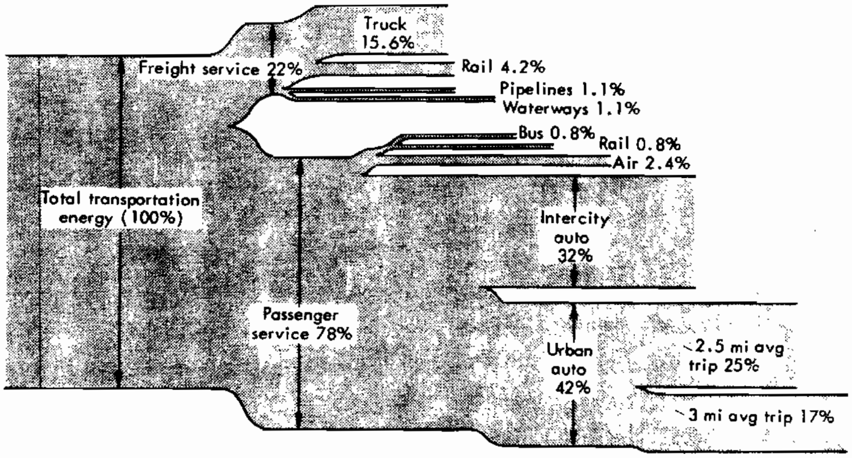


Figure 2

Critical in this study is the mix of automobile driving venues, 1970 data presented in figure 2. The mix has changes little, as the layout of our living venues, including public transportation, have changed little [22]. In this period the percent of transportation use for automobiles has dropped from 74% to 62% [3], in part due to improved mileage, but also because the percent of oil used in air transport has quadrupled to 9.8% [3], in spite of jetliner efficiency more than doubling in this period [14,47,61].

The DOE 1995 NPTS document [33] more recently surveyed light vehicle use patterns. Researchers are refining this data including using GPS tracking technology [54].

In view of the lack of more representative data for California, the automobile distribution in figure 2 is assumed to be a reasonable estimate for this study.

A review of California Energy Commission proceedings in the last year are positive in that the "Workshop PIER" forum includes many "public" participants, including businesses and organizations that are aggressively seeking solutions. These activities have been escalated with the passage of legislation in California. The public sector is offering excellent inputs, with expected stakeholder bias, however the CEC has a difficult challenge to act expediently, with practicality and good science, and without political favoritism.

However, the sum of near term alternative energy solutions, including ethanol, biomass, solar, and wind, realistically allow approximately a 10% reduction in fossil energy consumption [7,21,36,39,41].

The long term (20+ years) options including hydrogen, coal-gas, nuclear, biogen, and next generation ethanol, solar and wind, assuming technical viability is proven [4,5,6,20,21,24,26,36,37,39,41], might be available too late to be of value [7].

The Government and Businesses optimistically promote many alternatives without reasonable risk scientific basis [16,28,29,31,46,45,55], which is misleading the public about the seriousness of the situation.

Consequently conservation and efficiency are the only substantial short-term solutions.

There is a critical problem in assessing the Hybrid automobile efficiency potential, as the EPA mileage method used to assess efficiency is very simplistic, and inaccurate. The method does not allow buyers to understand what they can expect in their driving venue, *and more important it does not provide the data needed to understand the potential in-service fleet improvements in efficiency, and the resulting reduction in oil consumption, as we assess technological alternatives.*

Nine months of "real world" testing of a Toyota Prius Hybrid car, and a non-hybrid car have demonstrated, *up to four times improvement in mileage using hybrid technology. This observation is in contrast to EPA mileage ratings and estimates made by EPRI and others [3,8,43].*

Recent NREL hybrid reports [54] confirm the need for a more representative driving data and mileage models, including for ADVISOR analysis. The EPA has recently revised the mileage test method [9] but not in a way that addresses the deficiencies.

Significant deficiencies include accounting for extreme climate environments, congested conditions, and vehicle useful load.

A more accurate mileage estimate model is suggested in this paper.

Additionally, an analysis is presented of theoretical and experimental aspects of general efficient auto design issues, the Hybrid performance advantage, the "Plug-in" hybrid and the all-electric car concept.

The Aircraft industry offers a different design venue, where an aircraft's performance and efficiency envelope, including useful load, largely neglected in EPA estimates and new generation car offerings, are thoroughly documented for use by the flight crew and purchaser. Several other vehicle design issues are compared to aircraft design, as the quality of design has been higher in the aircraft industry, although aircraft have a considerably higher manufacturing cost (ten-fold).

II) The Hybrid Advantage

There are four fundamental reasons a well-designed Hybrid car can achieve improved efficiency over a conventional design:

a) Braking energy is regenerated, absorbed back into the battery instead of into friction brake heat.
b) The gas engine is off when not needed (efficiency is less than 0 at idle while stopped in traffic, for example).
c) The gas engine can be smaller and preserve same acceleration performance by using the electric motor in parallel.
d) The gas engine can be operated at a more efficient operating point when in use.

More details about these advantages are presented in section III, however in summary, the combination allow up to 4 times mileage improvement.

There is also a down-side to hybrids:

a) The weight of a hybrid system is heavier than a conventional car, and vehicle efficiency is inversely proportional to weight.
b) The battery technology is not yet demonstrated to achieve the ultimate hybrid car, including the "plug-in" or all electric (EV) versions. Batteries remain heavy, have a limited life, are expensive, and related safety issues are not well understood.
c) Complexity and costs for a Hybrid are inherently higher.

The limited battery life issue is major, as the cost of the battery is directly related to the energy that was required to produce it, including raw material mining, production labor (the energy to support the work force) or production energy. Fortunately a 10 year 150,000 mile warranty was enforced for Toyota hybrid batteries, and the control schemes used are clearly minimizing stress on the battery to achieve this warranty. *The Prius battery replacement cost is $3,000 requiring a $0.02 per mile battery replacement fund, in addition to the $0.05 per mile cost of gasoline (assumes life is warranty period).*

III) Hybrid design details and performance

This hybrid analysis is a simple theoretical model supplemented with experimental data. Most hybrid developers are using computer programs similar to "ADVISOR" [10] to do analysis, including NREL [51,52,53,54]. One report [51] analyzes the Prius, however the vehicle NREL used was an older model, in contrast to the Prius THS II used in this study, offering many efficiency and performance improvements.

The requirements for the ideal hybrid car are safety, performance, drivability, efficiency, versatility, features, and reliability. Drivers would likely prefer not to go back a 60's vintage featureless Volkswagen, nor back to the EV1 that drives like a slow truck and is inconvenient for most drivers.

Presently the Toyota Prius is the hybrid efficiency "gold standard". Toyota's web site [11] has an excellent description of their technology, although there is a limit about what is disclosed.

Additionally, the lengthy 2001 EPRI hybrid paper [8] is available from their website.

Testing completed includes city driving in San Francisco, and freeway driving. The principal "city drive" test protocol was a 7 mile loop with a 2 hour midpoint layover, including an average of 20 stops, 30 mph max speed, in non-congested conditions, and an elapsed average time of 17 minutes on each leg. This protocol constitutes 60 % of City driving, as shown in figure 2, less consideration for congestion.

The Traffic Engineers in San Francisco have designed a better than average traffic flow system as compared to many suburban venues, minimizing "induced congestion".

The non-hybrid data was obtained on an Isuzu Trooper. This vehicle is an efficient vehicle in view of its load and volume capacity. As shown in figure 3, it has the same percent useful load as the Prius (27%), weights 38% more, and has 4 times higher volume capacity. The Trooper has all the non-hybrid efficiency technologies, and *less* acceleration performance than the Prius. (Normalization of the weight difference is discussed later in f))

Figure 3 shows the comparison, including several additional hybrid and non-hybrid vehicles. Refer appendix A for detailed explanations.

line		PRIUS	CAMRY-4	CAMRY HB	HYLNDR	HYLNDR-HB	HYLNDR-HB-4WD	TROOPER 4WD
1	EMPTY WEIGHT (LBS)	2995	3307	3680	3704	4070	4275	4300
2	GROSS WEIGHT	3795	4315	4655	5360	5625	5625	5500
3	USEFUL LOAD	800 lbs	1008 lbs	975 lbs	1656 lbs	1555 lbs	1380 lbs	1200 lbs
4	PERCENT USEFUL WEIGHT	27%	30%	26%	44%	38%	32%	28%
5	HYBRID WEIGHT PENALTY			373 lbs		366 lbs		
6	TOTAL HP (HORSE POWER)	110	158	187	215	268	268	200
7	GROSS WEIGHT/HP (1/acceleration)	34 lbs/hp	27 lbs/hp	25 lbs/hp	25 lbs/hp	21 lbs/hp	21 lbs/hp	27 lbs/hp
8	CITY EPA MPG	60	24	40	19	32	31	17
9	HIWAY EPA MPG	50	33	38	25	27	27	22
10	OBSERVED CITY MPG	40						7(10 normalized)
11	OBSERVED HIWAY MPG	60						22(31 normalized)
12	KLBS-MILES PER GAL-CITY-epa	48	24	40	26	50	44	20
13	KLBS-MILES PER GAL-HIWAY-epa	40	33	38	41	42	37	26
14	HB CITY IMPROVEMENT-real		4					
15	HB CITY IMPROVEMENT-epa			1.66		1.93		
16	%ELECTRIC HP	26%		22%		22%		

Figure 3

The first significant conclusion from this data is that in city driving the Prius obtained a 4 times mileage improvement over conventional technology, in contrast to EPA estimates on the Camry hybrid advantage of only 1.7 times. *Consequently, it is impossible to use EPA estimates to assess the efficiency benefit of Hybrid or any other new vehicle technology.*

In addition, Yellow Cab estimates the Ford Escapes in service, without the Toyota THS II improvements, reflect about 3 times mileage improvement with a very aggressive driving style [49].

The city drive test protocol used in this study is conservative, as in congested conditions, including on the highway, the hybrid has an even higher advantage. Congestion is a large problem in California.

Another conclusion from the data (figure 3 line 12) is that the Toyota Highlander SUV has a slightly higher mileage rating than the Prius (subject to the limits of the EPA test) if you include useful load, i.e. pound-miles per gallon (alternatively passenger-miles per gallon). If the capacity of an SUV or truck is needed, they can be energy efficient, in contrast to the negative press regarding SUV's. Many people need higher useful load, and it is less efficient to make two trips instead of one because the vehicle does not provide the capacity. (In figure 3 KLBS is 1000 pounds of useful load). More discussion about useful load is presented in f).

a) **A Unique Hybrid Approach**; For basic hybrid description refers to the documents sited [8,11]. Figure 4 represents the Toyota approach using a "gas engine power splitter", a planetary differential. Part of the gas engine power goes directly to the wheels, thereby eliminating the electrical inefficiencies of the battery, converter and electric motor, and the rest of the gas engine energy goes to a variable impedance generator to either charge the battery or power the electric motor. In essence, they have an electronic infinitely variable automatic transmission that;

i. Allows operation at the most efficient gas engine PRM.
ii. Eliminates the shift-jerk effect that is very annoying and inefficient in under-powered cars, as shown in figure 5.
iii. Allows maximum gas engine power during the entire acceleration period, thereby requiring a smaller engine to achieve the same 0 to 60 mph acceleration performance.
iv. The generator also serves as the gas engine starter, a critical component in a hybrid, to provide efficient seamless and quiet starts.

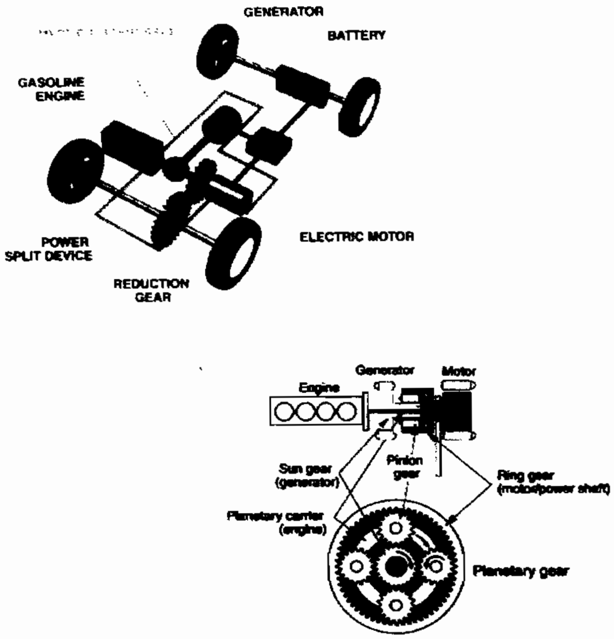


Figure 4

Other forms of infinitely variable transmissions (referred to as CVT's) have been in use for decades in other applications, and many car companies are exploring them, however CVT's are very difficult to make with high conversion efficiency and reliability. Mercedes in view of these challenges opted for the seven speed conventional automatic transmission for new generation cars.

The above expectations are confirmed in figure 5 [11] where the Camry non-hybrid has less acceleration performance than the Prius in spite of a 20% higher power to weight ratio (figure 3 line 6).

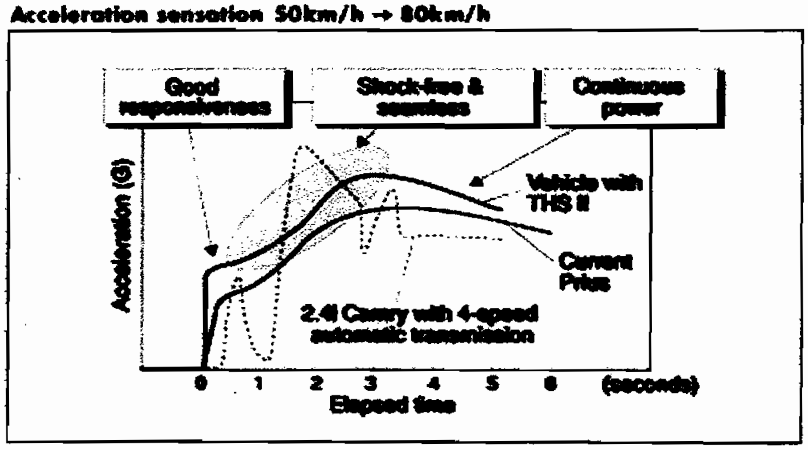


Figure 5

b) **Gas Engine efficiency characteristics**; Figure 6 shows an estimate of gas engine power output versus conversion efficiency (efficiency is the mechanical energy delivered versus the energy in the fuel).

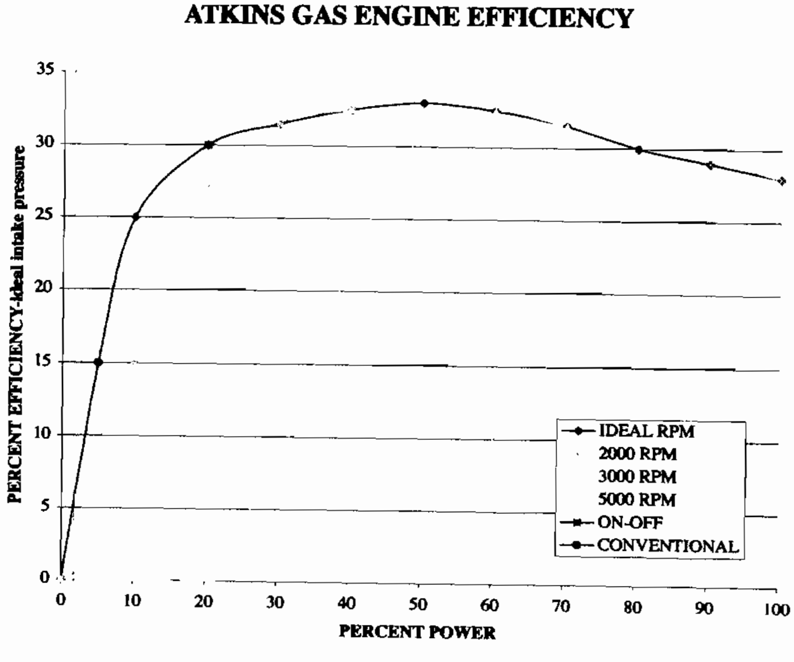
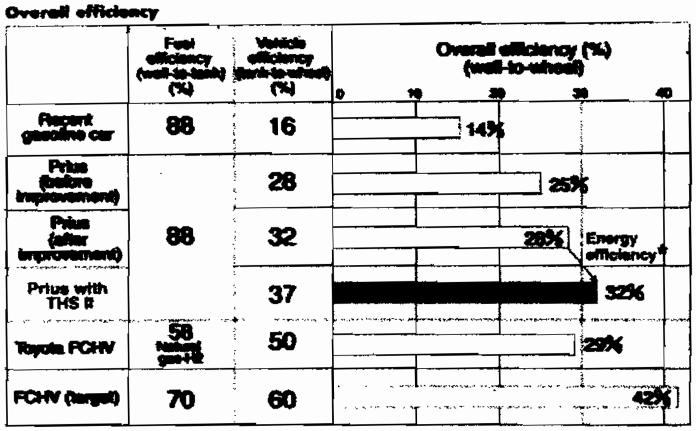


Figure 6

The top curve is the maximum efficiency attainable at the ideal engine RPM, and the lower curves show efficiency at specific RPM's (in the most complete form this plot has a third dimension, air intake pressure, determined by the throttle valve). The CVT transmission allows the engine to operate at the most efficient RPM and intake pressure for the power desired.

Prius testing indicates that overall propulsive efficiency, referred to as tank to wheels, is about 28% (appendix B). As shown in figure 7 [11] Toyota's published tank to wheels number is 37%, however no test conditions or assumptions are offered. Obtaining 37% tank to wheels efficiency would be a very impressive accomplishment [12]. NREL ADVISOR models are using about 33% peak gas engine efficiency [54].



Overall efficiency

	Fuel efficiency (well-to-tank) (%)	Vehicle efficiency (tank-to-wheel) (%)	Overall efficiency (%) (well-to-wheel)
Recent gasoline car	88	16	14%
Prius (before improvement)	88	28	25%
Prius (after improvement)		32	28%
Prius with THS II		37	32%
Toyota FCHV	58 Natural gas+H2	50	29%
FCHV (target)	70	60	42%

Figure 7

Testing also demonstrates that the Prius tank to wheels efficiency characteristic is very flat (efficiency plateau), as a slow versus medium and maximum hill climb speed resulted it the same amount of gas to climb 280 feet over a 0.4 mile distance. This performance is likely a result of the variable valve timing used in the Prius engine, in principal an Atkins Cycle. *This data suggests it is equally efficient for slow versus fast acceleration, i.e. aggressive driving style (appendix B).*

c) **Hybrid gas engine size and duty cycle**; In addition to the above benefits, the hybrid approach of the gas engine and electric motor operating in parallel allows the gas engine to be additionally smaller and preserve the same acceleration (power to weight ratio). A smaller gas engine;

   i) Allows the design to operate closer to the peak efficiency per b), particularly at low speeds.
   ii) Has a smaller thermal mass.

Thermal mass is significant in that a short trip requires the engine to be heated to an efficient and non-polluting temperature, and although Toyota has gone to the extreme of a "thermos bottle" to store engine coolant heat, in the long term the energy required to heat the engine mass is lost.

The Prius, with a light 1.5 liter aluminum gas engine with electric powered accessories detached operating in a temperate climate obtains 22 mpg city mileage for the first mile in city driving, and then rises to about 50 mpg. This observation is significant, as 60% of city driving are trips less than 3 miles, per figure 2. A "more electric" car could improve efficiency in this driving venue as a 3 mile trip could be completed in electric mode.

Hybrid technology also allows the gas engine to "cycle", turning on and off, thereby allowing it to operate close to its peak efficiency. Note from figure 6 the on-off hybrid operating point versus the conventional operating point required for a constant speed. The engine turns on to drive the wheels and charge the battery, and then turns off. The Prius does this to some extent. For example, driving at a constant speed of 30 mph, the gas engine is cycling, with an overall mileage of over 100 mpg, and about 35 mpg when the gas engine is on.

Extending this concept to higher speeds suggests a design with a smaller gas engine and a larger battery and electric motor, where the engine only operates at its peak efficiency, however the battery becomes the limiting factor in weight and life. The Chevy Volt concept vehicle represents this approach [59].

Gas engine cycling allows non-congested highway mileage improvement up to 2 times for a car with high acceleration performance. The more underpowered the car the less the freeway efficiency benefit, because a conventional underpowered car is already operating at an efficient engine power point on the highway. Most people would likely prefer a more powerful car for safety reasons if there was no efficiency penalty (also enabling for an efficient "Ferrari" type sports car, but not a significant market segment).

d) **Battery characteristics;** Figure 8 represents battery characteristics published by manufactures [13]. Note the exponentially falling life the more completely the battery is discharged (100% represents complete discharge). Note also that although the Li-ion batteries have over 2 times higher energy density (KW-HR per pound), they have an inherently lower life. To date Toyota has used the NiMH batteries, and Li-ion batteries are the "new hope" for all the hybrid-plug-in-electric advocates. Li-ion batteries have been in development for at least 30 years, and a better battery is still needed.

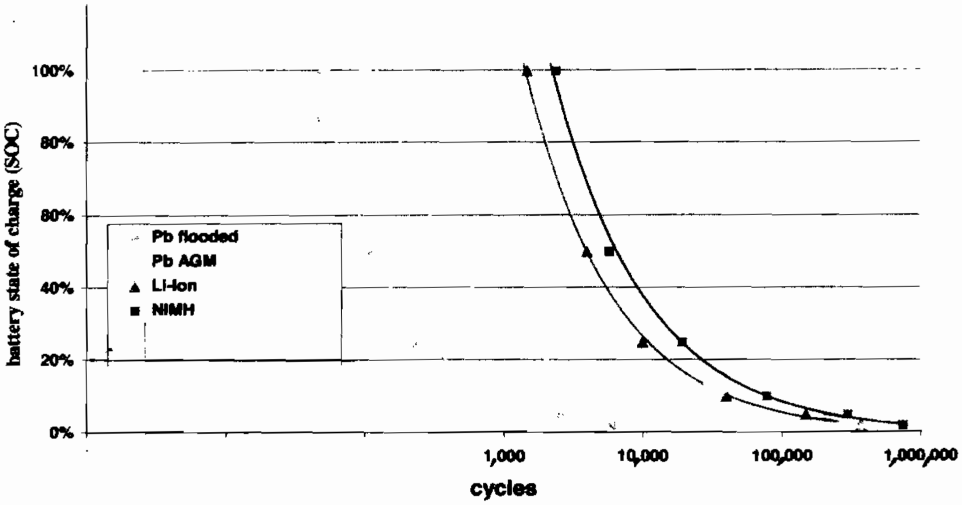


Figure 8

There are also safety issues with Li-ion batteries, as Lithium explodes when exposed to water. Although we only have had a small number of notebook computer battery incidents, the potential of a car battery fire and containment, particularly in a collision, needs further study. Tesla Motors has some concepts in this area [38].

Battery cost, which is directly related to the energy cost of production, remains high, in spite of a relatively high production rate (331,000 Toyota hybrids in the US alone, using over 13 million battery cells). The Prius NiMH replacement battery cost presently is $3000, in contrast to EPRI forecasts it should be less than $700 [8,13].

e) **Regeneration;** Improved regeneration is one of two large opportunities to improve the efficiency of a hybrid car.

If regeneration were 100% efficient the measured 100-mpg mileage at 30 mph constant speed would also be the measured city mileage. Testing shows the Prius regeneration efficiency is about 50% for light braking and about 30% for moderate braking (appendix C).

Regeneration efficiency could be higher however improvements would result in increased vehicle cost and weight. The Prius only uses 2 wheel regeneration, and 4 wheel friction braking. The more aggressively you brake, the more the friction brakes are used. In addition the electrical losses (I squared R) are higher with heavier braking. Both effects result in less regeneration.

Using 4-wheel electric drive with larger electric motor(s) and battery it is possible to approach the electric efficiency limit for regeneration of about 80%. There are several companies exploring the 4 wheel electric motor drive concept, including the present Toyota offering in the 4WD Highlander hybrid SUV (11) and the Hypercar Revolution [60].

The Prius control strategy for the battery seeks about a 60% state of charge (SOC) (51). With this strategy the battery capacity is adequate for recovering regeneration for most driving venues, however in a descent of more than about 100 feet per minute, particularly with a full load, the battery rapidly becomes fully charged and beyond that point the energy is lost. Between regeneration, acceleration, and environmental control, discussed in g), about 70% of the Prius battery capacity is used, in contrast to EPRI and other estimates only 23% is used [8,48,51].

f) **Vehicle weight;** To the first approximation, auto efficiency is linearly related to weight; if the vehicle is twice as heavy, the overall mileage will be one-half.

Excess design weight has an exponential effect on efficiency. For example, for a 3000 lb car with an 800 lb useful load, if you 'waste" another 300 lbs in the design, it is necessary to increase the empty vehicle weight by almost an additional 300 lbs to meet all the above mentioned vehicle requirements (larger engine, wheels, brakes, structure etc), to preserve the original 800 lbs useful load, performance and safety. Consequently the car weights 3600 lbs empty, and has an intrinsic 20% reduction in efficiency (mileage).

Aircraft are more weight sensitive than other transportation vehicles, but the design principals are the same. The maximum weight limitations for both cars and airplanes are based on safety and reliability, and they should not be exceeded.

The rule for the best aircraft design is it can carry the empty weight in "useful load" (100%), in spite of the added aircraft weight burden of wing structure. Jetliners achieve this goal [14]. On a smaller scale a Beech 35 aircraft fabricated out of well-engineered riveted aluminum has 66% useful, and is capable of carrying 4 people at 160 mph, achieving 20 mpg with an 800 mile range [15]. (drag is proportional to the square of velocity, so normalizing to 60 mph this is equivalent to 140 mpg)

Toyota has made every affordable effort to make the Prius light, resulting in an empty weight is 2995 lbs and a useful load of 800 lbs (27%), minimal for a five passenger five door car. There are five fundamental reasons for the lower percent useful load;

i) Cost constraints; not a significant issue in aircraft design.
ii) Crash safety; weight and structure provide safety, and not a requirement in aircraft design.

iii) Small collision tolerance and repairability (bumpers); not a requirement in aircraft design.
iv) Features; Older (60's) economy cars, i.e. VW Bug's, Fiat's were lighter, but they did not have conveniences (A/C, PS etc.), safety, or pollution control.
v) Hybrid weight penalty.

From figure 3, line 5, the hybrid weight penalty for Toyota's technology is about 370 lbs, likely not including the approximate additional 300 lbs overall design penalty (Toyota uses common parts for hybrid and non-hybrid cars). Also shown in figure 3 line 15, the Camry is only 22% electric (electric versus gas power), and the more electric the design, the higher the hybrid weight penalty.

EPRI estimates that hybrids should be lighter [8] appear speculative.

Some researchers have suggested that "composites" can solve the weight challenge [16,60]. For decades composites have failed to deliver on the expectation in aerospace. Aircraft have used composites where appropriate, but no small or large whole-composite passenger aircraft has been developed that was lighter than its equivalent riveted aluminum structure, after meeting fatigue requirements [14,15,61].

Automobiles present an additional challenge to provide crash safety, required from all impact angles. The necessary material property is "toughness", a real Engineering materials term, representing the ability to crush and absorb the energy of impact. Historically composites have had poor toughness.

An automotive comparison is the Hypercar Revolution, where it is claimed these composite problems have been solved [60]. The comparison provided would have been more relevant to a Prius, and ideally with more performance specifications. The Prius uses heavier hybrid technology, however overall Toyota's attention to weight control is extensive.

The Prius structure uses light weight polymers and aluminum extensively, and the remaining steel structure components are the passenger doors and "Uni-body" chassis. These steel components are estimated to weight less than 400 pounds, and if a 50% weight reduction could be achieved using composites without compromising crash safety, this reduction would only amount to 200 pounds in a 3000 pound car.

A more affordable and repairable light-weight alternative would be an aluminum Uni-body design as Porsche has employed in some of their cars, although a more expensive solution than steel.

Refer appendix D for structural composites case studies.

g) **Climate effects;** The effect of climate, including hot days, cold days, and rainy days, is the second large opportunity to improve hybrid and plug-in efficiency, where a tolerable environment needs to be provided inside the vehicle.

In a temperate climate 50 mpg city mileage is achieved in the Prius, however if defrost, or A/C is used mileage drops to 25 mpg, which agrees reasonably with NREL ADVISOR analysis [51]. In addition if heat is used mileage drops to 30 mpg.

The Prius in these climate conditions is spending nearly as much energy in "environmental control" as in propelling the car, in spite of the Prius heat and cool capacity being comparatively weak. The energy requirement in the Mid-West in Winter, or Arizona in Summer is considerably higher. There are design solutions for climate efficiency, but would increase vehicle cost.

The Prius is less than optimal in the heating mode, as the gas engine runs to provide engine heat transferred to the interior via engine coolant, and results in the battery being charged to full capacity in city driving, as the engine has nothing else to do with the surplus energy. A supplemental electric heater would enhance Prius heating efficiency.

In a cold climate the Hybrid vehicle is loosing some advantage over a conventional car because the gas engine operates to heat the car enviroment much more frequently, however there is a simple solution.

In theory, most of the waste heat of the gas engine could be recovered to heat the car's environment. Presently the Prius engine cooling waste is used, but waste exhaust heat could also be used, as Volkswagon and aircraft have done decades ago. This paradigm is similar to electric power "co-generation" plants where the waste energy, between 40 and 70 percent in large-scale electric powerplants, is used to heat and cool (by an absorbsion cycle) living and business space venues. Less than 5% of electric power today is co-generation.

An all-electric car takes no advantage of this 40 to 70% loss in electric power production.

The energy demands for cooling the car interior in a hot climate are high, and represent another advantage of the hybrid car. Prius THS II air conditioning is electric powered, allowing it to operate at the peak efficiency vapor cycle point. While stopped in traffic the gas engine is not running continuously. The battery discharges to about a 30% SOC, and subsequently the gas engine operates to recharge the battery. The result is much higher efficiency.

This typical driving venue is apparently not reflected in the ADVISOR model used in the EPRI estimate that control algorithms only use 23% of the battery capacity [8], nor the NREL report on the older Prius where the A/C was driven directly off the gas engine [51].

In addition to climate control inside the car, the outside air temperature has a significant effect on efficiency. Prius testing in temperatures ranging from 40 F to 80 F with no heat or cooling operating inside the car, city mileage drops 10% at the lower temperature, due to the engine thermal mass issues discussed in c), also in agreement with NREL advisor analysis [51]. This loss is one benefit of a "more electric" design, discussed in section V.

Lastly a hybrid, plug-in or EV car has the added temperature control burden for the battery. The battery ideal temperature range is 20 to 40 C, and during high power loads the I squared R losses generate significant heat. This cooling requirement is larger for cars with a larger percentage of electric versus gas power.

A comparative benchmark for environmental control efficiency is a jetliner that operates in an outside air temperature of –40 C, and cabin air does not require heating. Refer to appendix E for detail.

h) **Hybrid complexity and cost**; An examination of Prius design detail reveals a high degree of complexity, hidden behind a seemingly simple car.

Functions that previously were driven by the gas engine are now electric.

The system control to achieve optimal efficiency and performance is complex, including the gas engine on-off control that optimizes engine temperature, efficiency and emissions, without compromising engine life or reliability. The Prius gas engine cycles "on" for nearly every acceleration, in contrast to the EPRI analysis limiting cycling to 20 cycles per trip [8]. The Prius gas engine appears to cycle on at any point the power requirement can be met with the gas engine operating on its efficiency plateau, in addition to operating to manage engine temperature and battery state of charge.

Braking and regeneration optimization represent another increase in complexity, particularly because they are "coupled".

Approximately 18 microprocessor controlled sub-systems are used to provide the Prius system functionality.

In a poorly engineered design with subsystem "coupling", reliability drops exponentially with increased complexity, and reliability reverts back to energy. A high maintenance car, even if it has high mileage performance, the "energy costs" of it not being available, the lives of the people that have to repair it, and the replacement parts, all add up to a poor energy efficiency car.

A benchmark in complexity-reliability theory is the jetliner, where if every subsystem were required to be functional before departure, few planes would fly. There is a FAA requirement documented for each subsystem, with a flight and calendar time allowed for repair before the aircraft is required to be removed from service [56]. Equally representative, the Boeing 777 after having been is service for over 10 years, continues to experience emergency releases of new flight control software to prevent serious in-flight upsets [58].

In spite of hybrid complexity, the Prius reliability has been excellent [35]. However, Yellow Cab, representing an extreme robustness test, has experienced a higher maintenance rate in the Ford Escape using Toyota hybrid technology due to "electrical problems" as compared to the commonly used Crown Victoria [49].

The EPRI estimate of $2500 additional cost for a hybrid [8], and the TIAX less cost analysis [20] appear speculative, as they do not account for the complexity of the Prius, nor the inherent higher maintenance cost, after accounting for fewer hybrid brake replacements.

IV) Performance assessment and EPA mileage estimates

A more accurate EPA mileage estimate is essential, both for automobile purchasers, and more importantly for assessing auto technology.

The matrix of alternatives should include:

a) City driving
b) Congested city driving
c) Suburban/country driving
d) Freeway driving
e) Congested freeway driving
f) California temperate climate
g) Mid-west winter climate
h) Arizona summer climate
i) Aggressive driving style
j) Useful load (number of people or weight)

Accurate city, congested highway and severe climate mileage estimates are major shortcomings in EPA ratings.

EPA highway mileage ratings are deceptive as some drivers have no congestion, and others have serious congestion (common in California), and ratings do not allow a buyer to know what to expect in their venue.

Figure 9 presents one more complete mileage concept;

	TEMPERATE	BELOW 32 F	ABOVE 90 F
CITY			
CONGESTED CITY			
HIGHWAY, 60 MPH			
HIGHWAY, 70 MPH			
CONGESTED HIGHWAY			
USEFUL LOAD FACTOR			

Figure 9

"Useful load factor" is a comparison of the useful load of the vehicle as compared to average useful load of 1000 pounds for automobiles, including SUV's. The present situation of stake-holders comparing mileage of cars without accounting for over 2 times difference in useful load (i.e. a two passenger versus four passenger car) makes no scientific or practical sense.

Likely objections to this new mileage model are unwarranted, including;

a) Too expensive; In view of the multi-trillion dollar auto industry, the *percentage* cost to the *manufactures* in providing this data is small.
b) Legitimacy; Nobody would trust the car manufactures to provide this data. All aircraft manufacturers provide this data directly, and are held accountable for its accuracy, and there is no reason the car companies cannot do the same.
c) Too complicated to understand; The complexity of a purchaser interpreting the information is less complicated than a bus schedule, and could be explained by the sales person
d) The mileage goals cannot be achieved; Toyota has already largely done it.

Applying this model to estimate hybrid and conventional car mileage shown in figure 10 (refer to appendix F);

HYBRID-MILD MIDSIZE

VENUE	WEIGHTING	60%	20%	20%
		TEMPERATE	BELOW 32 F	ABOVE 90F
CITY	15%	50	45	30
CITY, 3 MILES	26%	40	25	25
CONGESTED CITY	15%	50	40	25
HIGHWAY, 60 MPH	15%	60	55	50
HIGHWAY, 70 MPH	15%	55	50	50
CONGESTED HIGHWAY	14%	50	40	25

AVERAGE MILEAGE 44.56

NON-HYBRID MIDSIZE

VENUE	WEIGHTING	60%	20%	20%
		TEMPERATE	BELOW 32 F	ABOVE 90F
CITY	15%	12	12	9
CITY, 3 MILES	26%	10	8	8
CONGESTED CITY	15%	6	6	5
HIGHWAY, 60 MPH	15%	50	50	40
HIGHWAY, 70 MPH	15%	45	45	35
CONGESTED HIGHWAY	14%	6	6	5

AVERAGE MILEAGE 19.434

PERCENT HYBRID REDUCED OIL USAGE 57%

Figure 10

This estimate is for a mid-size car, but comparatively, it applies to all classes, sub-compact through SUV vehicles.

This estimate also includes the simple cold climate enhancements described in section III-g).

The above analysis also suggests that Hybrid technology applies to all automobile types, compact, luxury, sport, truck, SUV's and for the noted variety of driving venues. The Prius is a great San Francisco car but in Minnesota or Arizona, or in mountainous territories, it might not be the best choice. *The proposed EPA mileage standards would force the manufacturers to effectively address all of these market segments.*

V) The Hybrid "plug-in" and EV option

There are many hybrid plug-in and EV advocates [3,8,20,26,28,31,38,43,46,48,54,55], but unfortunately, there are many issues that are not adequately addressed, particularly for California.

a) **Energy source**; In California, much of the present, and all of the new substantial electric power in the near future will be natural gas fired, and there are small natural gas reserves in the US [2,59]. The US and California are increasing imports in the form of liquefied natural gas (LNG) [17] from sources like Russia that have large reserves, and competing for them with for example, "China Rising", where they are planning many new LGN terminals [2,59].

Russia is not a stable or easy place to do business. Russia believes they can do whatever they want in negotiating for their energy natural gas wealth, as they have recently done, double the price or shut it off [18,19]. In addition Russia terminated joint ventures with non-Russian energy companies after these companies invested of $ billions [19].

The DOE has a natural gas price forecast through 2030 in spite of this political uncertainty [2,59], and reliance on this forecast carries significant risks.

In addition, CEC workshops have shown that the renewables electric portfolio is not developing as rapidly as desired, as required by legislative mandate [21,41], and any improvement in development rate is speculative.

Many of the plug-in and EV advocates are suggesting solar power to charge vehicles. Unfortunately there are significant problems with solar electric PV, including 10 times higher capital cost, only a few hours out of the day of generation, limited life, availability and predictability [24,40]. Improvements in next generation PV's are speculative. The heavy subsidies for PV's do not equate to energy efficiency.

California is clearly at risk for natural gas supply depletion and imports political interruption, and consequently burdening electric power with significant numbers of plug-in electric cars is at best questionable. The rolling blackouts experienced a few years ago had a severe impact on Businesses, which we are trying to attract to California.

However if you are in Texas, where they are planning many new coal fired electric plants, or in France where they are predominately Nuclear, an electric car might be a good solution.

b) **Mileage**; Many claims about plug-in hybrid car efficiency of 100 plus mpg [3,28,48], are not accounting for the electric power nor its production efficiency. An accurate comparative analysis for California should be a natural gas fueled hybrid car versus a plug-in hybrid car, accounting for natural gas fired power electric production efficiency discussed later in this paper. This issue has been raised in NREL reports, where it is suggested both the gas and electric power usage be documented for a plug-in [54].

No reports regarding plug-in efficiency have presented any data about grid power production efficiency [3,8,20,26,28,48,51,52,53,54,55].

c) **Battery issues**; The battery life and weight penalty issues are larger for a plug-in or EV. For example, for a 20 mile "real range" plug-in with reasonable battery life for the Prius, the battery could be 200 lbs heavier. As noted in III-f), added weight has an exponential effect on efficiency. A plug-in conversion of a Prius significantly reduces the useful load of 800 pounds, marginal before the conversion for a 5 door 5 passenger car.

d) **Safety**; The Prius has the Ni-MH battery located under the back seat, where in the worst collision it will remain intact, and in-field crash incidences have confirmed the safety margin.

The Plug-in advocates are using an Li-ion battery with the advantages and disadvantages noted above. Even with a Li-ion battery, the size of the battery is much larger, and typically located in the rear of the car, including Prius conversions [48]. The location carries the risk of severe damage in a rear-end collision. This problem is identical to the gas tank location problem 30 years ago where accident death was by fire, not by impact. The Prius gas tank is located in the middle of the car for this reason.

e) **Practicality;** Plug-in's appear to be appropriate for upper-class suburban people. In this venue you use your car much more for short trips, and there is a place to plug them in. The majority of cars in large cities are not in a garage where you can plug them in, and the percentage is less in lower income venues. This issue is in contrast to the EPRI plug-in survey [8] that may not reflect final customer acceptance [32]. For example, once a customer finally got a plugin, and had to deal with the hassle of plugging it in every night in stead of "filling up" once a month, their attitudes might change.

f) **The all-electric option;** All the above issues are less favorable for an EV, and little has been published in the CEC or EPRI forums about real efficiency, specifically how much natural gas is used to provide the electricity, and how much electricity is used per "real driving" mile, of all-electric cars that have been in service, per zero emission legislation in California.

Zero emission legislation is a deception, as electric power production emissions are ignored.

In addition, no analysis has been presented regarding how many electric cars could be plugged in without major infrastructure changes.

Determining the cost and energy efficiency of electric power production in California is problematic.

Electric power production and transmission efficiency data held by the CEC, PUC, PG&E and ISO, is not available to the public, a fact confirmed in direct conversations [25] and in CEC workshop discussions [23]. Consequently there is little understanding or incentive how to optimize electric power production efficiency, nor is data available to justify the true energy efficiency of a plug-in hybrid or EV car. The CEC is aware this "transparency" problem must be solved [23].

The CEC on-going effort in electric power Scenario Analysis to include future unpredictable renewables entering the electric power grid further complicates any conclusion [23,34].

An additional electric power issue for plug-in's and EV's is the electric power grid load variation during the typical day. Many of the plug-in advocates suggest electric power is almost free at night when you would charge your car, but this claim is un-justified. There are many other *necessary* first strike solutions for electric grid load leveling and efficiency, including time dependent rate meters for everyone, solar air conditioning, thermal storage, peaker plants, co-generation, and distributed generation [4,21,27,42,44,50,51].

In spite of this uncertainty, an estimate of plug-in efficiency is; [26,27]

	Best guess	Range
Nat Gas Powerplant electric conversion efficiency	45%	(35-58)
Electric transmission and distribution efficiency	90%	(80-95)
Charger efficiency	95%	(90-97)
Battery charge acceptance efficiency	95%	(90-97)
Battery discharge efficiency	93%	(85-95)
Electric motor efficiency	95%	(85-95)
Larger battery weight penalty (20 mi real range)	90%	(80-90)
Net plug-in efficiency	**29%**	**(13 –42%)**
Prius gas "tank to wheels" efficiency	**28%**	**(28-37%)**

This analysis suggest that plug-in's and EV's are likely no more efficient, not including the potential reduction in battery life.

A plug-in would likely require a battery about 4 times larger, so the Prius numbers of $0.05 per mile for gas, and $0.02 per mile for the battery reserve, would increase for a plug-in to an approximately $0.05 for gas and electric energy, and $0.08 per mile for the battery reserve. (gas and electric price assumes a similar vehicle efficiency noted above, and equivalent pricing for natural gas, i.e. no subsidies, or volume discounts, and not accounting for any potential battery cost reduction).

A purchaser considering a plug-in would be advised to buy from a manufacturer that will guarantee warranty, safety and performance, which the plug-in conversion companies have not provided [48].

In spite of this uncertainty, PG&E sent out a flyer to promote Plug-in's in our monthly bills [31].

Another example of lack of energy accounting is Austin Power, where plug-in's are promoted without presenting electric power production efficiency data to justify the policy [55].

VI) Conclusions

Assuming the above analysis is representative, if our politicians pursued revising EPA mileage testing, and with legislation forced domestic car manufacturers to "catch up to Toyota" in Hybrid technology we could have a large number of car types available in less than 5 years (accomplished in 18 months in silicon valley), and by rebate accelerate replacing the existing auto fleet, typically 13 years. *We could reduce light vehicle transportation oil consumption by 57%, eliminating oil imports, and reducing overall US CO2 emissions by 850 million tons per year [30] with no infrastructure changes. And the percentage reduction in California is even higher because of our mild climate*

In a correspondence from Senator Diane Feinstein after her talk at the Commonwealth Club in San Francisco about Global Warming, the Senator outlined the 10 in 10 legislation she introduced (10 mpg improvement in 10 years) (30). A suggestion was offered that it can and should be 20 in 5, based on demonstrated Hybrid technology, and revised and accurate EPA mileage estimates (24 mpg estimated in the above analysis). When this opportunity was suggested, the senator's office replied; "it's not going to happen". *This response clearly indicates the magnitude of the challenge in enacting significant new legislation.*

Toyota, after likely spending billions of dollars, is rapidly proliferating this technology across their product offering, while our domestic manufacturers are coming up with concepts that to date are inferior to Toyota, unfortunately a conclusion that cannot be made from the simplistic and inaccurate EPA ratings used today.

Credit is due to our domestic auto manufacturers, as they have in the last three decades provided us with cars that are much more efficient, reliable, and safe, and also led the way, with "encouragement" from the Environmentalists, for emissions reductions by 1000-fold (not including the CO2 issue).

However domestic car manufacturers are way behind Toyota on Hybrid technology. Domestic manufacturers need to be open to extending a partnership with Toyota, as it is uncertain a better hybrid approach will be developed.

There are opportunities for improved Hybrid cars however an improved car would be more expensive, and would be facing a diminishing return due to increased vehicle weight.

There is a large opportunity to address the high energy demand in extreme hot and cold climates, with simple solutions, as this energy demand frequently exceeds the car's propulsion energy requirement in existing hybrids.

An improved battery would be enabling for hybrids and plug-in's. There may be a new battery breakthrough, but in view of the 30 year development period to date for Li-ion batteries, this goal is not likely to be achieved in the near term.

Affordability is a critical factor, because unless a large part of the existing vehicle fleet can be replaced with hybrids, there would be little overall energy savings. The Hybrid must be the "Peoples Car".

However, there is no justification for a customer survey to assess acceptance to pay for a more efficient vehicle [8], no more than for a customer to be allowed to buy a car with out existing pollution controls for a lower price. Higher efficiency standards must be enforced with aggressive legislation, with reasonable consideration of economic impact.

Presently in California large numbers of plug-in's and EV's make little sense because of our electric power challenges, including the slow development of renewables, high dependence on natural gas, no coal or nuclear allowed, and risk of a drought threatening hydo-electric power.

Natural gas supply is a major risk for California, and in spite, *natural gas is considered by the CEC as an alternative vehicle fuel [20].*

Lastly, in spite of the political phenomenon about being "Green" and "Global warming", a large number of American's likely have no intention of giving up their wasteful life-style without aggressive legislation. Testing the Prius in San Francisco in the last year resulted in an average of three "hate gestures" a week from drivers behind (i.e. tailgating, honking, passing illegally), and was not experienced in the non-hybrid vehicle. The one-percent hybrid population on the road today are at best the first adopters, and do not represent overall public opinion, in contrast to claims "everybody loves them".

Bob Giebeler has been a California resident since birth. He Graduated from UC Davis in Engineering Sciences, and has worked in medical and scientific instrumentation for 30 years, where with efficient Teams approximately $4 Billion of product was delivered to customers. He is also an innovator holding 28 patents, and a member of the Arnold Beckman Inventors Hall of Fame. He is also a registered Mechanical Engineer, a member of the IEEE Executive Committee in San Francisco, and completing a Masters in Business Administration. He has been involve in aviation for over 40 years, including certifications as Airline Transport Pilot, Flight instructor, and Aircraft and Powerplant Service Engineer. His research interests include Energy Technology and Policy, the focus of his studies at UC Davis, and Cardiology and Metabolimics.

Address for correspondence: bgif251@yahoo.com

References [x]:

1 Lawrence Livermore Laboratory; "Energy: Uses, Sources, Issues" UCRL-51221, May 30, 1972
2 U.S. Department of Energy; "Natural Gas Imports and Exports", Q4, 2005
3 U.C. Berkeley; "Towards Energy Independence in 2025" March 2006
4 U.C. Berkeley; Policymaters, Spring 2006; "An Energy Policy for the 21st Century"
5 U.C Berkeley; "An Integrated Hydrogen Vision for California" July 2004
6 SCIENCE; "Ethanol Can Contribute to Energy and Environmental Goals", January 2006
7 ASPO; "Peaking of world Oil Production" May 2005
8 EPRI; "Comparing the Benefits and impacts of Hybrid Electric Vehicle Options", July 2001
9 EPA website; Fuel Economy Guide, www.fueleconomyguide.gov
10 ADVISOR website; www.nrel.gov
11 Toyota website; www.toyota.co.jp/en/tech/environment
12 U.C. Davis; Thermophysics (Giedt), Otto cycle efficiency, 1970
13 EPRI workshop; VARTA battery presentation, November 2003
14 Airbus aircraft corporation; www.airbus.com/en/aircraftfamilies
15 Beech Aircraft corporation; www.Rathyeon.com
16 Rocky Mountain Institute; Common Wealth Club presentation; "The Green Future is Here Today", Amory Lovins
17 PG&E Press release; PG&E corp, "Williams, and Fort Chicago agree on partnership for new gas transmission pipeline", April 2006
18 The Economist; "What if Russian gas runs low?", November 2006

19 IEEE Spectrum; "Showdown on the Energy Frontier", December 2006

20 CEC workshop; TIAX October 16 2006 , "Alternative Transportation Fuels Plan" Lorraine White (CEC) and Larry Waterman (TIAX) www.tiaxllc.com

21 CEC workshop; December 7, 2006, "Integrated energy Policy Report Update"

22 CEC workshop; "Land Use and Energy in California", September 22, 2006

23 CEC workshop; "Scenario-Based Assessment of Resource Plans Predicated of Large Penetration of Preferred Resources" January 29, 2007

24 CEC workshop; "Photovoltaics Research Plan", November 13, 2006

25 California ISO; Independent System Operators www.caiso.com. Contact; Sue Happ, 919.351.4400

26 CEC workshop-ILEA; "Fuel chain Energy losses", 2006 www.ilea.org

27 Mechanical Engineering; "Power and Energy; A year of turbulence", June 2004

28 CalCars; www.calcars.org. Contact, Ron Gremban, rgremban@calcars.org

29 The white house; "Hydrogen Fuel, A clean and Secure energy future", January 2003

30 Senator Feinstein; correspondence dated October 11, 2006. Contact Rachel Miller 202.224.3841.

31 PG&E promoted plug-ins, Common Wealth Club; "Plug-in Hybrid Vehicles", June 29, 2006; contact Gail Slocum, 415.973.6583

32 Harvard Business Review; "Marketing is Everything", No. 91108, January 1991

33 U.S. Department of Transportation; "Nationwide Personal Transportation Survey", FHWA-PL-98-002

34 CEC Workshop; "Intermittency Analysis Project" , February 13, 2007

35 Prius User and Technician survey

36 Scientific American; "Is Ethanol for the long Haul?", January 2007

37 IEEE Spectrum; "Corn-O-Copia; Energy looser", January 2007

38 Tesla Motors inc; "The Tesla Roadster Battery System"

39 UC Berkeley Goldman School of Public Policy, Policy Matters; "Peak Oil and the Myth of the Hydrogen Economy" Spring 2005.

40 CEC workshop; "New Solar Homes Partinership", November 5, 2006

41 CEC Workshop; "Roadmap for Development of Biomass in California", November 16, 2006

42 CEC workshop; "Thermal Energy Storage Systems", January 9, 2007

43 CEC, ARB joint agency report; "Reducing California's Petroleum Dependence", August 2003, P600-03-005F

44 Joint CEC-PUC agency meeting; "Energy Action Plan", September 18, 2006

45 Bill Clinton; "If Brazil can do it we can too…" (in promoting California Prop 87)

46 The White House; the President's "Twenty in Ten Goal", February 23, 2007

47 Aviation Week; "Greening of our Blue Skys" February 2007

48 EnergyCS; Plug-in Prius offering, www.energycs.com

49 Yellow Cab Driver survey, San Francisco, 200 rides

50 Broad Air Conditioning (china) www.broad.com

51 NREL; "Battery Usage and Thermal Performance of the Toyota Prius and Honda Insight for Various chassis Dynamometer Test procedures", 2002

52 NREL; "Energy Storage Systems Considerations for Grid-Charged Hybrid Electric Vehicles", 2005

53 NREL; "Test Results and Modeling of the Honda Insight Using ADVISOR", 2001
54 NREL; "Plug-in Hybrid Vehicle Analysis" milestone report, NREL/MP-540-40609, November 2006
55 Austin Energy; "Transportation Convergence", 2005
56 Federal Aviation Administration Part 121 operations regulations
57 General Motors Corporation
58 Aviation Week; Boeing 777 in-flight upset, est. March 2005
59 DOE; "International energy outlook", 2006
60 Hypercar, Inc.; "Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure"
61 Boeing Commercial Aircraft Company

Appendices: (available upon request)

A) Vehicle Comparison Chart Details
B) Prius Tank to Wheels Efficiency Calculation
C) Prius Regeneration Efficiency Calculation
D) Composite Structures Case Studies
E) Climate Effects and Environmental Control
F) Mileage Model Estimate

Affiliations; This work was funded by Bob Giebeler, a private tax paying citizen of the United States and California State

Abbreviations:

DOE;	United States Department of Energy
NPTS;	National Personal Transportation Survey (DOE)
PIER;	Public Interest Energy Research (CEC)
CEC;	California Energy Commission
ARB;	Air Resources Board (California)
PUC;	Public Utilities Commission (California)
NREL;	Nation Renewables Energy Laboratory (DOE)
ADVISOR;	Exploratory tool for optimizing vehicle efficiency
EPA;	Environmental Protection Agency
mpg;	Vehicle miles per gallon of fuel
mph;	Vehicle miles per hour speed
EPRI;	Electric Power Research Institute
SUV;	Sports Utility Vehicle
RPM;	Engine revolutions per minute
CVT;	Continuously variable transmission
SOC;	Battery state of charge

KW-HR;	Kilowatt-hours of energy
Li-ion;	Lithium ion battery
4WD;	Vehicle four wheel drive
VW;	Volkswagen, a car company
A/C;	Air conditioning, both cooling and de-humidification
PS;	Power steering
FAA;	Federal Aviation Administration
CAFÉ;	Vehicle mileage standards (DOT)
EV;	Electric vehicle
LNG;	Liquefied natural gas
PV;	Photo-voltaic solar electric panels
Ni-MH;	Nickel-metal-hydride battery
PG&E;	Pacific Gas and Electric
CO2;	Carbon di-oxide, a green-house gas
LLL;	Lawrence Livermore Laboratory
ASPO;	American Society for Peak Oil
IEEE;	Institute of Electrical and Electronic Engineers
ILEA;	Institute for lifecycle Environmental Assessment
TIAX;	TIAX, LLC,; Contact Larry Waterland
F;	Fahrenheit, a temperature
C;	Centigrade, a temperature
EV I;	General Motors electric car