The Electrification of the Automobile and Opportunities It Presents for Your Engineering Career

BYU-I ASME student chapter forum

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www.inl.gov

Idaho National Laboratory

Personal Background

Living the dream

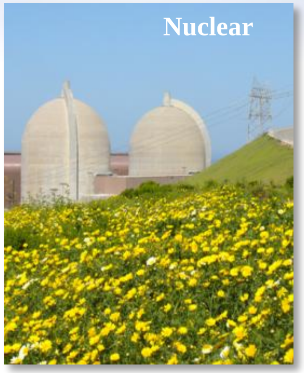
- BSME from BYU (Provo), 2001
- Numerous internships before and during undergraduate program

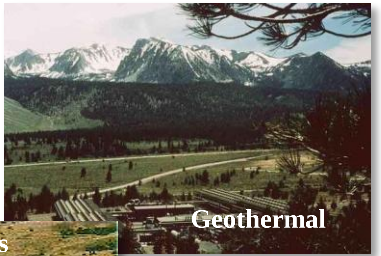
- Ford Motor Company 2001 – 2007
  - Powertrain Product Development

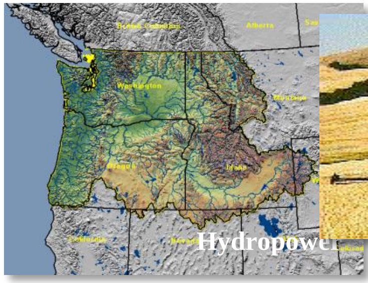
- Idaho National Laboratory 2007 – present
  - Energy Storage and Transportation Systems

Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) Federal laboratory
- 890 square mile site with 3,600 staff
- Support DOE's strategic goal:
  - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Energy Critical Infrastructure Protection







Advanced Vehicle Testing Activity (AVTA)

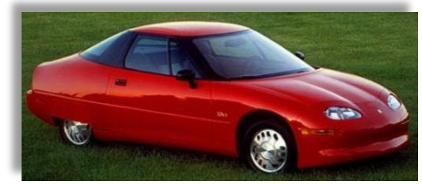
- Part of the U.S. Department of Energy’s Vehicle Technologies Program
- INL and ECOtality N.A. conduct the AVTA’s light-duty vehicle testing, with Argonne National Laboratory performing dynamometer testing

AVTA Goals

- Determine actual petroleum displacement and overall operating cost of advanced technology vehicles through *testing* and *real-world demonstrations*
- Provide benchmark data to industry and government research and development programs
- Assist fleet managers and consumers in making informed vehicle purchase and operating decisions

AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEV)
  - 12 models, 259 vehicles, 1.5 million test miles
- Hybrid electric vehicles (HEV)
  - 18 models, 47 vehicles, 5 million test miles
- Full-size battery electric vehicles (BEVs)
  - 40 EV models, 5+ million test miles
- Neighborhood & Urban electric vehicles
  - 26 models, 1.2 million test miles
- Hydrogen internal combustion engine vehicles
  - 7 models, 500,000 test miles



The EV Project

- INL is a principle participant with ECOtality N.A. in largest electric vehicle / charging infrastructure demonstration ever undertaken
- 5,700 Nissan Leaf BEVs
- 2,600 Chevrolet Volt EREVS
- >14,000 Level II EVSE charging units
- >300 DC fast chargers
- 7 market areas in:
  - Oregon, Washington, California,
  - Arizona, Tennessee, D.C.

Charging Infastructure Locations

- > 40 project partners, including electric utilities

www.theevproject.com

Project Supporter
U.S. DEPARTMENT OF ENERGY

ecotality NORTH AMERICA

NISSAN

GM

INL Idaho National Laboratory

Electrified Vehicles as a Solution to Oil Dependency

Areas of concern

- Energy security
  - Insufficient domestic supply of easily obtainable oil forces us to rely on imports
- Global climate change
  - Tailpipe and smoke stack CO_2 emissions
- Economic stability
  - Unbalanced supply and demand affect all levels of the economy (global, national, personal)

Electrified Vehicles as a Solution to Oil Dependency

Advantages of Plug-in Electric Vehicles

- Displace petroleum consumption with electricity
- Provide ***alternatives***
  - Use domestically generated electricity from a variety of sources
  - Use existing infrastructure
  - Leverage nuclear and renewable energy sources (wind, solar, hydro, geothermal)

Electrified Vehicles as a Solution to Oil Dependency

Challenges with Plug-in Electric Vehicles

- Current technology limitations (batteries!)
- Some infrastructure required
  - Charging stations (short term)
  - Communication between vehicles and electric grid (mid-term)
  - Additional electricity generation/transmission/distribution (long-term)
- Consumer market acceptance

Electrified Vehicle Powertrain Architectures

Battery Options
- Energy Capacity
- Peak Power
- Chemistry
- Voltage

Liquid Fuel (gasoline, diesel, E85)

Cost (currently dominated by battery)

Complexity

Conventional vehicle

Mild Hybrid (HEV)

Belt Alternator Starter
Chevrolet Malibu
BMW 1 Series

Integrated Starter Generator
Honda Civic
Honda Insight

Full Hybrid (HEV)

Power Split
Toyota Prius
Lexus RX400h
Ford Fusion
Chevrolet Tahoe

Parallel
Hyundai Sonata (2012)
Infiniti G (2012)

Blended Plug-in Hybrid (PHEV)

Power Split

Conversion
Hymotion Prius
Ferrex Escape

Prototype
Ford Escape
GM 2 Mode SUV

Production
Toyota Prius (2012)
Ford TBD (2012)

Extended Range Electric Vehicle (EREV)

Series

Prototype
Ram Pickup

Production
Renault Kangoo
Chevrolet Volt (2011)
Fisker Karma (???)

Battery Electric Vehicle (BEV)

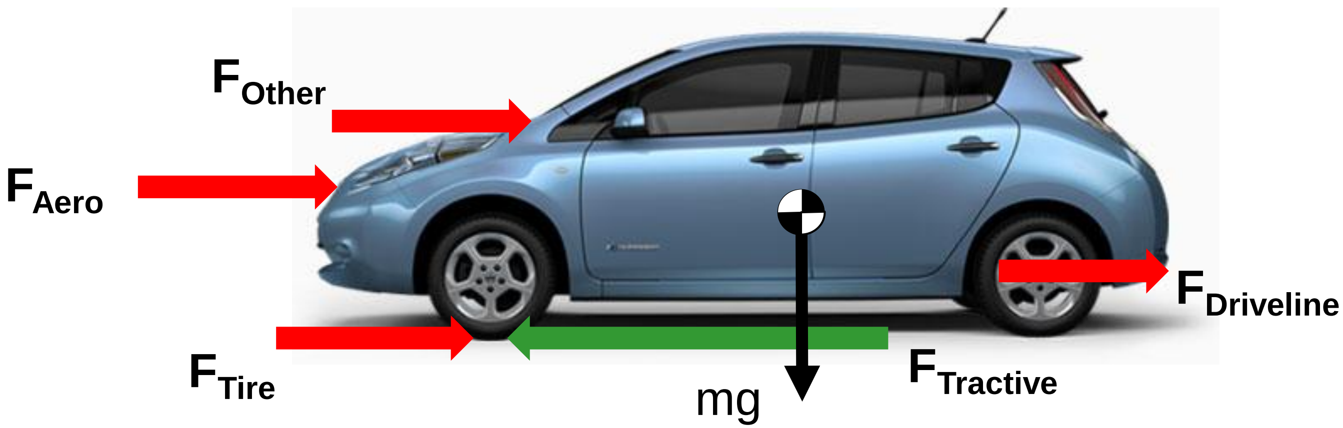
Prototype/ Conversion
BMW Mini e
AC Pro Ebox
US Postal Service LLVs

Production
Tesla Roadster
Mitsubishi iMiev
Nissan Leaf (2011)
Ford Focus (2012)

Dates given are announced target years for start of production

Underlying Physics Principles

- Conservation of energy – it has to come from somewhere
- How much energy does it take to get from point A to point B?



Find the power (P) required to maintain a speed of V

*** Assume Rotational Inertias are negligible**

$$F_{Tractive} = m\,a = m\frac{dv}{dt}$$

$$P = F_{Tractive} V = m\frac{dv}{dt}\,v$$

$$\sum F_x = m\,a$$

$$F_x = F_a + F_{tire} - F_T = -F_{inertia}$$

$$F_{Tractive} = m\,a + (F_{Aero} + F_{RR} + F_{Tire})$$

$$F_A + F_{RR} + F_{Tire} = F_{resistance}$$

$$F_{resistance} = CV^2 + BV + A$$

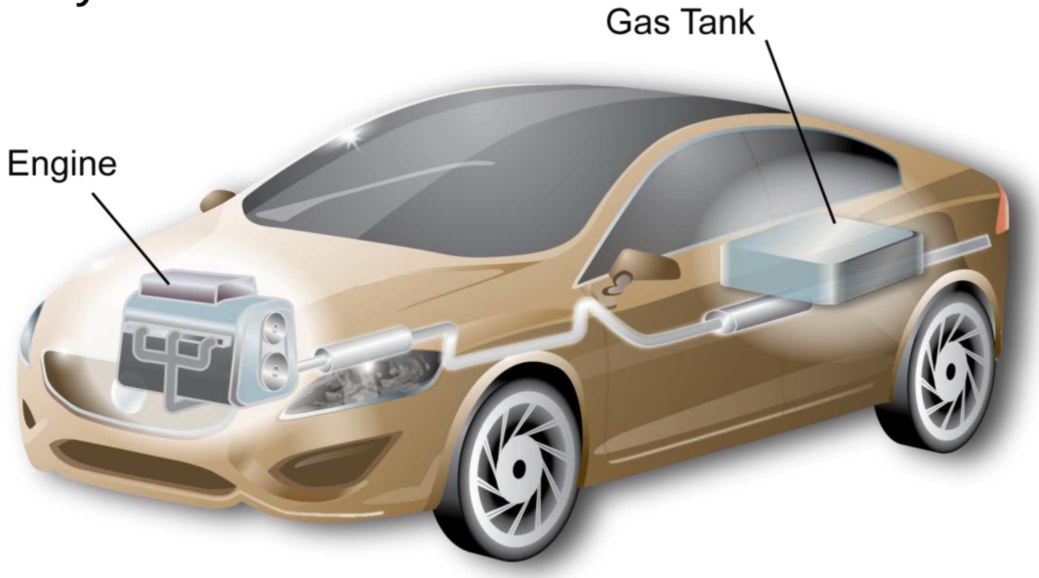
Comparison of Energy Density of Fuels

- Onboard energy storage is the constraint
  - It’s all about the batteries

Insert plot of Wh/kg vs. Wh/L for various fuels and battery chemistries here

Comparison of Vehicle Technology

Conventional vehicle with internal combustion engine (ICE) only

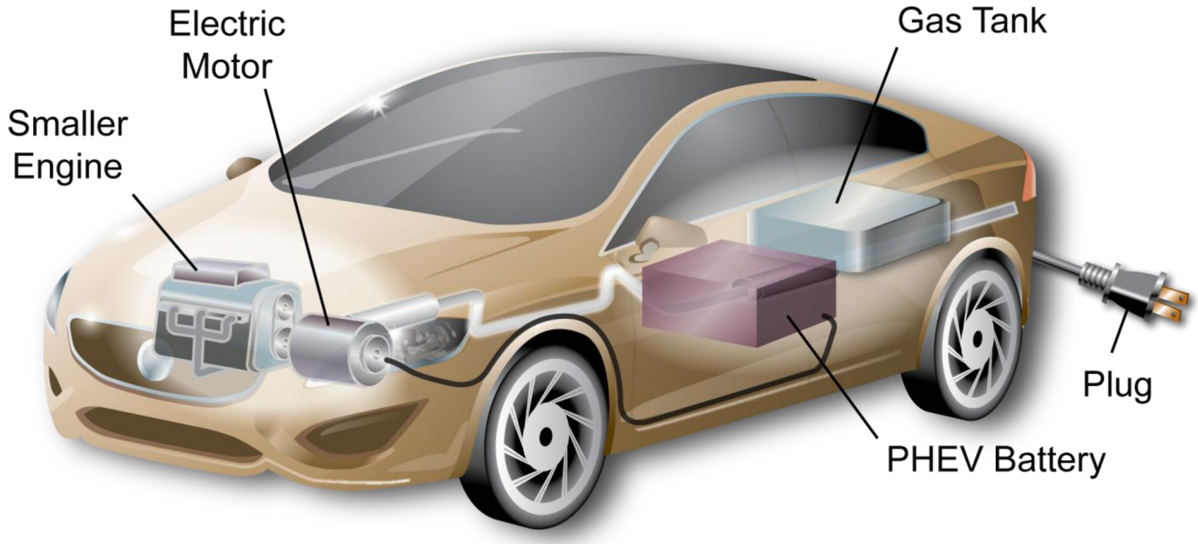


Comparison of Vehicle Technology

- Hybrid Electric Vehicle (HEV) with ICE and electric drive
- Does not plug in to electric grid

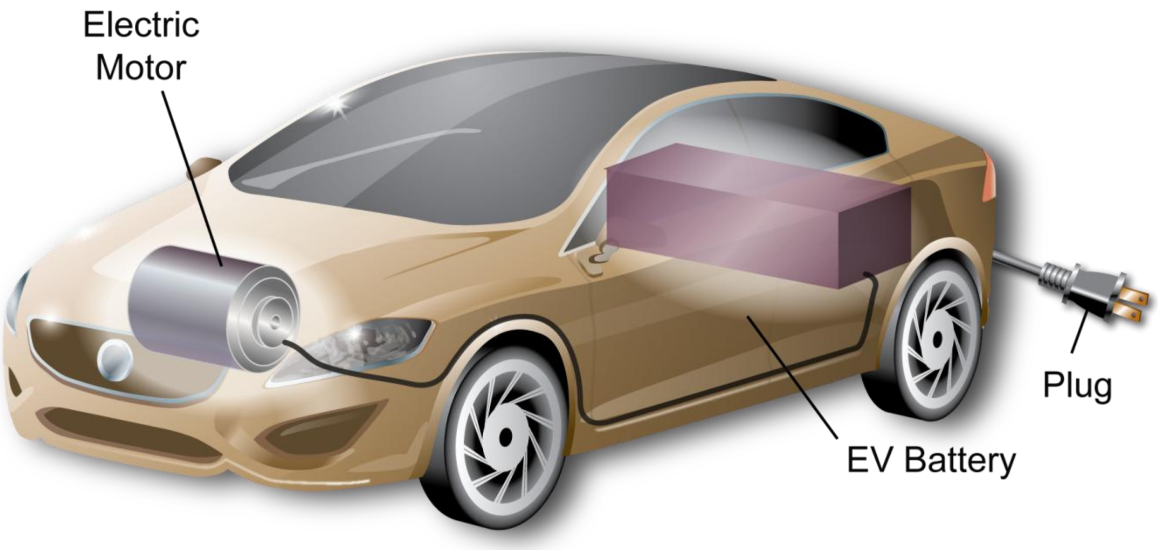
Comparison of Vehicle Technology

- Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive



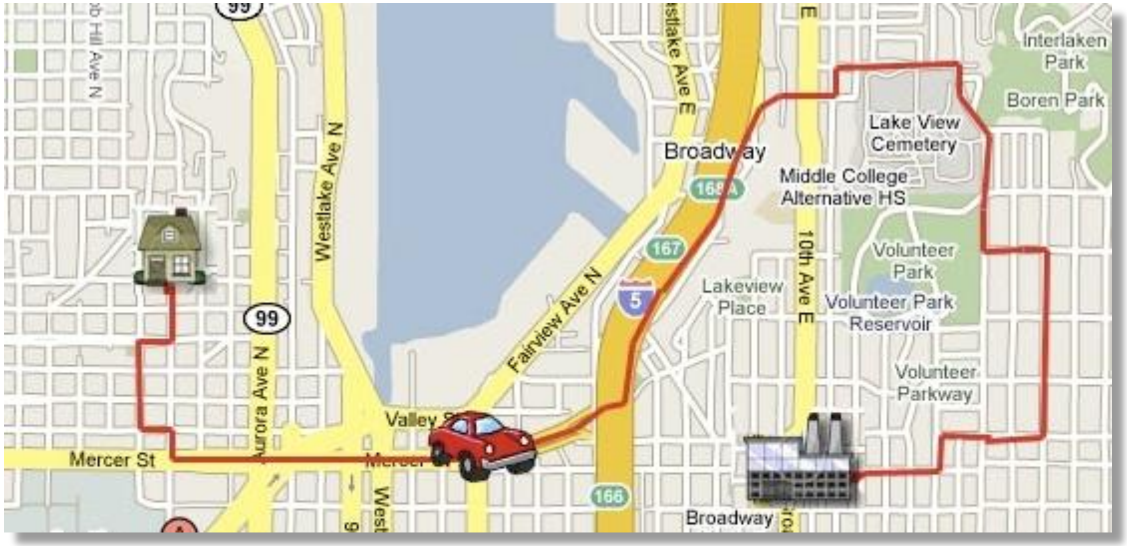
Comparison of Vehicle Technology

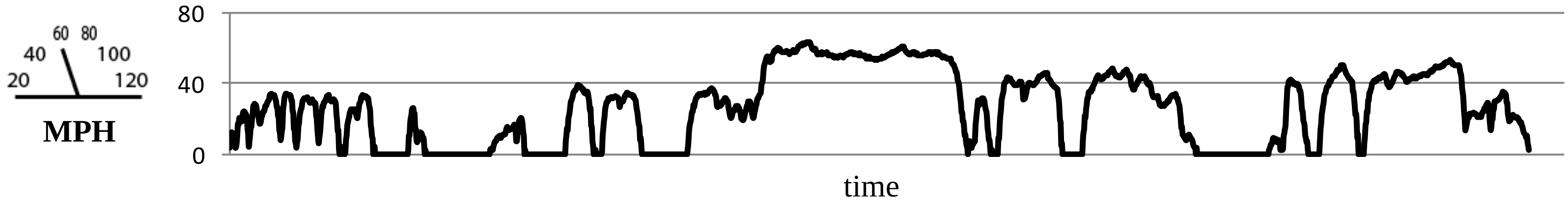
- Battery Electric Vehicle (BEV) with electric drive only



Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle





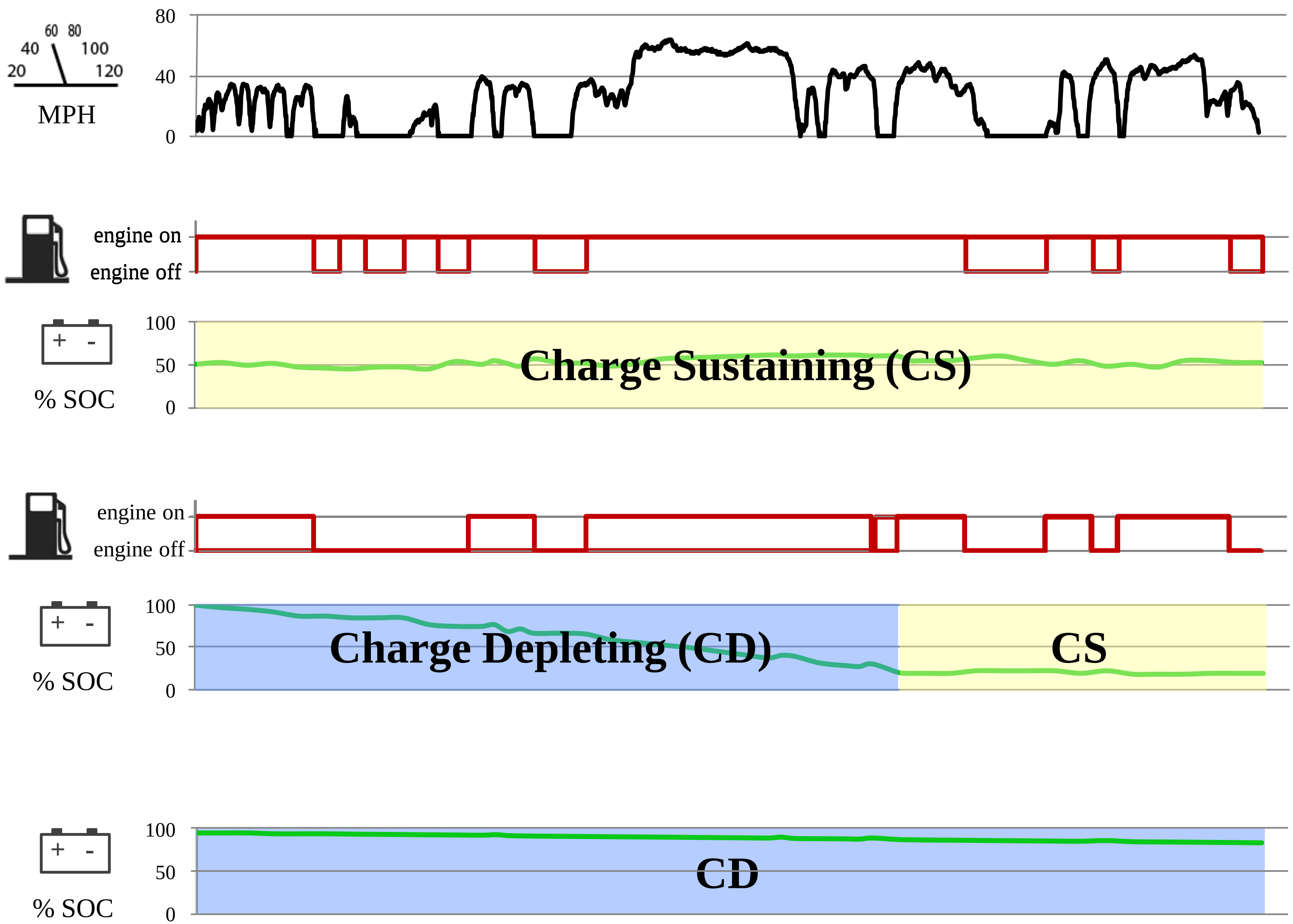
Conceptual Comparison of Vehicle Operation

Conventional vehicle

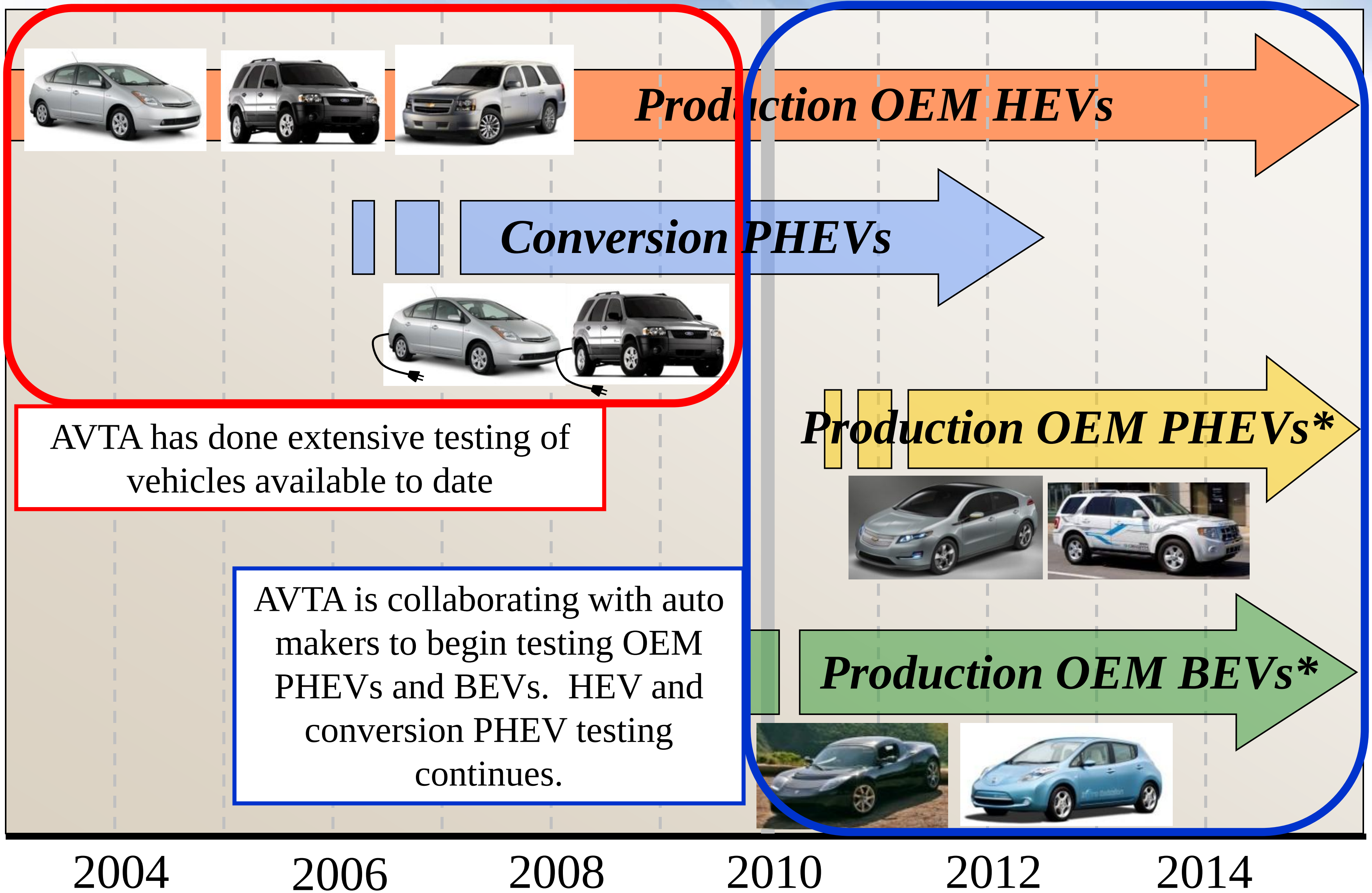
HEV

PHEV10
(blended)
(all-electric
capable)

BEV
(100 mi
range)



Timeline of Advanced Electric Vehicle Availability



* Refers to PHEVs and BEVs produced for the mass market. OEMs have produced PHEVs and BEVs in low volume intermittently since the 1990's.

Opportunities for You in the Auto Industry

The industry has shrunken dramatically

- Sales

Year	Annual North American Light-duty Passenger Vehicle Sales
2007	16,089,222
2008	13,194,563
2009	xxx

Source: Ward's AutoInfoBank, Ward's Automotive Group

- Lay-offs

"A big year for auto industry layoffs"

Publication: Manufacturing & Technology News

Date: March 11, 2007

The U.S. automotive industry has announced the layoff of almost 90,000 workers so far this year, and this year's total could top the 110,000 announced layoffs made last year, according to Challenger Gray & Christmas…

Source: http://www.allbusiness.com/manufacturing/3895023-1.html

HOWEVER…

Opportunities for You in the Auto Industry

… Auto companies and suppliers are aggressively recruiting engineers with specialized skills in:

- Design, integration, and testing of
  - High voltage power electronics
  - Electric motors
  - Batteries
  - Auxiliary electric systems (electro-hydraulic regenerative braking systems, electric power steering, etc.)
- Controls development and verification
- Noise, vibration, and harshness (NVH) systems integration and testing
- Vehicle network communications protocols
- Anything with the word BATTERY in it!

How to Develop These Skills

- Undergraduate coursework and projects
  - Mechatronics
  - Analog and digital controls
  - Embedded controls programming
  - Vehicle design projects that involve electrical and mechanical systems
- Graduate courses focused on electric vehicles and grid integration
- Student competitions

There's no substitute for hands-on experience (with proper safety supervision!)

EcoCar

A DOE advanced vehicle technology competition meant to simulate a real-world integrated vehicle design and development process. Develop vehicles following a modified GM Global Vehicle Development Process (GVDP) and deliver a fully developed vehicle equivalent to a prototype ready for a production decision.

Leading edge automotive technologies with the focus of minimizing environmental impacts and pathways Towards a sustainable transportation future. Only fuels approved for use in EcoCAR are E10, E85, B20, compressed gaseous hydrogen, and electricity.

Ohio State University
University of Victoria
Mississippi State University
Embry-Riddle Aeronautical University
University of Waterloo
Virginia Polytechnic Institute and State University
Pennsylvania State University
West Virginia University
Rose-Humlan Institute of Technology
Missouri University of Science & Technology
Georgia Institute of Technology
University of Wisconsin-Madison
University of Ontario Institute of Technology
Michigan Technological University
Texas Tech
North Carolina State University
Howard University

SAE Formula Hybrid

Students design, build and race high performance, fuel efficient plug-in hybrid vehicles

Arizona State University
Brigham Young University
California Polytechnic State University
California State Polytechnic University
Case Western Reserve University
Colorado State University
Dartmouth College
Drexel University
Embry-Riddle Aeronautical University
Ferris State University
Florida A&M University
Florida Institute of Technology
Illinois Institute of Technology
Lawrence Technological University
McGill University
Milwaukee School of Engineering
National Chiao Tung University
New Hampshire Technical Institute
North Carolina State University
Oakland University
Politecnico di Torino
Rensselaer Polytechnic Institute
San Jose State University
Sardar Vallabhbhai National Institute of Technology
St Cloud State University
Technical University Russia
Texas A&M University
Thapar University
Tufts University
University of Alabama - Tuscaloosa
University of California - Davis
University of California - Irvine
University of California - San Diego
University of Houston - College of Technology
University of Illinois at Urbana-Champaign
University of Manitoba
University of Vermont
University of Wisconsin - Madison
Wentworth Institute of Technology
Yale University

0 – 60: 3.9 secs 80 mpg

Advanced Electric Drive Graduate Programs with DOE awards

- Colorado State
- West Virginia University
- Purdue University
- Missouri University of Science & Technology
- Wayne State University
- Michigan Technological University
- University of Michigan

Conclusion

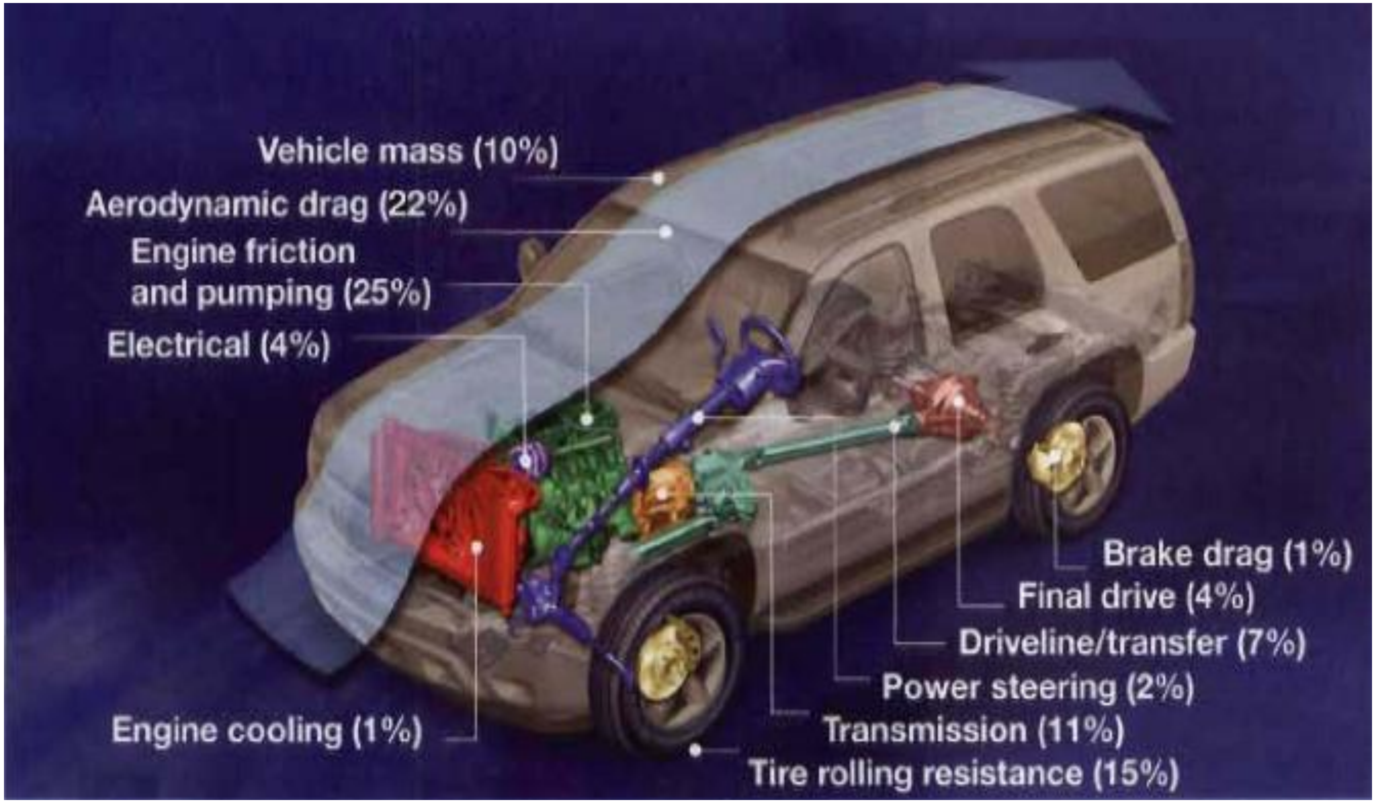
- The progression toward vehicle electrification is under way
- There are a lot of forces at work that may speed or slow the progression, not the least of which is technology development
- One thing is certain:

  Engineers with specialized skills required for electric vehicle and charging infrastructure product development are in high demand

APPENDIX

Vehicle Losses

Example: Chevrolet Tahoe (non-hybrid)



Source: Automotive Engineering International, March 2010

What Do Engineers Do All Day?

- Communicate
- Paper work
  - Conduct business processes for project management, safety, procurement, budgeting, etc.
- Engineering
  - Define, design, analyze, create, test/verify, iterate
  - Create models based on first principles (what you go to school to learn how to do)
  - Create models based on experimentation/testing and past experience (institutional knowledge)
  - Use models to create something
  - Verify it works (… it probably won't) and figure out why not
- Logistics
- Reporting

It's all about problem solving!

Automotive Engineering Challenges

- Increasing product complexity
- Pressures on:
  - Minimizing cost
  - Decreasing time to market
  - Continuously improving quality
- High volume
- All done in an extremely large business enterprise

But the test drive makes it all worth it!