PHEVs: The Technical Side

PG&E's Pacific Energy Center

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Ron Gremban, Technical Lead
The California Cars Initiative
rgremban@calcars.org

Background: Gasoline Vehicles

- Gasoline (Otto cycle) vehicles:
  - Emit 8.9kg CO_2/gallon
  - Well-to-wheels efficiency: 10-13%

Background: Diesel Vehicles

- Diesel vehicles:
  - Emit 10.2kg CO_2/gallon (14% more than gas)
  - Diesel fuel weighs 10% more/gallon than gas
    - De-rate diesel MPG by 10% for true economy
  - Well-to-wheels efficiency: 13-17%
  - No known way to meet PZEV/future emissions levels

Background: HEV Efficiency Improvements

- Strong hybrids (Atkinson/Miller cycle):
  - Well-to-wheels efficiency: 15-26%
  - Atkinson/Miller greatly reduces low-power pumping losses
  - Regenerative braking recaptures up to 50%

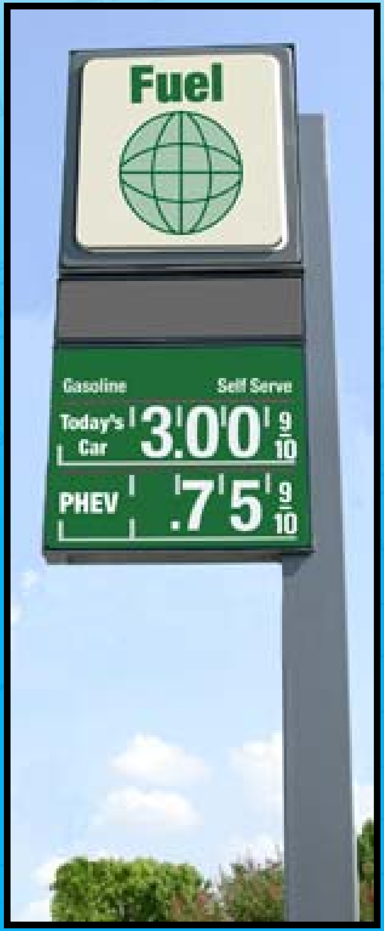
Further HEV Efficiency Notes

- Vehicle weight mainly affects city driving
- Aerodynamics affects highway
- City vs. Highway
  - Gasoline (Otto): Much worse city
  - Diesel: Slightly worse city
  - HEV: Better city; acceleration energy recovered

PHEVs Replace Liquid Fuel with Electricity

- Most normal daily driving can be electric
- Emissions:
  - Electricity increasingly “green”
  - Night-time charging = highest wind production
  - 50% source-to-wheels v. 12-20% max for H_2
  - Sulfur and other emissions are capped
  - Carbon caps pending in East, considered in CA
- Well-to-wheels fossil fuel efficiency: 18-44%
  - HEV: 17-26%; Otto cycle: 10-13%; H_2: 13-23%

Equivalent to $0.50-1.00/gallon



Greenhouse Gases: EV vs. Gasoline

Gasoline Vehicle CO_2

- 500 grams/mile @ 18mpg
- Strong HEVs: 250 grams/mile @ 35 mpg
- Gas will get dirtier

Electric Propulsion CO_2

- 1600 grams/kWhr = **190 grams/mile**
  - Approx. US average
- Worst states: 265 g/m

EPRI projections

2010: 500 g/kWhr = **59 g/mile**

2050: 375 g/kWhr = **44 g/mile**

PHEV Efficiency Improvements Over HEV

- Electricity used in place of most liquid fuel
- Increased regenerative braking
- Increased engine downsizing (strong PHEVs)
  - Engine only handles max steady-state load
    - ½ the size of existing HEV engines

PRIUS+ Performance

Project	Battery Manuf.	Battery Model	Chem -istry	Eff Ah	EV mi	Mix mi*	Added lb.	In-range Mpg*	Orig Mpg	City HEV Mpg	Comments
World's 1st	BB Battery	EVP20 -12	Lead-acid	12	10	20	300**	80	45	-10% due to extra weight**	OEM battery not removed; hilly Marin terrain
EDrive	Valence	U1-12XP	Li-ion	36	30	60	200	100	50	Unchanged due to lower impedence	Flat Los Angeles driving
Electro Energy	Electro Energy	N/A	NiMH	30	24	48	250	90	45	Unchanged due to lower impedence	Project nearly complete
Another Li-ion	Enax	N/A	Li-ion	33	27	54	100	90	45	Increased due to even lower impedence	Anticipated

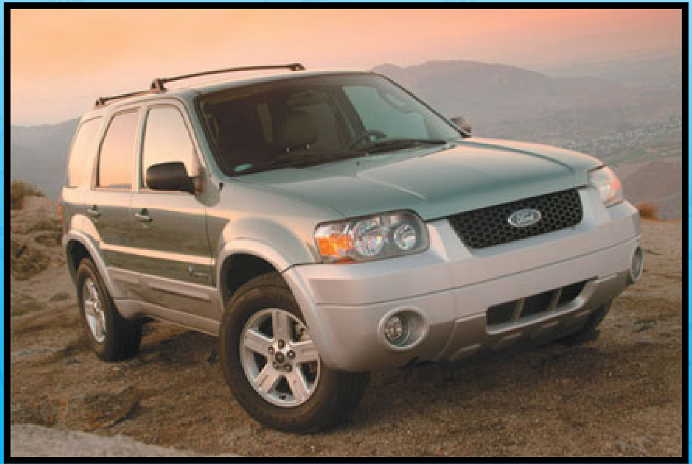
* Mixed city & highway driving (also uses around 130 Watt-hr/mi electricity)
** OEM battery pack unused but not removed, adding ~75 lb

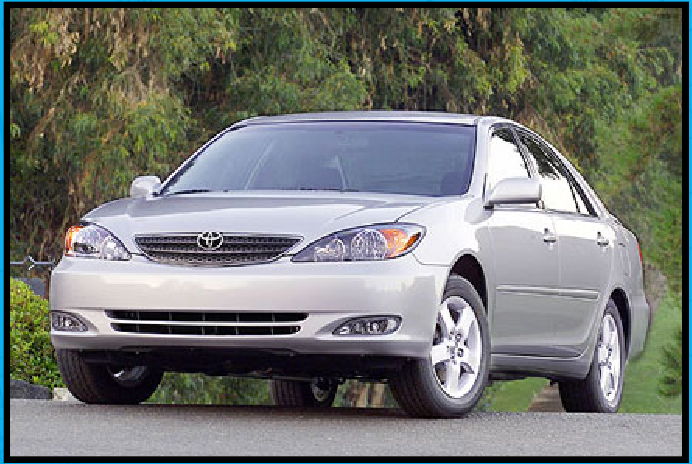
PRIUS+: Demonstrated PHEV Operation

- With minor modifications, current HEVs can become **effective** PHEVs
  - Not optimized
- No new technology required for practical PHEVs
- Current batteries can do the job
  - Electro Energy PRIUS+: capable NiMH pack
  - EDrive/Hymotion: capable Li-ion packs

A Prius' **Real** PHEV Capabilities

- EV operation at all speeds
- Sufficient EV power for most driving needs
  - 67 HP
- Other strong hybrids have similar potential capabilities





PHEV Batteries

- NiMH used in current HEVs, EVs
  - Low-failure, long life, practical for high energy
- Li-ion announced for next-gen hybrids
  - 2x specific energy of NiMH
  - Existing solutions for Li-ion problems
- More technologies on the horizon

What's Needed Now

- Battery qualification/incorporation by OEMs
- Risk to warrant battery life in first PHEVs
  - Nearly zero real-world PHEV experience
- Mass production of PHEVs
- Cost-savings of high-volume production and refinement

PHEV Energy Requirements

- Electric generation capacity
  - 2004 average US capacity: 938 gW
  - Average unused: 54% = 505 gW (higher at night)
  - **Average unused capacity can simultaneously charge 337 million PHEVs**
- If all ground vehicles were suddenly PHEVs
  - Total ground transport oil savings: 78%
  - Added generation requirements: 13%
  - 10x 2004 wind production: 142 tWh/year
    - 29% of the above PHEV requirements

Background: Ethanol and Biodiesel

- Upside:
  - "Flex-fuel" vehicles cost only ~$150 extra to manufacture
    - Retrofitting is difficult
  - Biodiesel can be run in existing diesel vehicles
- Downside:
  - Fuel production competes with food production and rainforests for land
  - Barely higher energy output than input

Background: Ethanol and Biodiesel

- Cellulosic ethanol
  - Farm and urban plant wastes
  - Carbon neutral!
  - **Enough for up to 30% of ground transport requirements before competing with food/forest land**
- Thermal depolymerization biodiesel
  - Far less raw material available than for cellulosic E2

Cellulosic Ethanol Plus PHEVs

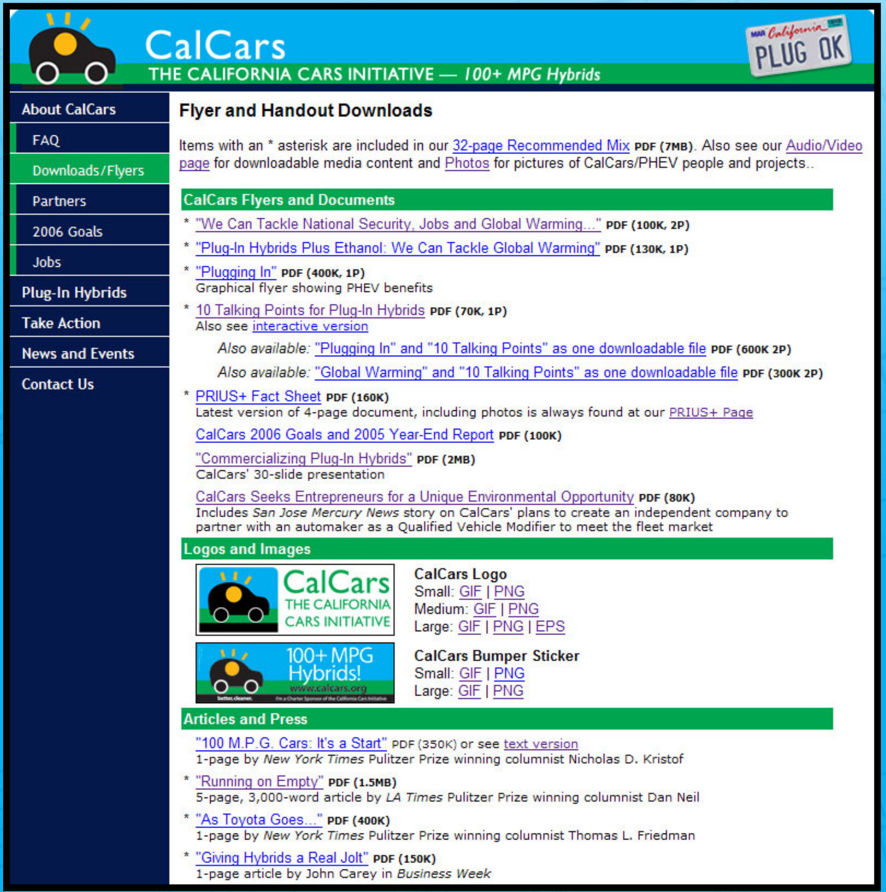
- US imports 60% of oil; 70% for ground transport
  - If all vehicles were **HEVs:**
    - 23% total oil savings
  - **Flex-fuel:** (cellulosic ethanol)
    - 21% total oil savings
  - **PHEVs:**
    - 55% total oil savings
    - Ground transportation CO_2 by 61% (73% by 2010)
  - **Flex-fuel PHEVs:**
    - 67% total oil savings – **97% of ground transport oil**
    - Ground transportation CO_2 cut by 81% (93% by 2010)

An All-Out Effort

- In 2-5 years, all new vehicles could be flex-fuel
- 12-20 years: most existing vehicles would be flex-fuel, for 30% ground-trans oil and CO_2 reductions
- 10-15 years: all new vehicles could be flex-fuel PHEVs
- 20-30 years: most existing vehicles would then be flex-fuel PHEVs, for 97% ground-trans oil and 93% CO_2 reductions

Check My Sources!

- This presentation, notes, and others are available at www.calcars.org/downloads.html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Items with an * asterisk are included in our 32-page Recommended Mix PDF (7MB). Also see our Audio/Video page for downloadable media content and Photos for pictures of CalCars/PHEV people and projects..

CalCars Flyers and Documents

* "We Can Tackle National Security, Jobs and Global Warming..." PDF (100K, 2P)
* "Plug-In Hybrids Plus Ethanol: We Can Tackle Global Warming" PDF (130K, 1P)
* "Plugging In" PDF (400K, 1P)
  Graphical flyer showing PHEV benefits
* 10 Talking Points for Plug-In Hybrids PDF (70K, 1P)
  Also see interactive version
  Also available: "Plugging In" and "10 Talking Points" as one downloadable file PDF (600K 2P)
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* PRIUS+ Fact Sheet PDF (160K)
  Latest version of 4-page document, including photos is always found at our PRIUS+ Page

CalCars 2006 Goals and 2005 Year-End Report PDF (100K)

"Commercializing Plug-In Hybrids" PDF (2MB)
CalCars' 30-slide presentation

CalCars Seeks Entrepreneurs for a Unique Environmental Opportunity PDF (80K)
Includes *San Jose Mercury News* story on CalCars' plans to create an independent company to partner with an automaker as a Qualified Vehicle Modifier to meet the fleet market

Logos and Images

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CalCars Bumper Sticker
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Articles and Press

"100 M.P.G. Cars: It's a Start" PDF (350K) or see text version
1-page by *New York Times* Pulitzer Prize winning columnist Nicholas D. Kristof
* "Running on Empty" PDF (1.5MB)
  5-page, 3,000-word article by *LA Times* Pulitzer Prize winning columnist Dan Neil
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