The Case for Plug-In Hybrid Electric Vehicles

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Seminar Outline

1. Magnitude of our oil addiction problem.
2. Present Efforts to Reduce Importation of Oil.
3. Why pure battery-electric vehicles are not feasible as a general purpose vehicle.
4. Status of present charge-sustaining hybrid-electric vehicles on the market.
5. The Plug-in Hybrid Electric Vehicle as the only near term solution to use less oil.
6. The role of DOE & Electric Utilities (my view).

1. Magnitude of our Oil Addiction Problem

How Much Petroleum Does U.S. Use?

- **15.4 million barrels are used each day.**
- **9.8 million barrels/day are imported.**
- **2/3 of these 15.4 mb/day are refined into an automotive fuel.**

(1 barrel = 42 US gallons)

Clearly there is an economic and political problem with the status quo!

2. Present Efforts to Alleviate Importation of Oil

a. Find more domestic oil.
b. Design more efficient conventional vehicles; more efficient engines /vehicles (less weight, aerodynamic).
c. Use alternative non-petroleum fuels; ethanol, biodiesel, hydrogen.
d. Employ hybrid-electric powertrains.

2-a. Find More Domestic Oil

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- **Alaska Natural Wildlife Reserve:**
  - **Massive political opposition.**
  - **Average Dept. of Interior estimate of 17,100 million barrels.**

    17,100 mb / 9.2 mb/day) = 1859 days = 5.09 years of no imported oil.

Conclusion: Short term solution even if environmental and political issues could be overcome.

2-b. Design More Efficient Conventional Vehicles

- **This is the major thrust of auto companies.**
- **Limit is being reached in tweaking IC engines.**
- **Weight reduction may add cost and maybe a balance against passenger safety.**

Conclusion: Auto industry is reaching a limit as to further gains with current vehicle sizes.

2-c. Use Alternative Non-Petroleum Fuels

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- Ethanol in E-85 blend (85% eth.+15% gas.)
- Price of corn (a food crop) has doubled.
- Less energy: 1.29 gal. of E85 are equivalent to 1.0 gal. of gasoline. (~22.5% less energy)

  (Gasoline @$3.00/gal = Ethanol @$2.33/gal)
- Needs new infrastructure.

  (In 2005 E-85/gasoline use = 2.85%)

Conclusion: Longer-term solution, work should continue.

2-d. Employ Hybrid-Electric Powertrains

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- **Current production HEVs are all charge sustaining with very little electric energy storage.**
- **If designed for fuel efficiency, current HEVs increase mpg by ~ 25%.**
- **Clean diesel engine vehicles are a match for current HEVs.**

Conclusion: HEVs are a good start, but need revision to PHEVs.

3. Why Pure Battery-Electric Vehicles Are Not Feasible?

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First the good news:

- They are zero emission vehicles (ZEVs).
- They use no petroleum based fuels.
- They can have very high performance.
- They can be refueled using available off-peak, relatively cheap electric energy with an available infrastucture.
- Emissions from power plants are easier to handle than millions of tailpipes.

So what is the bad news?

Two Major Issues With ZEVs

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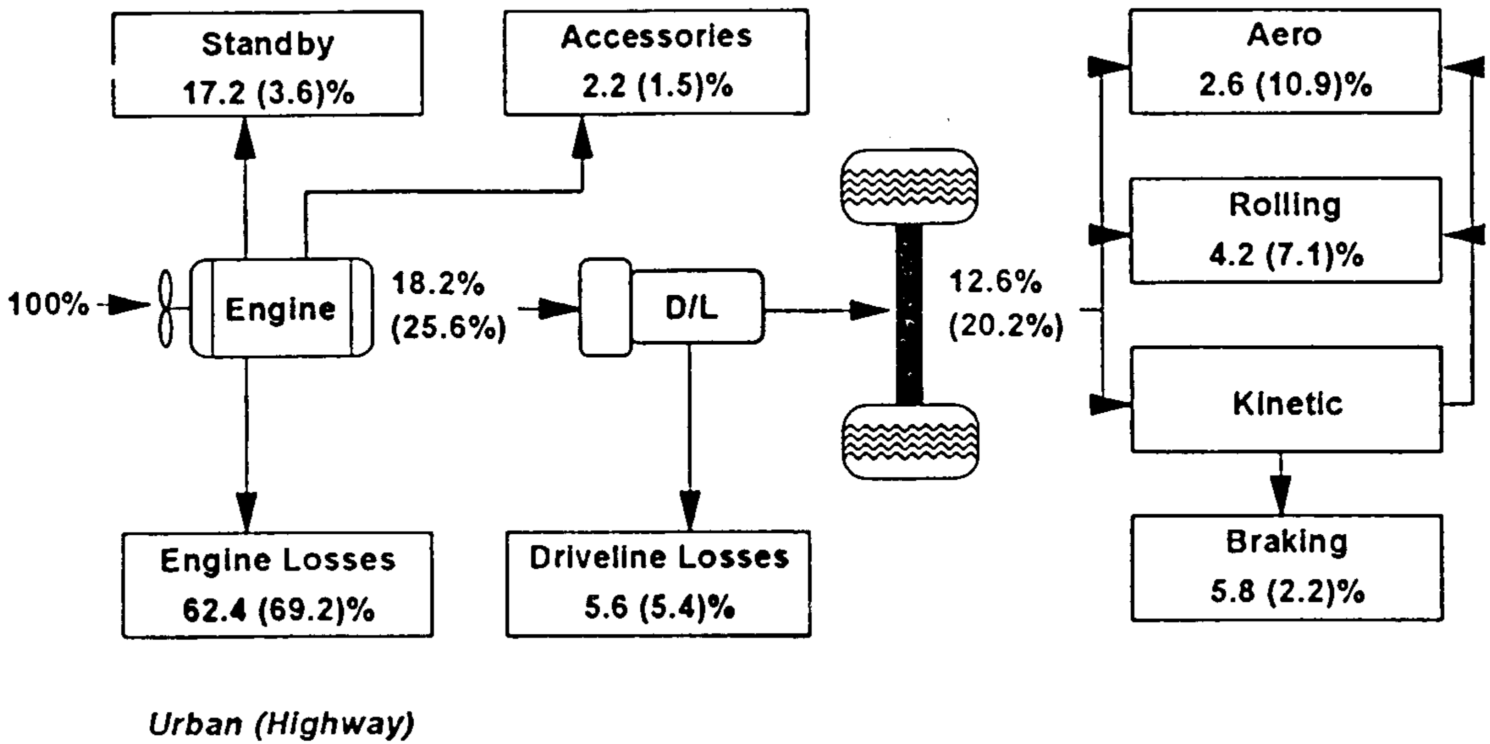
- **Limited on-board energy storage in battery pack.**
- **Very long recharging time relative to conventional vehicles.**
- **The net result is that long distance trips are not convenient.**

Conventional Mid-Sized Vehicle Energy Distribution



Battery Energy Deficiency Issue

	Energy Density (W-hrs/kg)	% Energy at Wheels	Wt. Equiv. to 15 gal (lbs.)
Gasoline	11,428	16.0%	106
Pb-Acid	35	81.1%	6,837
NiMH	70	81.1%	3,418
Li-Ion	136	81.1%	1,759

The last column is the weight of each energy store required to deliver an amount of energy at the driven wheels equal to the energy that an IC engine delivers in burning 15 gallons of gasoline (88.1 kW-hr).

Recharging Issue

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A single vehicle at a gas pump is receiving energy per unit of time (i.e. power) at a level of 22 MW.

(Based on pouring in 15 gallons in 90 sec)

A 240V 30A single-phase circuit requires 15.1 hrs. to refuel the vehicle to provide the same energy at the wheels.

4. Status of Present Charge-Sustaining Hybrid-Electric Vehicles

- **Georgia Tech Hybrid Ford Explorer**
  - Through the road, strong, parallel hybrid-electric powertrain.
- **Toyota Prius**
  - Toyota Hybrid System II (THS-II), power-split powertrain.

2004 Tech Model GT

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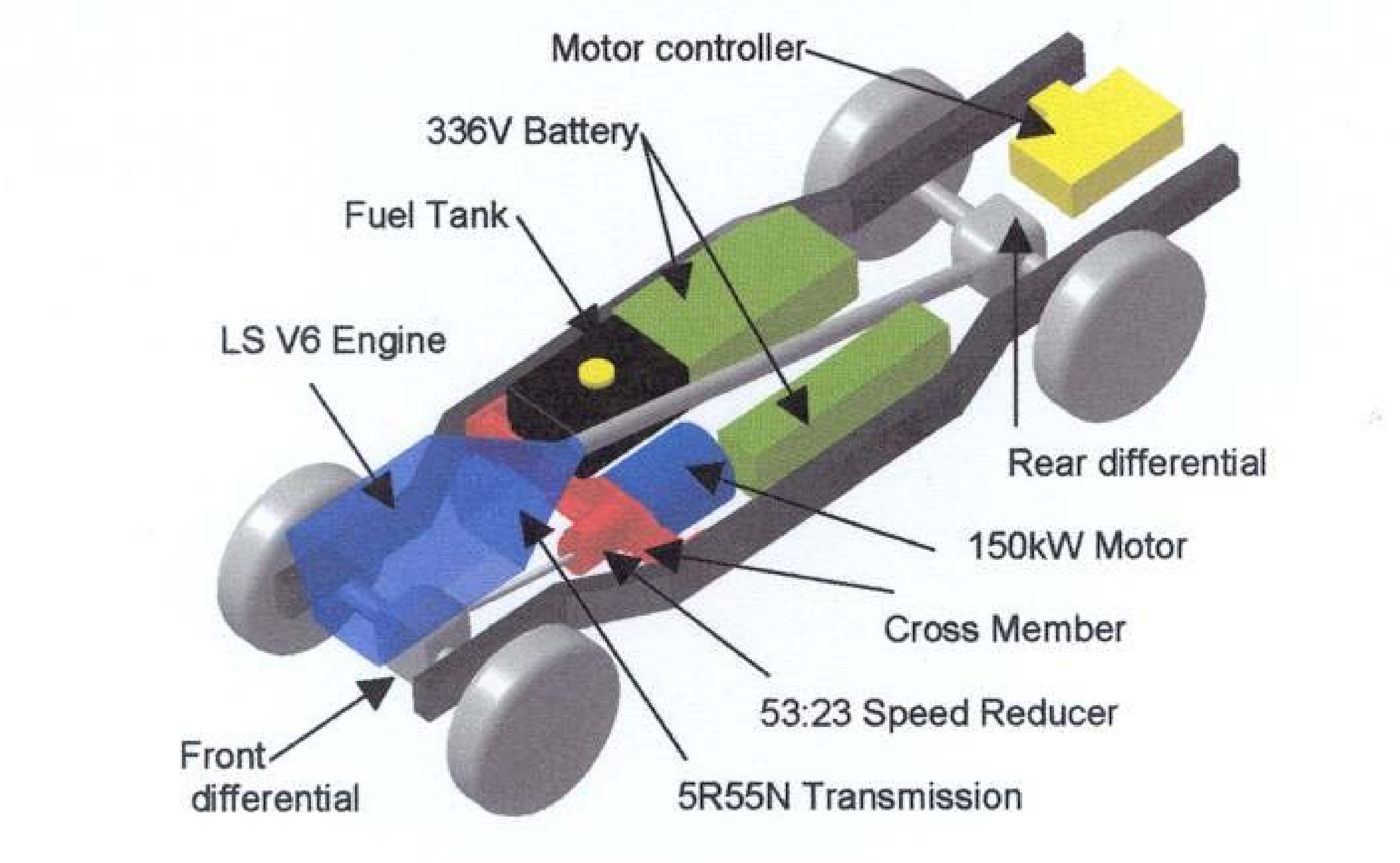
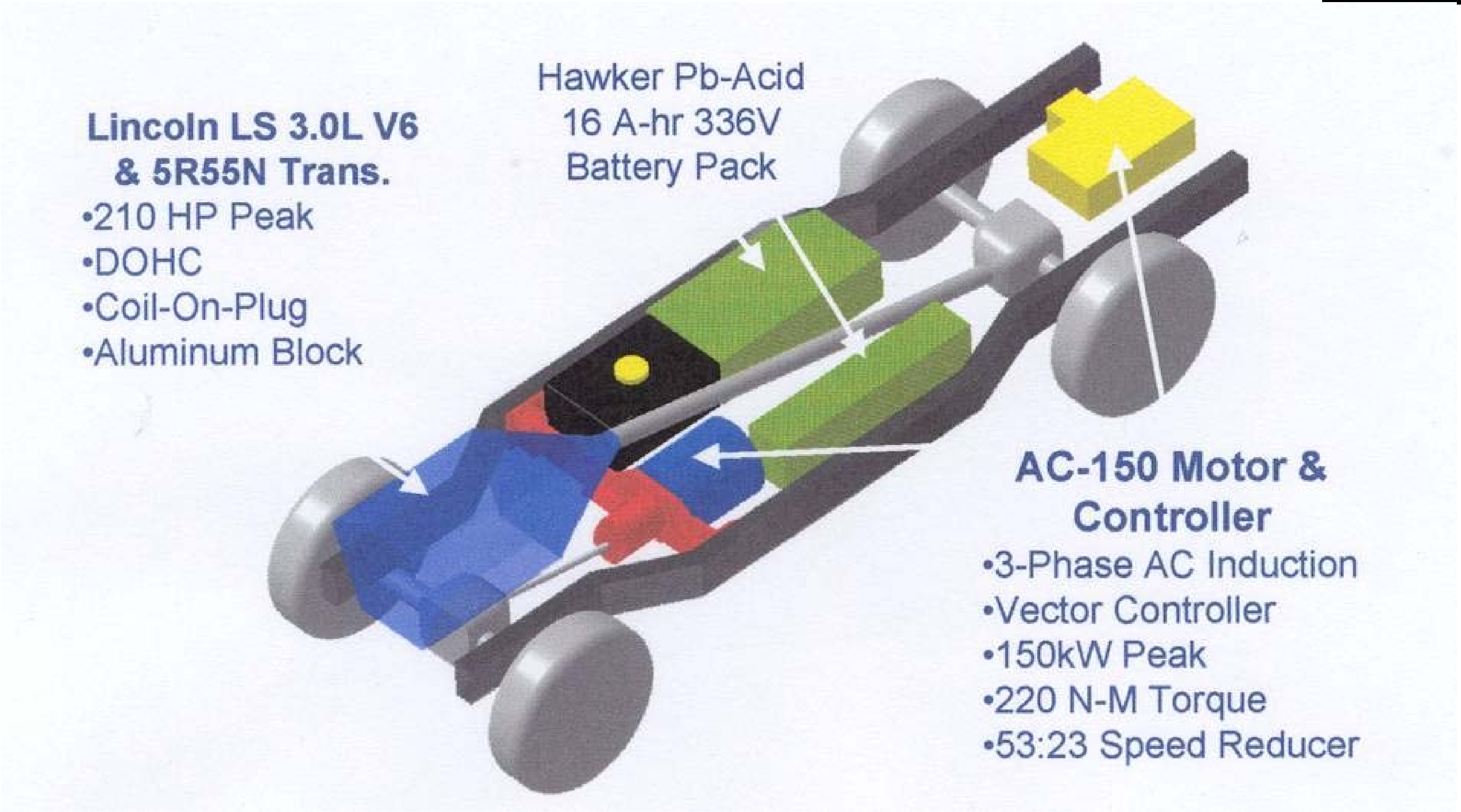
2004 Off-Road Event

Packaging Diagram for the Tech FutureTruck



Details on Major Components



On-Road FutureTruck Event (Laps 2-8)

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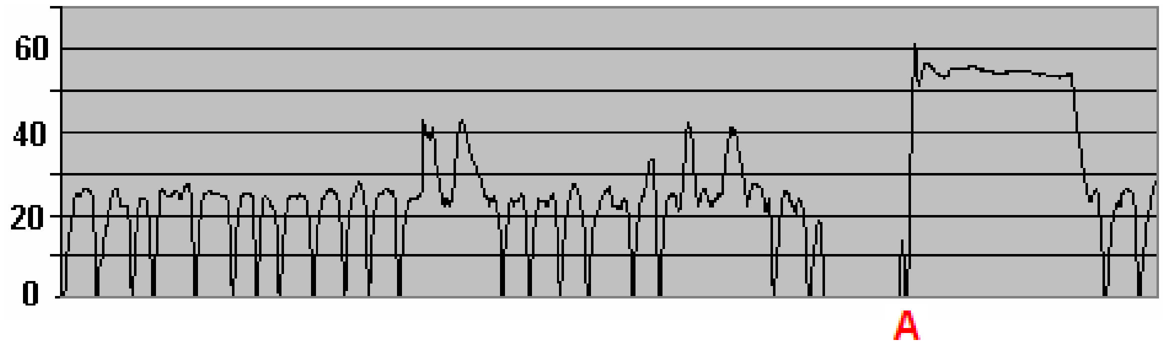
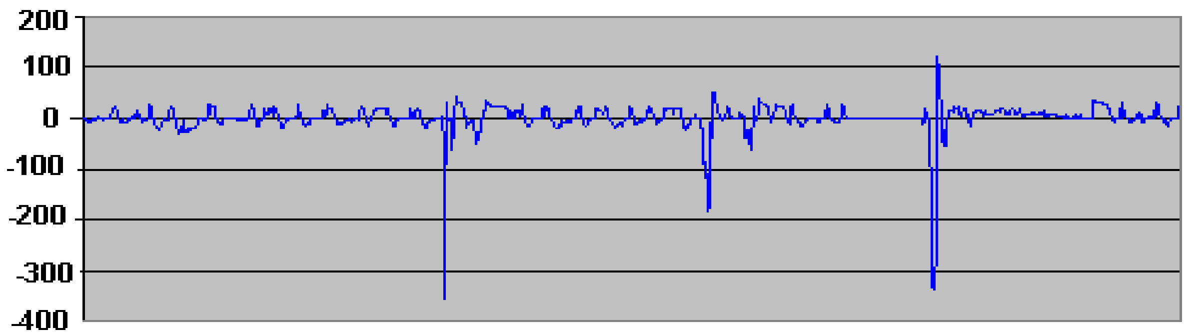
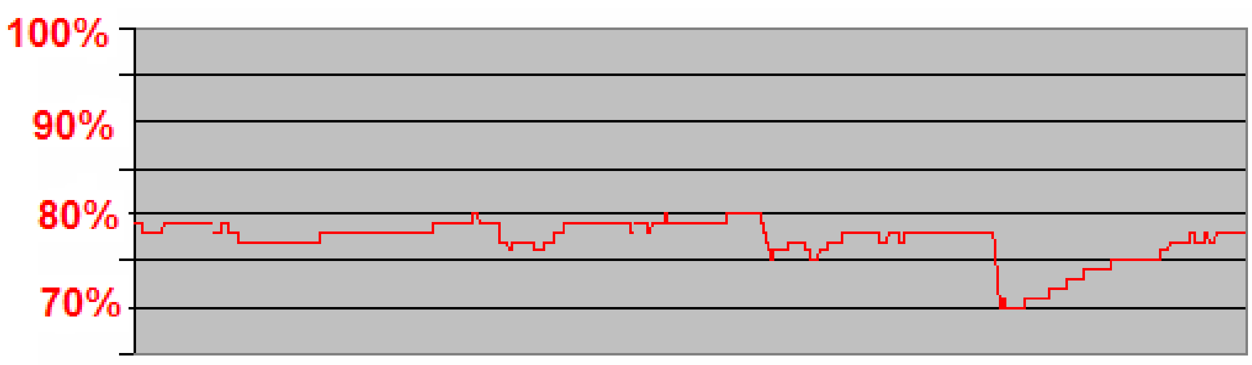
Vehicle Speed (mph)



Battery Amps



Battery SOC

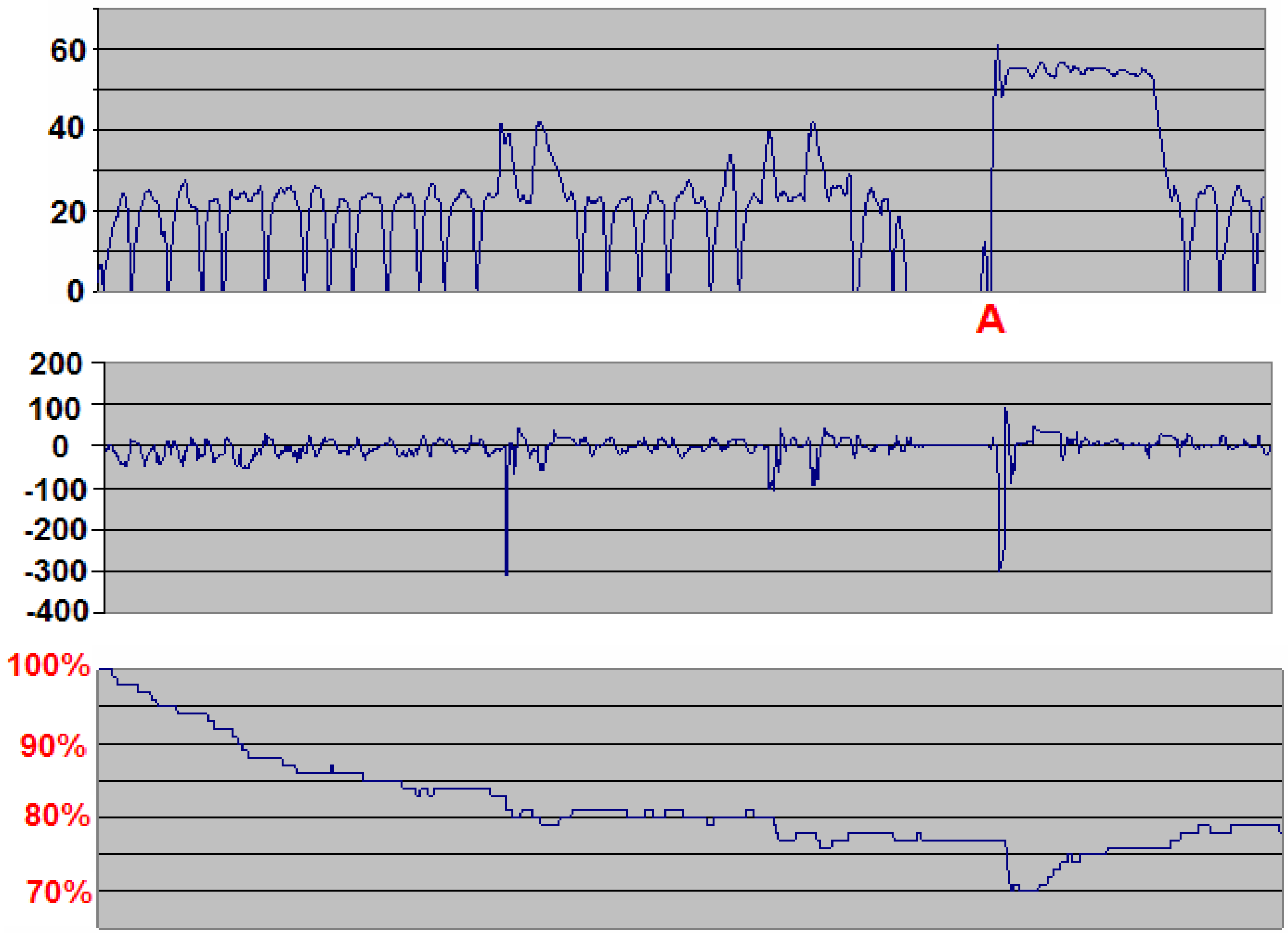


On-Road FutureTruck Event (Lap 1)

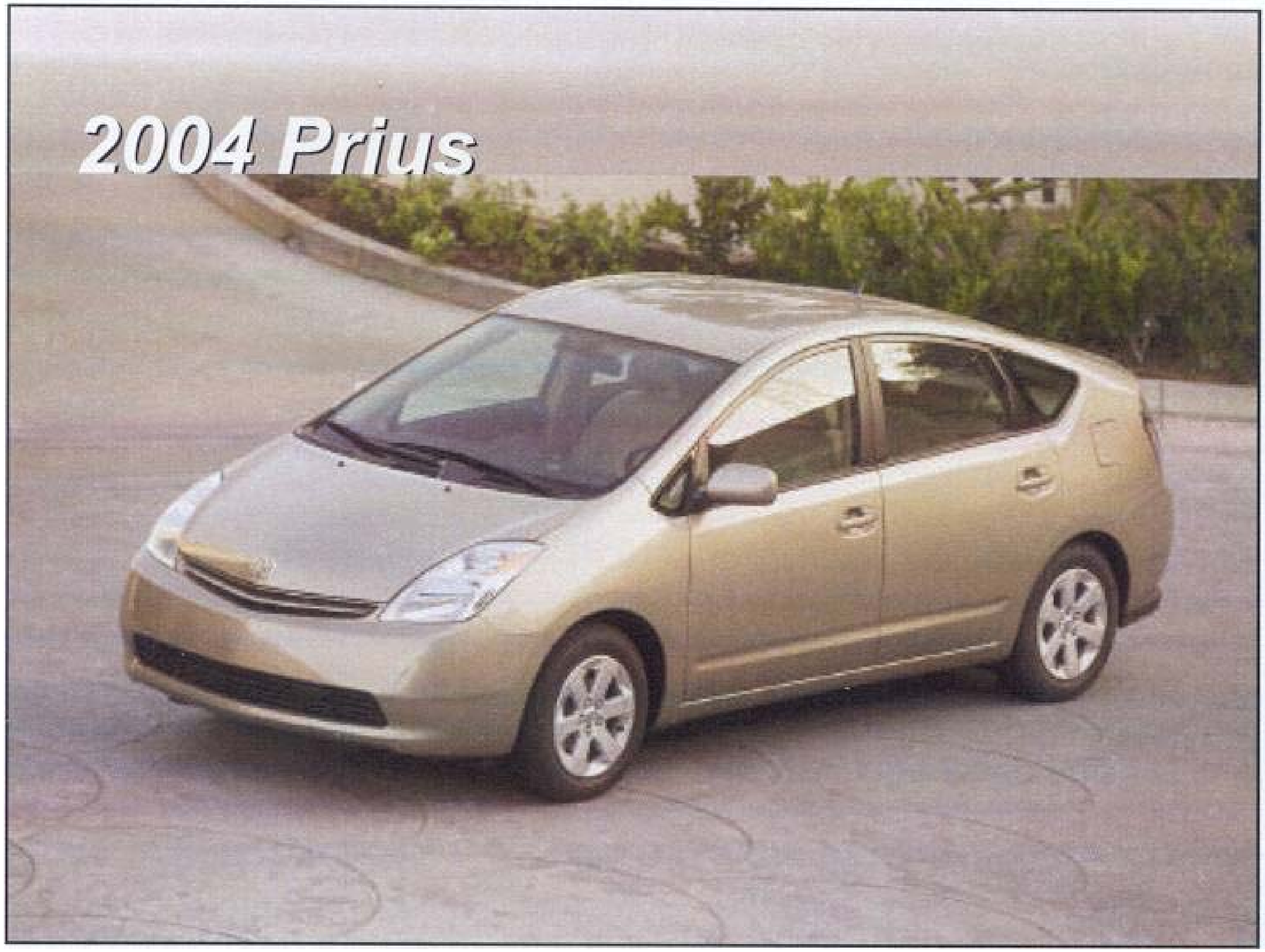
Vehicle Speed (mph)

Battery Amps

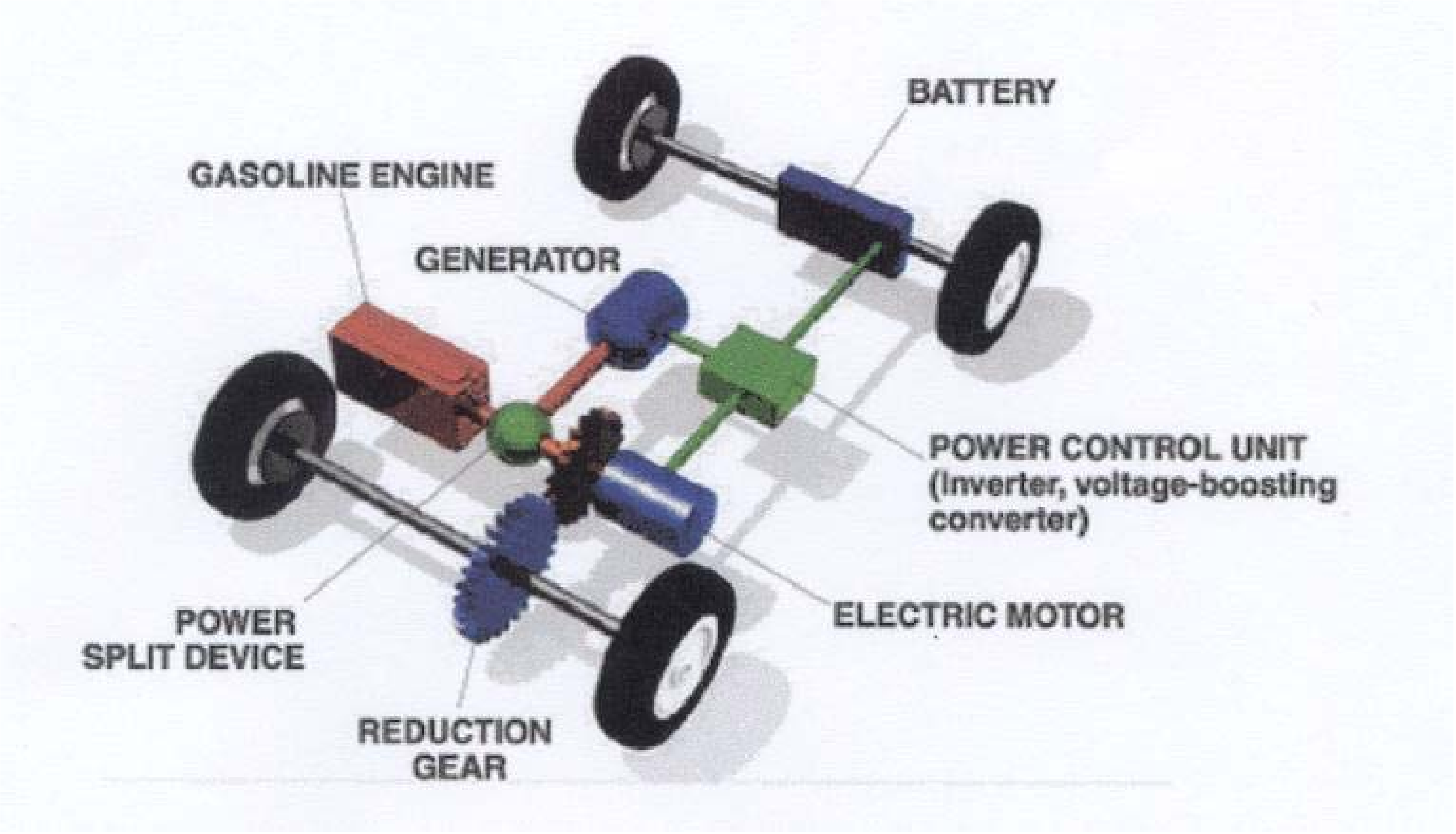
Battery SOC



The 2004 Toyota Prius



Toyota Hybrid System (THS-II)
(See SAE Paper 2006-01-0666)



The Bottom Line For Present HEVs

- Charge sustaining HEVs give about a 25% increase in fuel economy.
- Current trend has been directed towards performance over fuel economy.

Example: 2007 Lexus GS-450h has the fuel economy of the 6-cylinder GS, but the performance of the 8-cylinder.

5. Near-Term Solution: PHEV
Plug-In Hybrid-Electric Vehicle, a Dual-Fuel Vehicle

- **Add more battery energy capacity.**
- **For routine urban driving run a charge depleting control strategy. Trade electric energy fuel for gasoline fuel.**
- **Recharge from the electric utility grid at night using off-peak power.**

PHEV Structure & Control

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- Should be a parallel structure to use the synergism of the two torque sources, electric and IC engine.

  (Why is GM's Volt a series structure?)

- Generally the control should blend the two drive torques as charge is depleted.
- The objective is to minimize gasoline consumption while maintaining performance.

Off-Peak Power

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- Electric energy from the grid is (generally) produced as it is consumed.
- Therefore the system capacity must meet the peak demand.
- Thus there is enough generation available (midnight-6am) to recharge 100 million PHEVs in the present U.S. electrical system.
- The infrastructure is in place!

PHEV Advantages From Driver's Viewpoint

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Assumptions:

- All electric range: 40 miles (PHEV-40)
- Cost of gasoline: $3.00 / gal
- Stock Explorer fuel efficiency: 17.5 mpg (avg.)
- Total miles driven: 15,000 mi/yr
- Fraction of driven wheel energy supplied by the electric drive: 70%
- Cost of electric energy: $0.10 / kW-hr

PHEV Advantages
From Driver's Viewpoint

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Key Operational Results:

- **Fuel Efficiency: 59 mi / gal of gasoline**
- **Savings in cost of fuel: $1448 / yr (56%)**
- **Gasoline not used: 600 gal of 857 gal.**
- **Electric energy usage: 294 kW-hr / month.**
- **Cost of electric energy is equivalent to buying gasoline at $0.59/ gal**

(Cost of electric energy/gallons not used)

Benefits to the Country

- Huge reduction in our dependence on foreign oil (70% reduction in oil consumption).
- Overall reduction of CO2 emissions by virtue of the fact that utilities produce electric energy with much less CO2 per unit energy as compared to transportation.

Conclusions

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- There is a market for Plug-In Hybrids.
- There is a business case for electric utilities.
- Plug-In Hybrids can provide distributed generating sources to utilities in emergency situations. V2G operation.

6. Two Key Players To Realize PHEV Potential

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- The U.S. Department of Energy
- The public and investor owned electric utilities

Three Key Sequential Steps On What Needs To Be Done (Meisel's Opinion)

1. **Build demonstration vehicles using popular large sedans or SUVs (not the Prius).**

2. **Develop a partnership between electric utilities and at least one auto manufacturer to turn these prototypes into production vehicles.**

3. **Establish utility and government financial incentives to purchase PHEVs.**

As For DOE

(More Unsolicited Opinion)

1. **Maintain support for battery R&D.**
2. **Maintain alternative liquid fuel R&D (ethanol, etc.)**
3. **Minimize support for component R&D such as electric motors, inverters, etc.**
4. **Minimize money into all things related to hydrogen as an automotive fuel.**
5. **Realize that the system integration problems with PHEVs are the key issues.**
6. **Promote grid-supplied electric energy as an alternative to petroleum-based fuels.**

Questions & Discussion