Talk Notes from the slides, since I can't print them without the slides.

1. Good evening, I'm David Duehren. I was co-founder and CTO of a company called Brooktrout Technology. It was sold in the fall of 2005. Since then I've been pursuing my interests in clean energy. . I'm pleased to speak to you tonight.
2. If money was no object, and you wanted to buy the fastest accelerating car, what would you buy?
3. The Tesla Motors Roadster has the best acceleration. It costs about $100 grand, and is a bit of a dream to drive according to some reviews. But the added benefit of an electric car, is that it's also very efficient, dispelling the notion that "real drivers don't drive fuel efficient cars." Fuel efficient cars are the subject of this talk.
4. These are the topics I'm going to cover during the next 25 minutes. I'd appreciate if you can hold questions to the end. First we'll look at the forces driving change in the automobile industry.
5. Our addiction to oil is most severe in the transportation sector. About 97% of all motorized vehicles use an oil derived source of fuel. Other sectors of the economy have reduced their dependence on oil over the last 30 years. It's now time for transportation to move away from it as well. Perhaps the most worrisome point is the last one. There will be about 3 times as many cars on the road in 2050 as there are today.
6. Supporting that many cars, is projected to increase oil consumption to about two and half times our current consumption by 2050. Major consumers will be China and India, who are projected to be consuming in 2030, more oil than the world does today.
7. But there's a lot of doubt that the level of consumption can be met. Historically the growth in global production of oil has been about half of what it will need to be. And there's the question of where the oil will come from, whether the projections about "peak oil" are valid.
8. Given the extreme demands on the oil supply, it's clear that oil is not going to get cheaper. Just consider what has happened to the price of oil in the last week. And the risk is that it could go much higher. A terrorist attack or a natural disaster could cause the price of oil to spike to over $150/barrel, ignite inflation, and perhaps trigger a recession. Clearly our addiction to oil puts the whole economy at risk.
   The 1974 oil embargo caused the price of gas to quadruple. The stock market tanked. Economic malaise took its toll in the 2nd half of the '70s. Today, a terrorist strike could put the price of gas over $5/gal, oil in the $120 to $150 range. Inflation would pick up, and we might face a recession.
9. From a security viewpoint, the US is heavily dependent on off-shore oil. We currently import about 60% of our oil. This dependence on foreign sources of oil means continuing military expense to protect it, particularly from terrorist attack. So our addiction to oil is also military risk.
   Before the Iraq war, the US was spending over $50B in the Middle East to protect our access to Middle Eastern oil and keep shipping lanes open. Beyond that expense, just think about relying on Russia for oil.
10. Finally, oil powered transportation produces significant greenhouse gases, particularly carbon dioxide (CO2). And those emissions will grow as fuel consumption grows. The blue area represents cars and other light duty vehicles such as SUVs.
11. Another look at the same data shows that North America, primarily the US, is projected to remain the largest contributor to CO2.
12. One set of goals for fuel efficient automobiles focuses on reducing oil consumption and reducing carbon dioxide emissions. There are other goals for automobiles as well, particularly for other parts of the world where cost is a major concern.
13. Agenda Slide
14. Change, however, isn't easy. The automobile industry is huge. There are high demands for established companies to introduce a new car. There are many regulations that a new

car must meet, as well as be current with all of the non-engine capabilities of a modern vehicle (anti-lock breaks, airbags, reliability, etc). Not only that, there's a whole culture built up around our love of the automobile. Whether it's the roar of an engine, to the status of size and speed. Furthermore, except for its emissions, gasoline is really a great fuel.

And, as you'll see, alternatives to existing combustion engines are not yet mature technologies. Why should a major company take the risk?

15. It's not just the automobile manufacturers that need to change in order to meet the goals outlined earlier. Certainly we need to change the vehicles, but we also need improvements in road systems, public transportation, and user behavior.
16. Agenda Slide. Now we'll take a look at what efficiency improvements might come from conventional gas and diesel engines.
17. Have we gone backwards in mpg efficiency? You'd think we could have done better than this in 100 years.
18. The main reason for such little progress maybe that the market place does not place a high value on fuel efficiency, preferring size and speed instead – as is evident from the two charts. Or is it the success of the marketing campaigns of the automobile manufacturers? SUVs and trucks are the big profit centers of the domestic manufacturers, and they don't need to meet the Corporate Average Fuel Economy, a.k.a. CAFÉ mileage standards. The major improvements in the 1975-85 period were driven by the CAFÉ standards of 1975. Updating those standards is stalemated at this time. We seem to want neither regulation (updated CAFÉ standards) nor economic incentives (gas taxes) to improve fuel efficiency and reduce carbon emissions. This is changing in places. California, for example, is working to regulate CO2 emissions, including those from automobiles.
19. The US is stalemated on fuel economy, despite the fact that it's behind all other developed countries. Note that China is not meting its targets, and the EU has achieved theirs mainly via high gas taxes which are very unpopular here. Perhaps high gas prices will tilt the consumer interest toward fuel efficiency.
20. Engine performance is expected to continue to improve at roughly its historical rate. Besides engine improvements, new materials such as carbon fiber may be introduced that reduce weight without sacrificing strength. Work at MIT estimates that by 2020 we'll get an improvement of about 20% in mpg and as much as a 50% reduction in CO2 from internal combustion engines
21. Traditional engines will continue to improve. It's just a question as to whether the improvements will be used to improve efficiency, or performance. Timeframes shown are projections when the technology is well established in the marketplace. Please note also, that these improvements add cost.

    HCCI – Homogenous Charge Compression Ignition.

    For example, electro-hydraulic variable valve timing and lift, plus direct injection, 6 speed automated manual transmission, electric power steering and a more efficient alternator, would cost less than $800 would provide about a 30% reduction in C02.
22. Higher Corporate Average Fuel Economy standards could ensure those improvements are used to improve the fuel efficiency and reduce GHG emissions. You can see that we could almost halve our consumption of oil if we raised CAFÉ targets to 44 mpg.

    The National Commission on Energy Policy believes there are 3 factors responsible for current stalemate over CAFÉ standards. 1) Uncertainty over future costs of fuel saving technologies; 2) more stringent standards will lead to smaller, lighter vehicles and increased traffic fatalities; and 3) higher fuel efficiency standards will put the U.S. auto industry and auto workers at a competitive disadvantage. Each of these can be rebutted. For example, there is no scientific data that larger, heavier cars are in fact, safer and lead to less injury and death. In addition, new materials such as carbon fiber can change the tradeoff. And the lack of new CAFÉ standards has not prevented the US automobile manufacturers from being less

competitive than some of the foreign competition. It seems to me that they're failure to innovate is a big part of the problem

23. Agenda Slide. Bio-fuels
24. Alternative fuels can be derived from both non-renewable fuels as well as renewable fuels. Within non-renewable fuels, several are viable at today's oil prices. Development of fuels from coal is likely to happen. Coal is cheap and abundant in the US. The key barrier to using coal is the capital to build the first pilot processing plants, and then to scale up.
    CNG may become significant in various parts of the world where natural gas is more abundant
    All non-renewable sources of fuel generate considerable amounts of GHG.
    The rest of this section is focused on renewable bio-fuels, especially ethanol and bio-diesel.
    Coal to gas or liquids removes the major contaminants such as sulfur and mercury. It would also be fairly easily to capture and sequester the CO2. However sequestration technology is still not developed. There's also some possibility of co-generation of electricity in some of the conversion processes.
    Batteries charged from coal power plant are a more efficient way to use that dirty fuel compared to coal-to-liquid conversion.
25. Henry Ford's first engines ran on ethanol. Rudolf Diesel's first engine ran on peanut oil. Only later were these engines converted to run on petroleum distillates. So now it's back to the future. (pause)
    Most of these benefits apply to all alternate fuels. Brazil is showing the world that it's possible to both reduce oil consumption and reduce GHG emissions.
26. However, Bio-fuels have a few problems. First is the concern that there isn't enough biomass to replace all of the oil. Currently most of the US bio-fuels are produced from food plants, and there isn't enough land to grow enough for both. Second, the production of bio-fuels can have very negative environmental effects. In Brazil, the destruction of the rain forest to plant more sugar cane, reduces the GHG benefit from the ethanol. Production of bio fuels also requires energy. If this comes from coal, the CO2 balance is negative.
27. So what would make an ideal bio-fuel? If we could design it, this is what we'd aim for. It would be a non-food crop that required little fertilizer and water, have high energy content, could yield several crops per year, etc.
28. The big hope for bio fuels in the US is the development of cellulosic sources – corn stalks, wood, and other crops like switchgrass. Algae too seems to have great promise, although growing algae at any scale has been elusive.
    1 acre of corn yields 300 gal of eithanol
    1 acre of soybean yields 60 gallons of biodiesel
    1 acre of algae could yield as much as 5000 gallons of biofuel
29. This chart summarizes the CO2 impact of various alternative fuels. Coal-to-liquid without carbon capture, then tar sands, coal-to-liquid with carbon capture, then ethanol from corn using coal heat, then gasoline, etc. The greener the better. On the far right is corn and switchgrass based ethanol using biomass to supply the process energy. It matters how one makes alternative fuel if one is concerned about green house gas reduction.
30. That's a Camry Hybrid. I drive one of these, and have had a lot of people ask me about it. When I first bought the car, my son said it was 'cool'. It gets about 40 mpg on the highway and my average over the last year, for all the driving I've done, is 33.2 mpg.
31. If you had the misfortune of watching the Red Sox game on Saturday or Monday night, you might have seen the Chevy ads for its environmentally friendly vehicles. They included a hybrid truck, a plug-in hybrid passenger car – the Volt, and a fuel cell vehicle.

This section takes a look at all three of those technologies. They really are true multi-fuel vehicles because the electricity can be generated from a number of different sources.

32. First we return to the theme that started us off. Electric drive trains present the opportunity for a better propulsion system. They offer superior performance, smaller engines, and lower complexity. There are no valves, camshafts, fuel or water pumps, radiators, air filters, etc. Transmissions are simpler. And the lower complexity leads to much higher reliability. Imagine only having to take it in for annual inspection and new tires.
33. The horizontal access in energy efficiency, equivalent to mpg. The vertical access is acceleration measured by 0 to 60 times. The combination of high torque at low speeds, and high efficiency, enable new capability. Note the yellow square in the middle, is the Prius, which is a hybrid optimized for efficiency. And the Tesla roadster is in the upper right with both excellent acceleration and high efficiency.
34. Here you can see that the main component of inefficiency for a internal combustion engine, is the heat loss. Losses during idle are also significant. Hybrids eliminate idle loss. And it may be eliminated as one of the possible evolutionary improvements to conventional engines.
35. One way to get some of the advantage of electric motors is to combine them with an internal combustion engine. All Hybrids have an internal combustion engine and at least one electric motor. A vehicle is considered a full hybrid if the electric motor alone can drive the wheels. Series hybrids are full hybrids by design. Hybrids are not disruptive technology so they fit easily into the existing manufacturing system. For example, Toyota easily integrated assembly of the Prius, a hybrid only model, on its existing product lines. Note also, that hybrids don't disturb the service model for vehicles. They still need oil changes, etc.
36. Hybrids have more efficient engines. The smaller engine can be shutdown during idle, while coasting, going down a hill, and when the electric motor can do the job. They capture energy from slowing down, both by the engine and the regenerative brakes which convert motion to electricity . And they're getting better all the time.
37. In general hybrids show some of the advantage of the electric motors. They are more fuel efficient and more powerful. The hybrid vehicles have better acceleration times than the non-hybrid versions.. *Alliance Bernstein reports that the Highlander acceleration improved from 8.1 to 7.2 seconds with hybrid. The Lexus Rx 330 improved from 8.9 to 7.3 seconds. And the Hybrid Camry improved from 9.3 to 8.6 sec.*
38. The hybrids are coming, the hybrids are coming. Here's the most recent list I could find of what hybrids are available. There's a wide selection of cars, SUVs and some trucks.. Several more in various stages of development. (pause)
39. As the technology matures and manufacturing volume grows, the price premium for the hybrid technology will decline. This slide indicates that the $4500 to $6000 cost will fall to about $2000 by 2010.
40. Plug-in hybrids seem like a natural extension of the hybrid – just add more battery power. Unfortunately it's not quite that easy. Batteries add weight, and significant cost. Nevertheless, some individuals and some fleets are leading the way, mostly by converting existing hybrids to plug-ins. And perhaps most encouraging, both GM and Ford have announced Plug-In Hybrid programs.

    Historical company arguments for not doing Hybrids, especially Plug-In Hybrids
    1) Doubt about environmental benefits (Toyota)
    2) Need better batteries (GM)
    3) Hybrid Technology not ready for assembly lines (GM)
    4) Consumers don't want plug-ins.
    NYSERDA – New York State Energy and Research Development Authority converting 400 HEVs – Prius, Civics, Escapes

Calif SCAQMD – State of California, South Coast Air Quality Management District
Cost premium of Plug-in hybrids take a long time to payback. Gas of $3/gal isn't good enough particularly where electricity costs are $0.19 instead of $0.09

41. This is one of the first plug-in conversions of an existing hybrid. Prius' are prime targets for conversion.
42. The main limitation of plug-in hybrid vehicles is the battery. Gasoline delivers between 15 and 60 times the equivalent energy store of Li-ion. *Gasoline delivers about 3000 Wh/kg. This compares to 50-80 Wh/kg for NiMH, and about 200 for Li-ion - Factors of 15 to 60.*
    Lithium-ion is the up and coming technology for hybrid batteries. This is the same basic technology that was causing fires in laptop batteries last year. Fortunately newer chemistries have been developed. A local company, A123 systems, is a leading provider of Li-ion batteries that overcome these problems and are suitable for use in Plug-In hybrids. A123 batteries are being used in the Chevy Volt and Ford Escort programs.
    The A123 batteries address safety with a different cathode chemistry that also lowers the cost and improves the environmental profile of the batteries. The other innovation is the use of a nano structure to achieve a better trade-off between energy capacity and output power.
    I had a conversation with a representative of A123 systems recently. He told me that it was his impression that the Volt program had very high level support within GM and that it would be commercialized, and not just serve as a marketing tool to burnish the image of GM as a "green" company.
43. Plug-ins could have a dramatic impact on oil consumption as well as GHG emissions. Vehicle to Grid is a concept being investigated by the Electric Power Research Institute (EPRI) that would allow the plug-ins to help stabilize the electric power grid. It would allow plug-in hybrids to provide energy to the grid.
    You can get a plug-in flex fuel car today. Hymotion, a small Canadian company has a flex-fuel plug-in hybrid Ford Escape. Now all we need is celulosic ethanol.
    Cost of "electric fuel" depends on the cost of electricity. My last bill came in at $.18 per kwh including delivery charges. That would equate to about 3.7 cents/mile in electric mode, vs 8.3 cents for a 30 mpg car with gas at $2.50/gal.
44. This chart shows the mpg equivalents for various size plug-ins. The Plug-In (60) is the most fuel efficient. (pause)
45. This is similar information expressed in annual gasoline consumption. These estimates are based on statistics of how much of daily driving is within the range of the battery, enabling all electric operation most of the time, with night-time refueling.
46. A couple of points from this slide. First is that the reduction of CO2 by Plug-Ins is dependent upon how the grid generates electricity, and how it will in the future as new power plants are brought on line. Second is that, a plug in will always be better than one of today's conventional vehicles, but could be worse than a regular hybrid.
47. Now we move on to Hydrogen. There's been much hype about hydrogen as the next fuel for the automobile. Unfortunately it's mainly hype and an expensive government project to demonstrate the technology. It's a perfect political program since it doesn't threaten the major oil companies because it's so far in the future.
48. If it could be made to work economically and durably, a fuel cell vehicle would be attractive. Unfortunately there are multiple problems to be solved, including infrastructure. Several of the major manufacturers have demonstration vehicles. The current cost of these vehicles is in the range of several million dollars, much of the cost paid by our tax dollars. But we can't rule out technical breakthroughs, either. Clearly they're not viable in the near future, perhaps in 10 to 15 years.
49. Agenda Slide - A Look Down The Road. So what do we expect to happen.
50. An MIT report looked at the probable characteristics of the major engine alternatives in the year 2030 with some assumptions about the electrical grid composition in that time frame. Aside from fuel cells, plug-in hybrids provide the best option for petroleum reduction and C02 reduction, with hybrids close behind. And even combustion engines are expected to be much better than current engines. Bio-fuels were not included.

It also assumed that hydrogen was generated primarily by reformation of natural gas

51. The report also considered what it would take to achieve the target CO2 limits. It shows we will need a combination of technologies to get us there. As well as a change in behavior - We may not be able to get there without reducing Vehicle Miles Traveled.
52. Now let's consider how long technology takes to penetrate the automotive market. One way to do this is to look at historical patterns in the automotive marketplace. For example, the multi-valve engine took 3 years to 20% market penetration, 10 years to get 50% penetration, and 20 years to get 80% penetration. Hybrids and incremental improvements to combustion engines are the best alternatives in the near to mid term. So it's likely that they will take time to penetrate the market, unless there is some external driving force like high gas prices.
53. Here's an MIT projection from 2005 which suggest it will take another 10 to 15 years for hybrids to reach significant market penetration. Others are more optimistic about the adoption rates of hybrid vehicles. Alliance-Bernstein, for example, projects that hybrids will account for 50% of all new vehicle sales by 2015. In 2006, hybrid sales were less than 2% of the market, but on a sharp growth path. I expect the growth to continue because there are many more vehicle choices. A year ago, the Camry Hybrid was the only family size hybrid sedan on the market. A year later, Motor Trend magazine has a comparison of the Camry Hybrid with the Altima Hybrid.
54. There's no silver bullet, but at least we know that several of the options are technically feasible now, with the flex-fuel plug-in the most promising at this point.
    There also a lot of R&D being done in most areas, from bio-fuels to batteries, to fuel-cells, etc. So there's hope for advancement on many fronts.
55. Agenda Slide - What You Can Do
56. Don't consider buying an SUV or a truck unless it's a hybrid. In fact consider a hybrid for your next vehicle regardless. Hybrids are better for both CO2 reduction and better gas mileage in any size category. Note too, that minivans are better than SUVs and generally carry more people.
57. There are many things that can be done. Some are easier than others. Keeping tires properly inflated, for example, can improve gas mileage by 3%. An estimated 25% of cars and 33% of SUVs have under inflated tires. Some things are image driven - why do you really need an SUV? Others are more difficult because they mean changing lifestyles. Less aggressive driving can be a matter of habit or lifestyle. But slowing down from 75 to 65 mph would reduce gas consumption by 15%. Having a gage that shows instantaneous mpg can help. My Camry has one, as do some non-hybrids like the Mini-Cooper. And consider ride-sharing to our kids out-of-town sporting events
58. Support Clean Energy. If we have more electricity made from renewable, clean energy, then Plug-In vehicles will also dramatically reduce GHG. Support time-of-day electricity pricing. It will lower the cost of electricity for "refueling" a plug-in at night. California has had time of day pricing of electricity for a few years. NSTAR has begun market testing day/night pricing of electricity.
59. Thank you. Now it's time for Questions.