A Big Picture Overview of Electric Drive Vehicles

BYU-I Automotive Department

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INL/MIS-10-19287

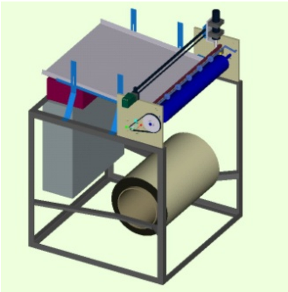
www.inl.gov

Idaho National Laboratory

Personal Background

Living the dream

- BSME from BYU (Provo), 2001
- Internships and senior design project during undergraduate program

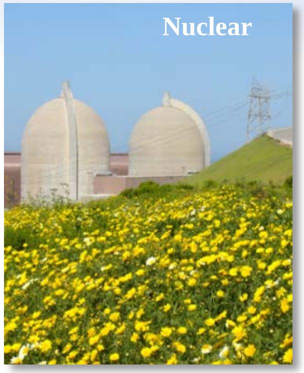


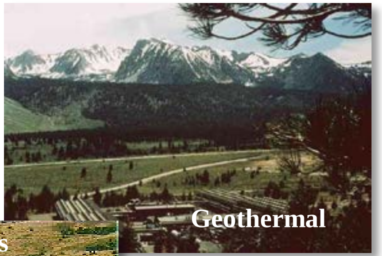
- Ford Motor Company 2001 – 2007
  - Product design engineer in Powertrain Product Development

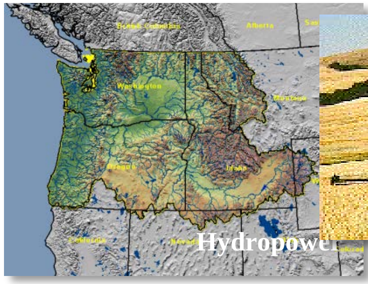
- Idaho National Laboratory 2007 – present
  - Vehicle test engineer in Energy Storage and Transportation Systems Dept.

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 North America 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

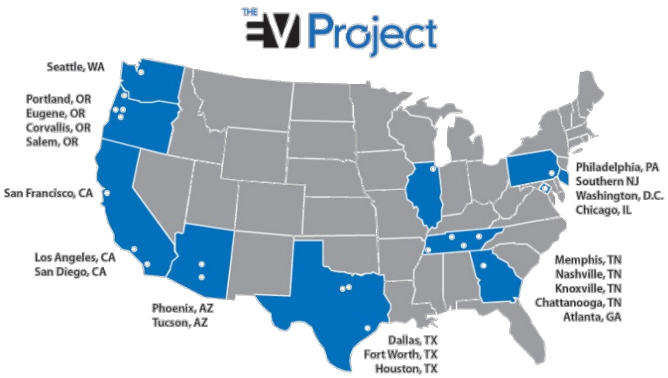
AVTA Testing by Technology

- Full-size battery electric vehicles (BEV)
- Extended range electric vehicles (EREV)
- Plug-in hybrid electric vehicles (PHEV)
- Hybrid electric vehicles (HEV)
- Neighborhood & Urban electric vehicles
- Hydrogen internal combustion engine vehicles

The EV Project

- INL is partner with ECOtality N.A. in largest electric vehicle charging infrastructure demonstration ever undertaken
- 19 metropolitan areas
  - Washington, Oregon,, California,
  - Arizona, Tennessee, D.C.
- 8,000 Nissan Leaf and Chevrolet Volts
- 13,000 Blink charging units

www.theevproject.com



Project Supporter

Transportation Oil Dependency

Areas of concern

- Energy security
  - Insufficient domestic supply of easily obtainable oil forces us to rely on imports

www.kotc.com.kw/fleetlist.html

- Global climate change
  - Tailpipe and smoke stack green house gas emissions

www.greentechmedia.com/articles/read/epa-grants-california-emissions-waiver

- Economic stability
  - Unbalanced supply and demand affect all levels of the economy (global, national, personal)

Electric Drive Vehicles as a Solution to Oil Dependency

Advantages of Plug-in Electric Vehicles

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

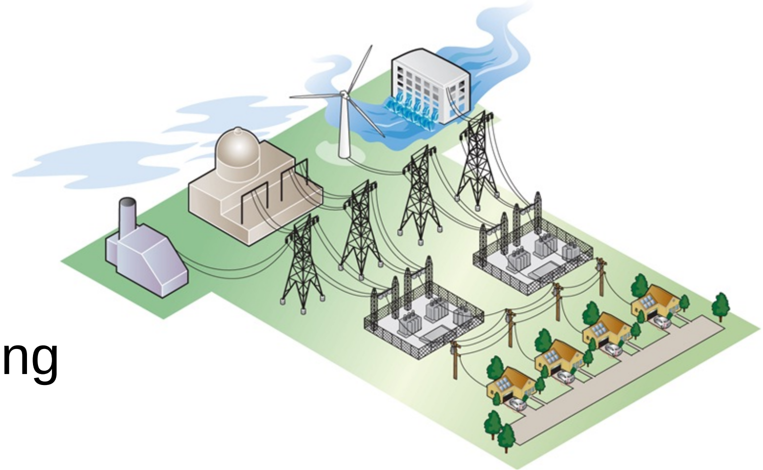
Pre-production image of Chevrolet Spark with Clipper Creek level 2 charging unit from http://www.chevrolet.com/spark-ev-electric-vehicle.html

Electric Drive Vehicles as a Solution to Oil Dependency

Challenges with Plug-in Electric Vehicles

- Complex ,or at least new, designs affecting:
  - Product development
  - Service
  - Procedures for first responders
- 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 acceptance

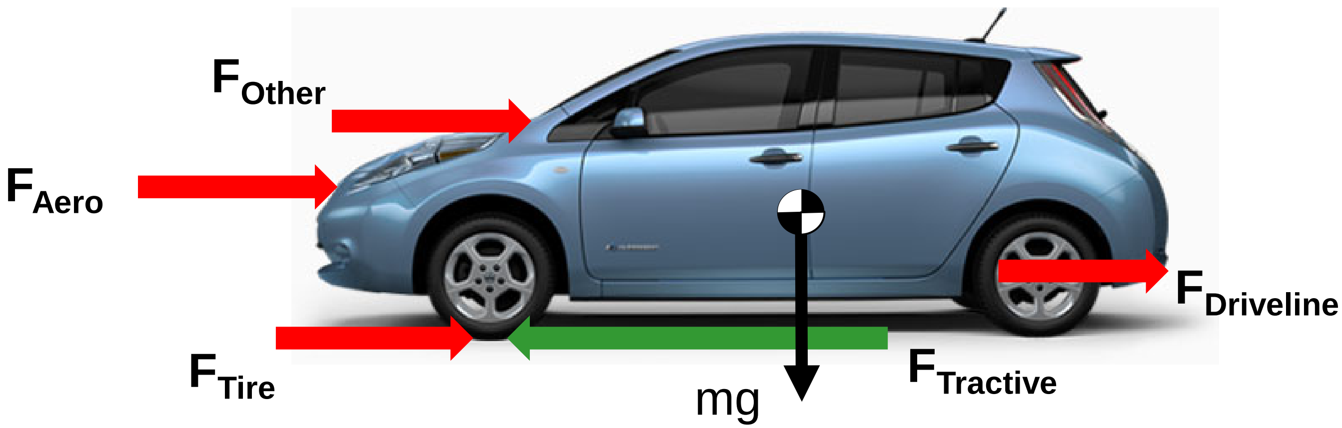
From Danish newspaper Ekstra Bladet, Oct 24, 2009
http://ekstrabladet.dk/biler/bil_nyheder/article1243890.ece



sce-smartgrid.com/content/
edison-internationals-smart-grid-vision

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?



<u>Find the power (P) required to maintain a speed of V</u>

$F_{inertial\ accel} = m_{vehicle} * a_{vehicle}$

$F_{aero} = ½\, C_D\, A_{frontal}\, \rho_{air}\, (V_{vehicle})^2$

$F_{tire\ rolling\ resistance} = C_{RR}\, m_{vehicle}\, g$

$F_{tractive} = F_{inertial\ accel} + F_{aero} + F_{driveline} + \ldots + F_{other}$

$P_{wheel} = F_{tractive} * V_{vehicle}$

<u>Find energy required to get from point A to point B</u>

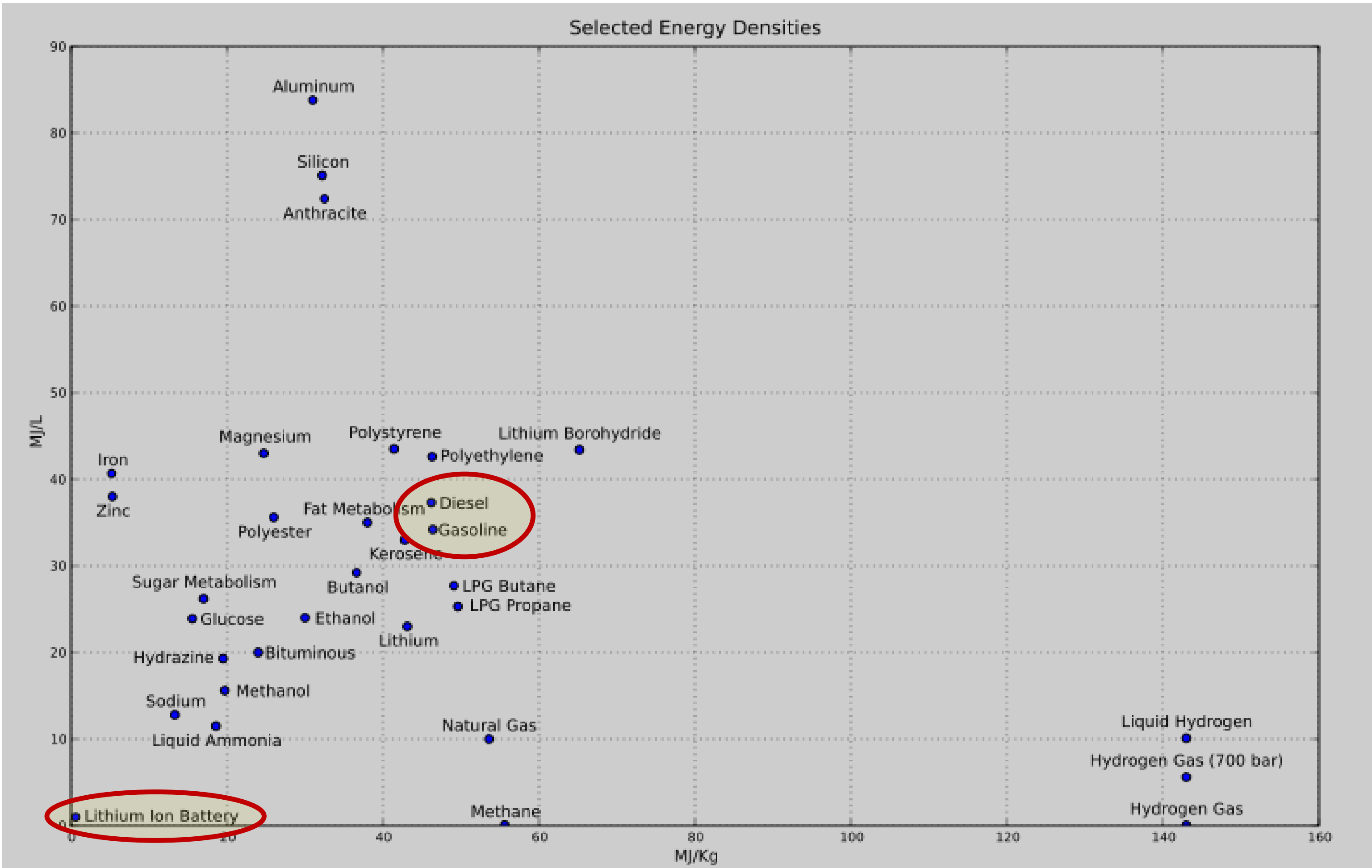
$$E_{wheel} = \int_a^b P_{wheel}\, dt$$

*** Assume Rotational Inertias are negligible**

Comparison of Energy Density of Fuels

- Onboard energy storage is the constraint

Volumetric energy density (MJ / Liter)

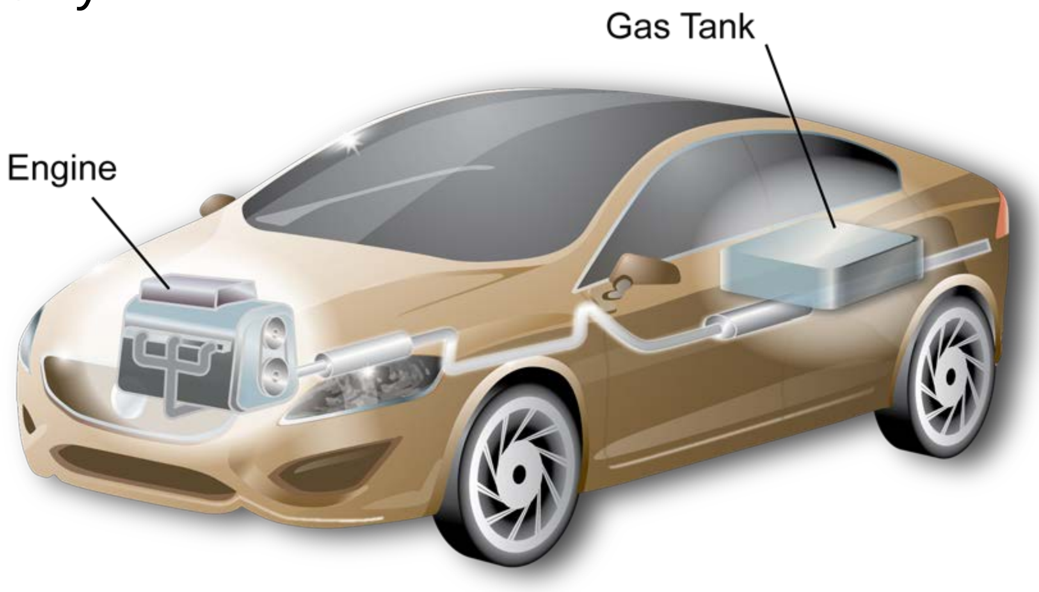


Gravimetric energy density (MJ / kg)

http://en.wikipedia.org/wiki/File:Energy_density.svg accessed July 2010

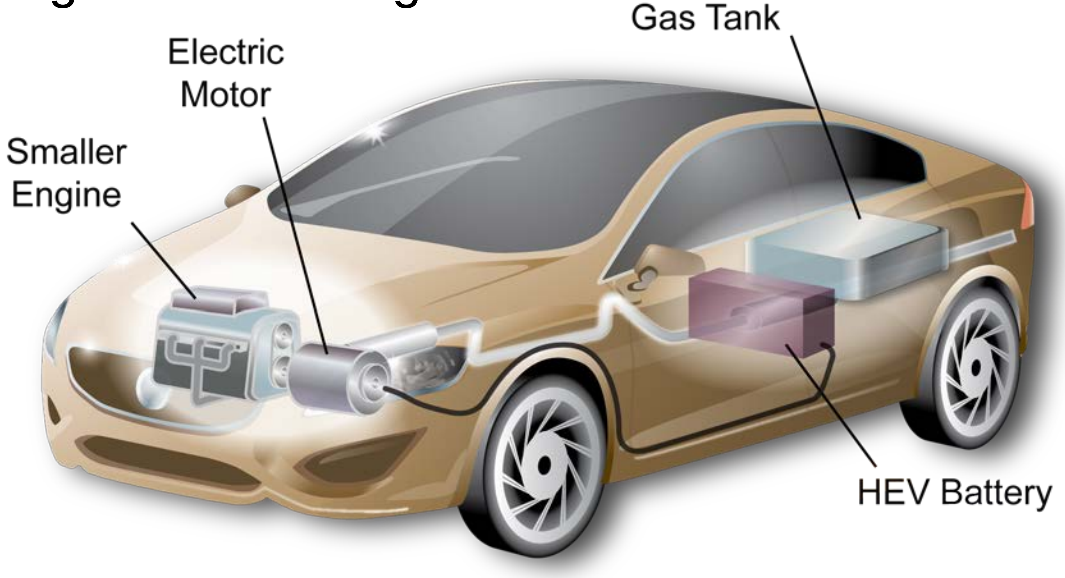
Comparison of Vehicle Technology

Conventional vehicle with internal combustion engine (ICE) only



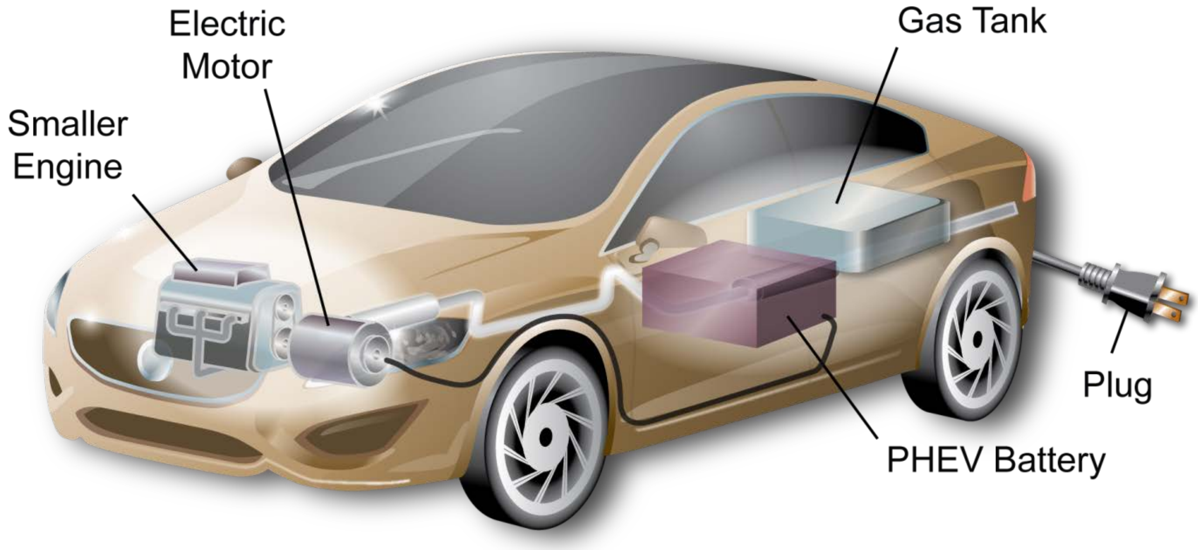
Comparison of Vehicle Technology

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



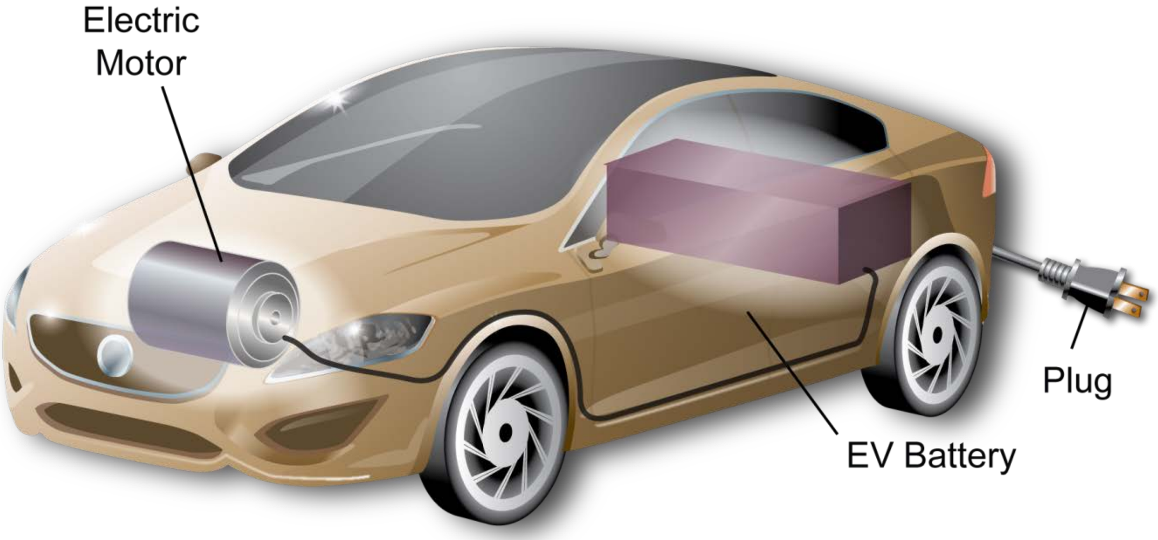
Comparison of Vehicle Technology

- Plug-in Hybrid Electric Vehicle (PHEV) or Extended Range Electric Vehicle (EREV) with ICE and electric drive



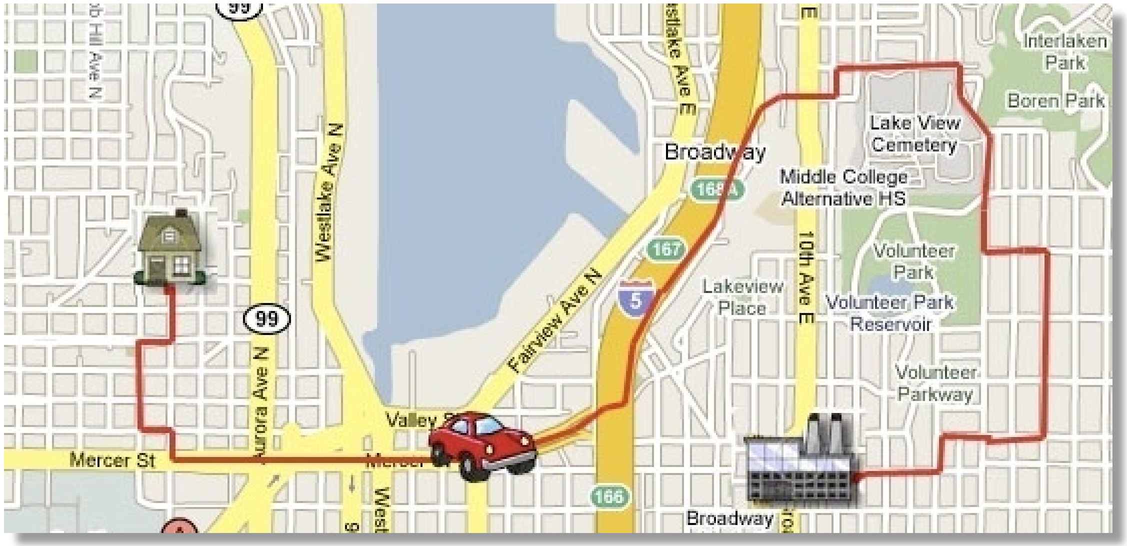
Comparison of Vehicle Technology

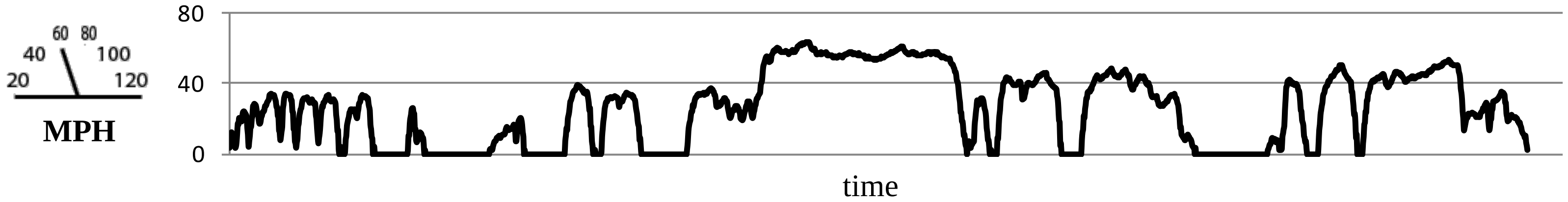
- Battery Electric Vehicle (BEV) with electric drive only



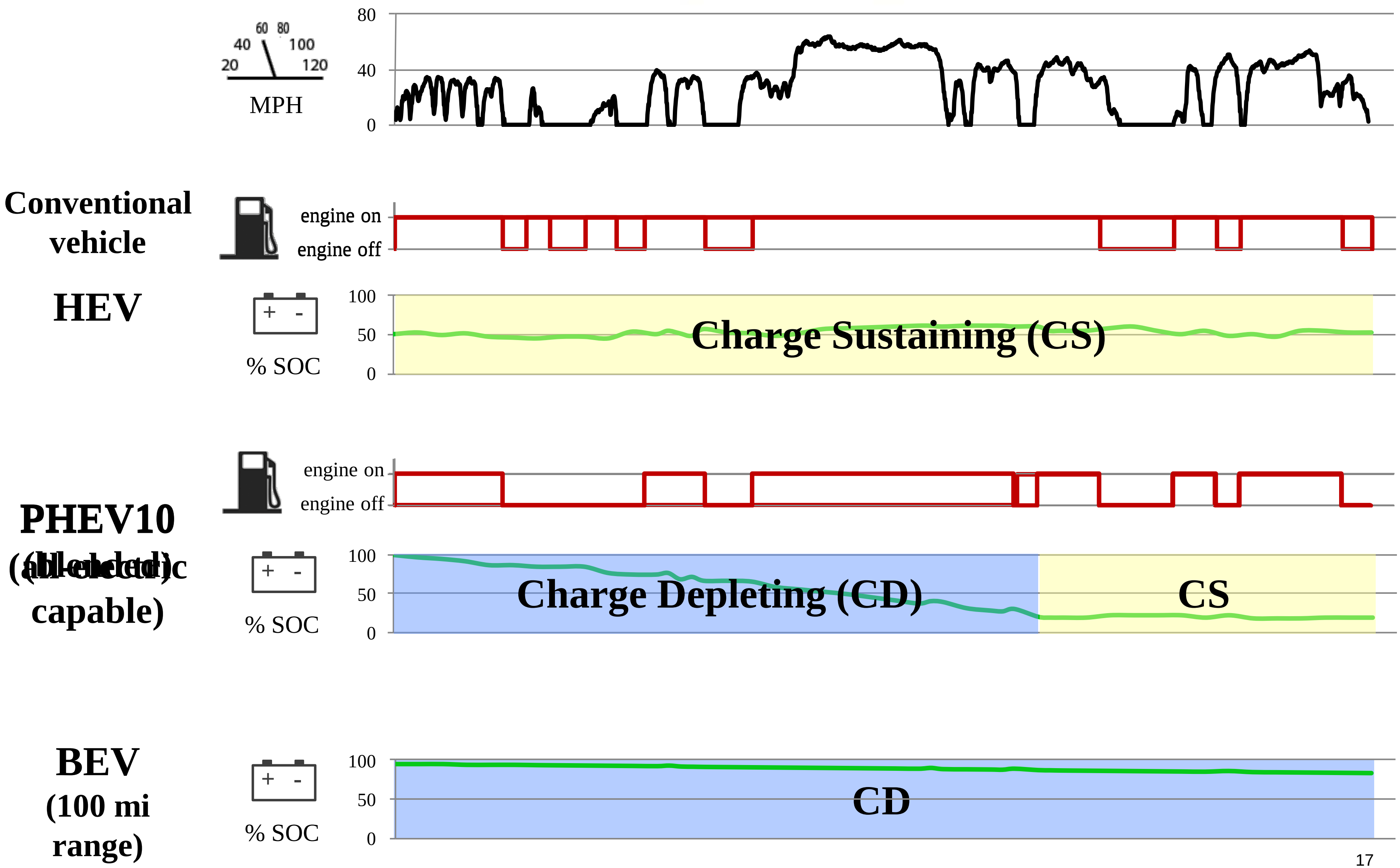
Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle



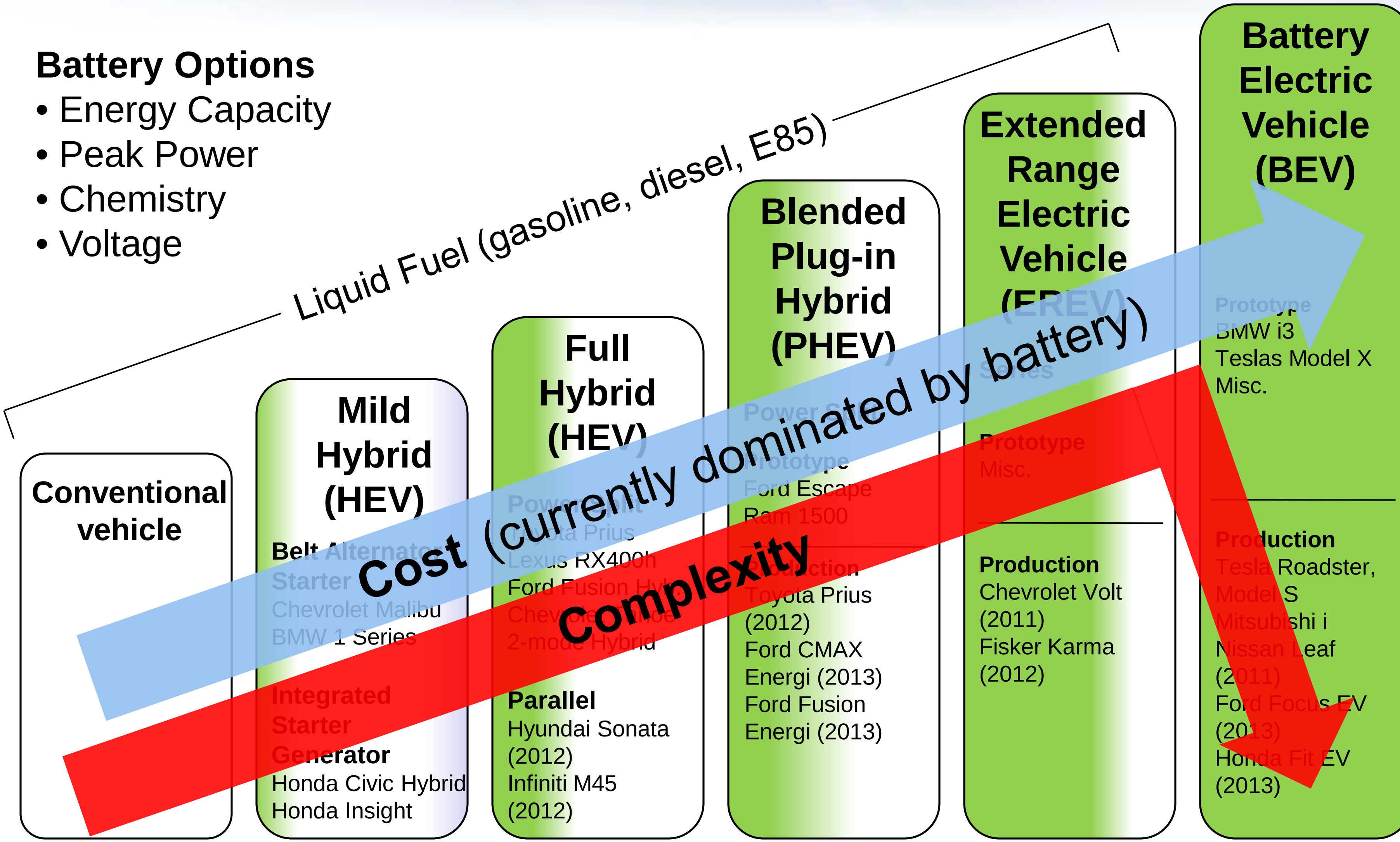


Conceptual Comparison of Vehicle Operation



Electric Drive Vehicle Powertrain Architectures

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



Dates given are approx. year for start of production

HEV Examples

Honda Insight

Chevrolet Tahoe Hybrid

Ford CMAX Hybrid

Hyundai Sonata Hybrid

Toyota Prius V

Infiniti M Hybrid

All images downloaded from manufacturers' websites Mar 2013

PHEV / EREV Examples

Toyota Prius Plug-in Hybrid

Fisker Karma

Chevrolet Volt

Ford Fusion Energi

All images downloaded from manufacturers' websites Mar 2013

BEV Examples

Tesla Model S

Honda Fit EV

Ford
Focus EV

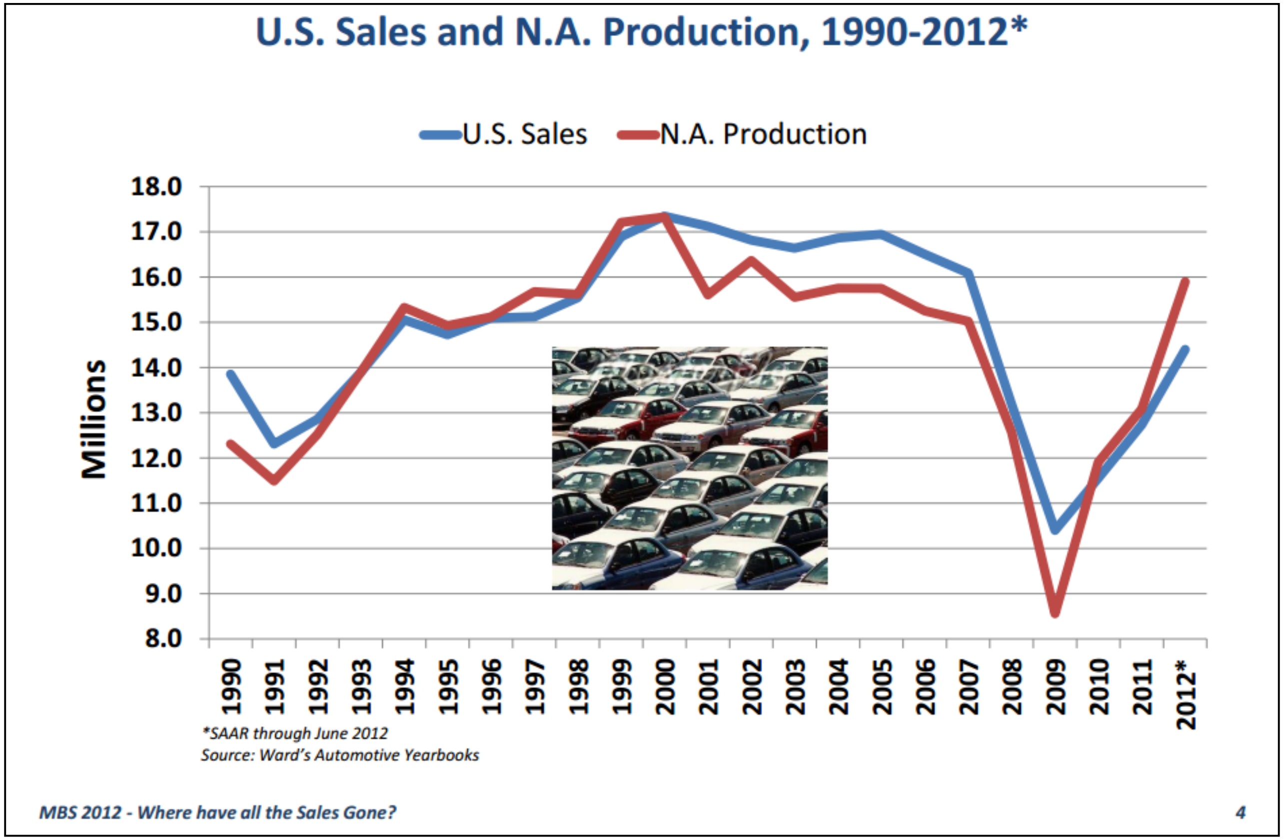
Toyota RAV4 EV

Nissan LEAF

All images downloaded from manufacturers' websites Mar 2013

Opportunities for You in the Auto Industry

The industry shrank dramatically in the recession but is now rebounding



Source: Sean P. McAlinden, "Where have all the Sales Gone?", Center for Automotive Research, http://www.cargroup.org/assets/speakers/presentations/6/mcalinden_sean.pdf, accessed Mar 18, 2013

Opportunities for You in the Auto Industry

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

- Design, development, 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

Conclusion

- The progression toward vehicle electrification is under way
- There are a lot of design options and trade-offs. What will the consumer choose?
- 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 clear:

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

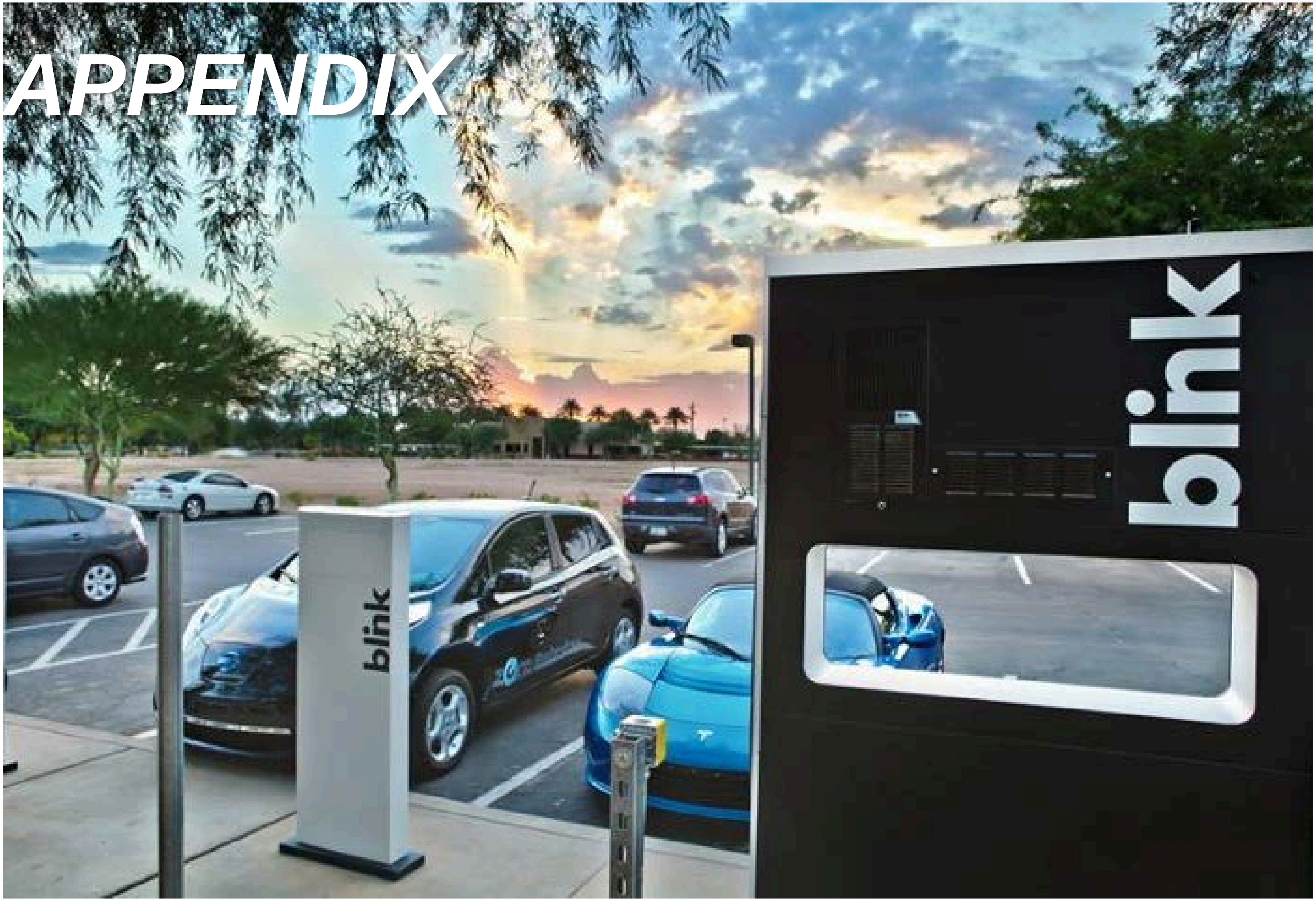
Acknowledgement

This work is supported by the U.S. Department of Energy's Vehicle Technologies Program

Additional Information

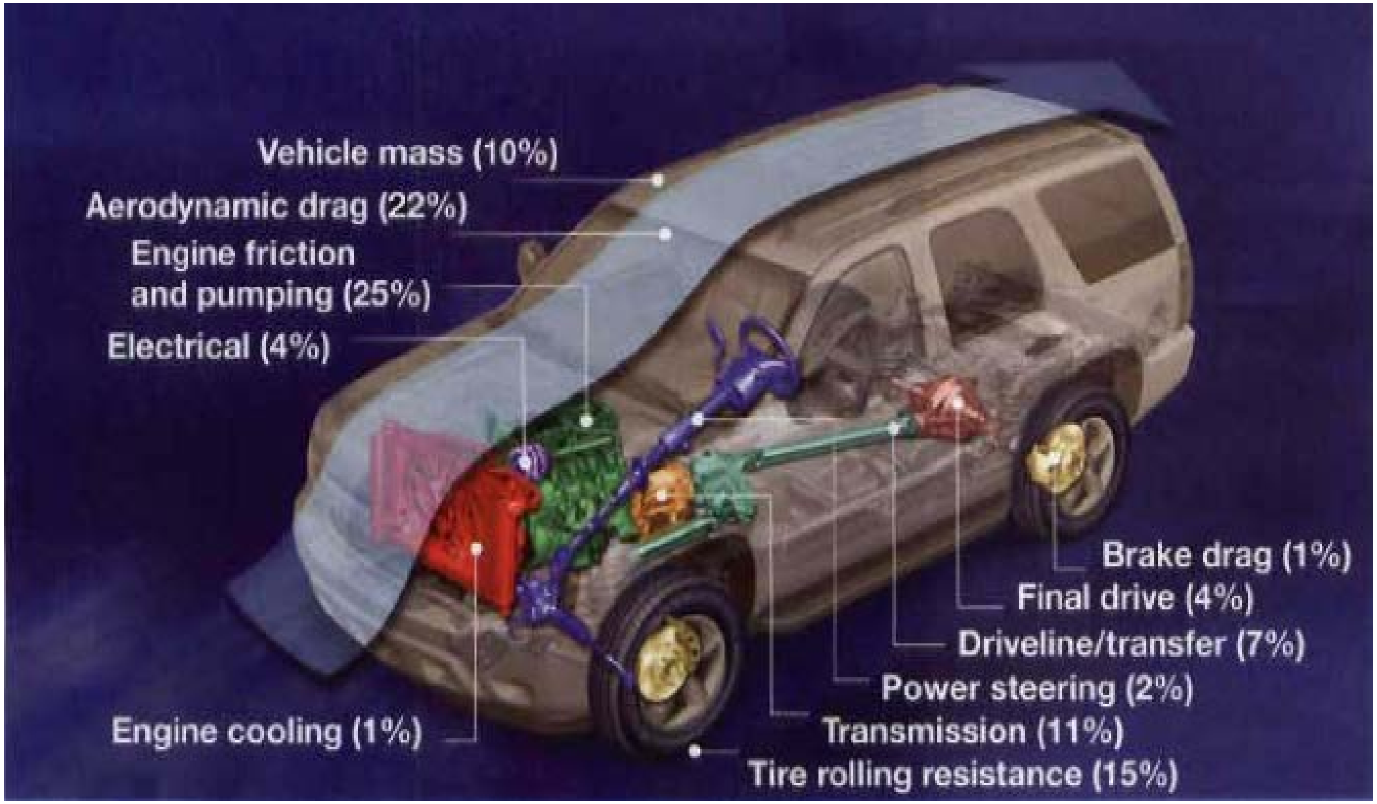
http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/

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!