Introduction to Hybrid Electric Vehicles: Motivation and History

“Progress, far from consisting in change, depends on retentiveness. When change is absolute there remains no being to improve and no direction is set for possible improvement: and when experience is not retained, as among savages, infancy is perpetual. Those who cannot remember the past are condemned to repeat it.”

George Santayana, in The Life of Reason (1905)

Tom Bradley and Ken Stanton
HEV Objectives

- What motivates this change in technology?
- Why hybrid (gasoline and electricity)
- Are hybrid and electric cars new technologies?
Vehicle History

Toyota Prius in the US, 2000

Ford Escape Hybrid 2005

Prius and Insight, 2010

Honda Insight 1999

Lohner Porsche 1901
Motivation

• Air Pollution
  – Gasoline is a hydrocarbon
  – Ideal combustion yields CO$_2$ and H$_2$O
  – In real-world conditions, additionally yields:
    • Toxic NO$_x$, CO, and unburned hydrocarbons (HC)
    • Byproducts are Ozone, Acid Rain, health problems
Motivation

• Environmental impact
  – CO$_2$ is a leading greenhouse gas
  – 32% of CO$_2$ emissions from transportation (1990-2000)
  – We will see increasing transportation-based CO$_2$ emissions from industrializing countries
Motivation

• Diminishing Petroleum Resources
  – It is believed that we will reach Hubbert’s ‘Peak Oil’ for world-wide petroleum production around 2020
  – If true, HEVs buy time, but they must be followed (~20-30 years) by more permanent solutions
    • e.g., vehicles not burning petroleum
Why Hybrids?

• Why specifically combine gas engine and electric motor?
Characteristics of HEV Drivetrains
(In approximate order of importance to efficiency)

• **Isolation of Engine from Vehicle Operating Conditions**
• **Regenerative Braking**
• **Engine Downsizing**
• **Electric Drive Mode**
• **Electrified Accessories**
• **No Engine Idle**
• **Energy Banking**
Isolation of Engine from Vehicle Operating Conditions
Regenerative Braking

- Motor/Generator Captures Braking Energy

- $KE = \frac{1}{2}m v^2$

- Cp of Steel $= 620$ J kg$^{-1}$ K$^{-1}$
Engine Downsizing

Engine Efficiency Map (assumed)
Engine Peak Torque Line (assumed)
Locus of Powerplant Operating Points, $R = 7, 10, 13, 16$
Line of Constant Power, 23kW
The Others

- Electric Drive Mode – Use Electric Energy
- Electrified Accessories – Water Pump, A/C, PS,
- No Engine Idle – 20% of EPA FE Test
- Energy Banking

\[ \eta_{\text{engine}} \leq \eta_{\text{max}} \cdot \eta_{\text{Batt-in-out}} \]

\[ \eta_{\text{Batt-in-out}} = 80\% \]

\[ \eta_{\text{max}} = 33\% \]

\[ \eta_{\text{engine}} > 27\% \]

Is wasteful

Engine Must be maintained at \( \eta > 27\% \)
History

- Electric and gas vehicles competed for supremacy from the 1880’s until the 1910’s.
  - 1881, first electric vehicle by Gustave Trouvé using lead-acid batteries and 0.1 hp DC motor
  - 1897, fleet of electric taxis in NYC out-competes horses in profitability
  - 1897, regenerative braking invented by M.A. Darracq
  - At first, electric vehicles were less complex and easier to operate than gas vehicles
  - With the advent of long-stretches of paved roads, and refinement of gas vehicles, electric vehicles lost ground.
  - 1912, peak production of electric vehicles

Detroit Electric (Edison), 1912
Other Types of Hybrids

- Flywheel hybrids
- Pneumatic hybrids
- Hydraulic hybrids
- Fuel-cell hybrids
- Plug-in hybrids
History

• The invention of the transistor in 1945 (Bell Labs), and the high-current, high-voltage thyristor gave EVs a re-birth
  – Allowed for highly-efficient AC motors
  – 1969 Lunar Roving Vehicle
  – 1980’s and 1990’s saw new EV development: GM’s EV1 and Peugeot’s 106 Electric
  – Still not competitive due to small power density of batteries
  – It is expected that power density will always trail that of fossil fuels
    • This point motivates HEVs…
History

• HEVs surprisingly old
  – 1899 - Parallel hybrid shown by Pieper at the Paris Salon using an air-cooled engine and an electric motor
    • Batteries charged by the engine when coasting or at a standstill
    • Motivated by need to assist IC engine, not fuel economy
  – Other series and parallel vehicles through to 1914; however, none used regenerative braking
  – Lack of electronic control (not invented yet!) made the integration of the two power sources non-ideal and cumbersome
History

• ‘Modern Era’ began with Dr. Victor Wouk, 1975
  – Parallel hybrid Buick Skylark – 30 mpg (2X)
  – Mazda rotary engine assisted by a 15 hp DC electric motor located in front of the transmission
  – Eight 12V automotive (lead-acid) batteries

• Interest and economic viability grew in the 1990’s when power electronics, battery, and electric motor technology matured
  – Electronic control of the ICE and potential for control of a hybrid powertrain
  – Culminating with commercialization by Japanese manufacturers
    • 1997 - Toyota Prius (came to the US in 2000)
Discussion Points

• How important is efficiency in your car purchasing decision?

• Which car sells more in the US in 2011 and why?
  – Toyota Prius, Toyota Corolla, Ford Taurus/Sable

• Why don’t you buy a more efficient (or faster, or more luxurious) car?