Argonne NATIONAL LABORATORY

Current and Future Trends in Alternative Fuel Vehicles… A Research Perspective

Henning Lohse-Busch, Ph.D.

ANL Advanced Powertrain Research Facility

IL Chamber of Commerce Panel

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U.S. Department of Energy

Energy Efficiency and Renewable Energy

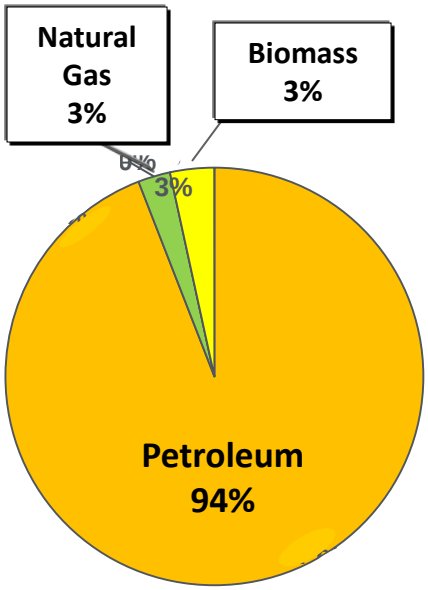
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

U.S. DEPARTMENT OF ENERGY

Outline

- Background
  - Our petroleum addiction
  - Research and technology road map
- The Basics
  - Fuel economy history
  - Physics to reduce vehicle fuel usage
  - Different types of new vehicles
- Closer look at HEVs, PHEVs and EVs
- Impacts on fuel economy
- Upstream petroleum and emissions for fuel and electricity

We Are Highly Dependent on Oil!



U.S. Transportation Fuel Share (2009)

- Transportation is responsible for 2/3 of our petroleum usage
- On-Road vehicles responsible for ~80% of transportation petroleum usage
- 240M vehicles on the road

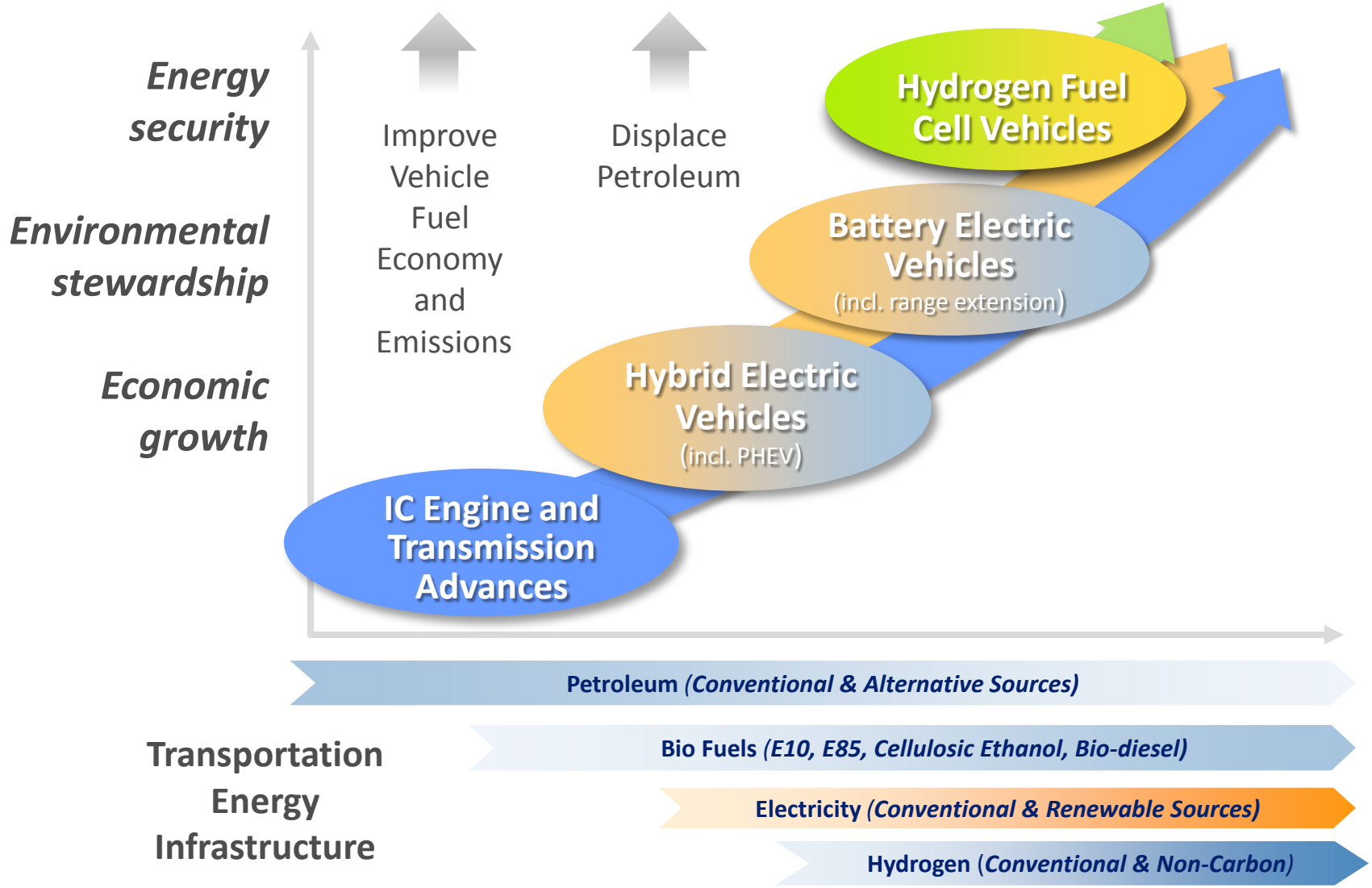
DOE/EERE Research Mission:
Decrease Petroleum Dependency & Reduce Greenhouse Gases

Develop more energy efficient and environmentally friendly highway transportation technologies that enable America to use less petroleum. The long-term aim is to develop technologies that will provide Americans with greater freedom of mobility and energy security, with lower costs and lower impacts on the environment.

Plug-in Hybrid

Alt fuels

Advanced Propulsion Road Map



U.S.DOE Advanced Vehicle Technology Research and Development Has a Diverse Portfolio

Hybrid Electric Systems

- Advanced Batteries
- Power Electronics & Machines
- HEV & PHEV
- Systems Analysis and Testing
- Electrification/Smart Metering
- Aerodynamics, Rolling Resistance & Accessory Loads

Technology Integration

- EPAct/EISA
- Rulemaking
- SuperTruck
- Clean Cities
- EcoCAR
- GATE

Advanced Combustion Engine R&D

- Low Temperature Combustion R&D
- Emission Controls
- Light- & Heavy-Duty Engines
- Waste Heat Recovery
- Health Impacts

Fuels Technology

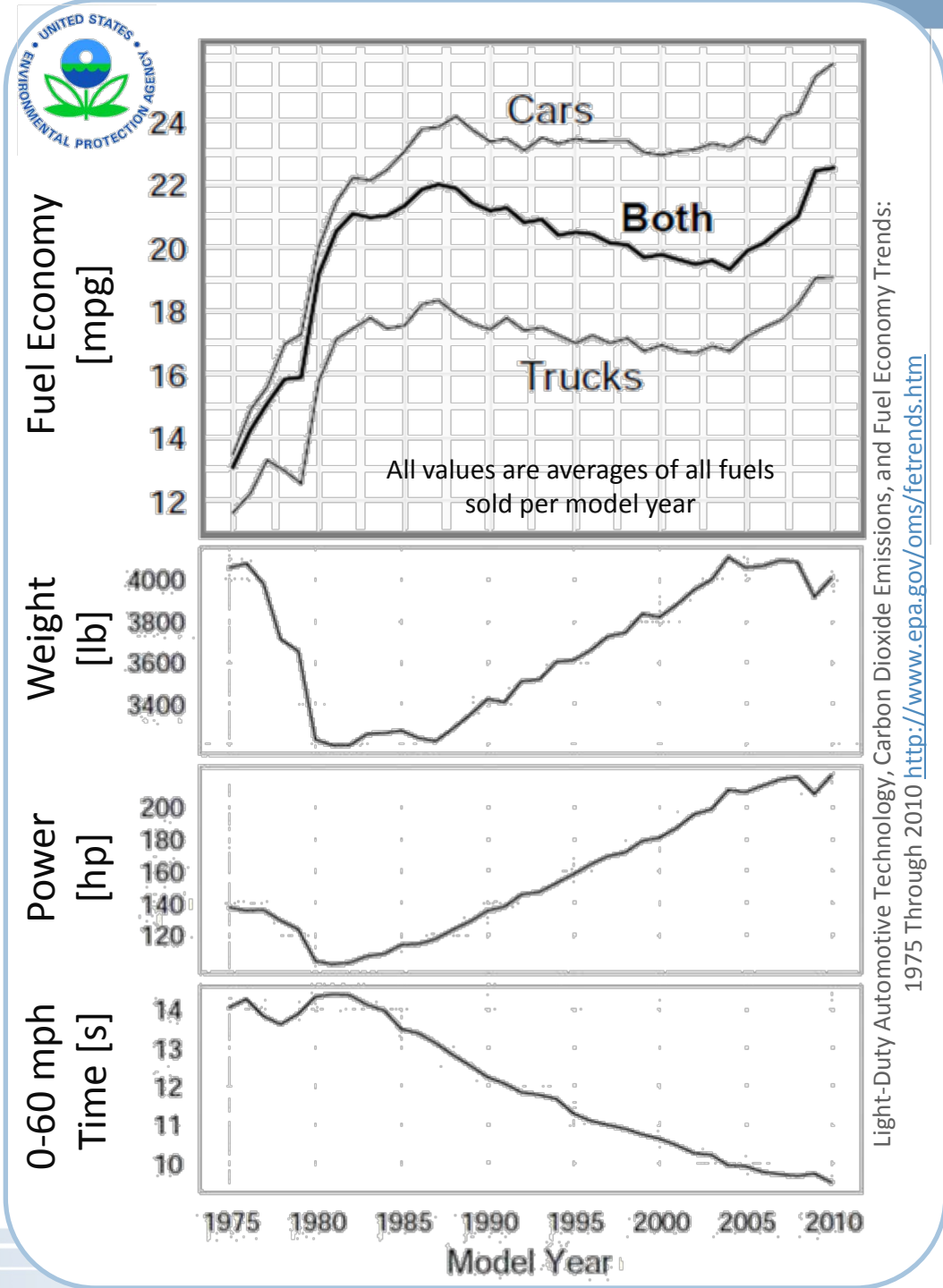
- Bio-Based Fuels
- Clean/Efficient Combustion Fuel Characteristics
- Intermediate Blends
- Advanced Lubricants

Materials Technology

- Lightweight Structures
- Lightweight Materials
- Processing/Recycling/ Manufacturing
- Design Data Test Methods
- HTML
- Propulsion Materials

Fuel Economy over the Last 35 Years

- From 1985 to 2005 fuel economy improved minimally while the engine power almost doubled
- In 2005 significance fuel economy improvements occurred corresponding to fuel price volatility at the pump and increased CAFE (Corporate Avg Fuel Economy)
- Efficiency improvements: Vehicle and engine down sizing, torque converter lock up, front wheel drive, PFI (10-15 years for max market penetration)
- 2005 improvements: hybrids, CVT, VVT, Multi valve, DFCO, …



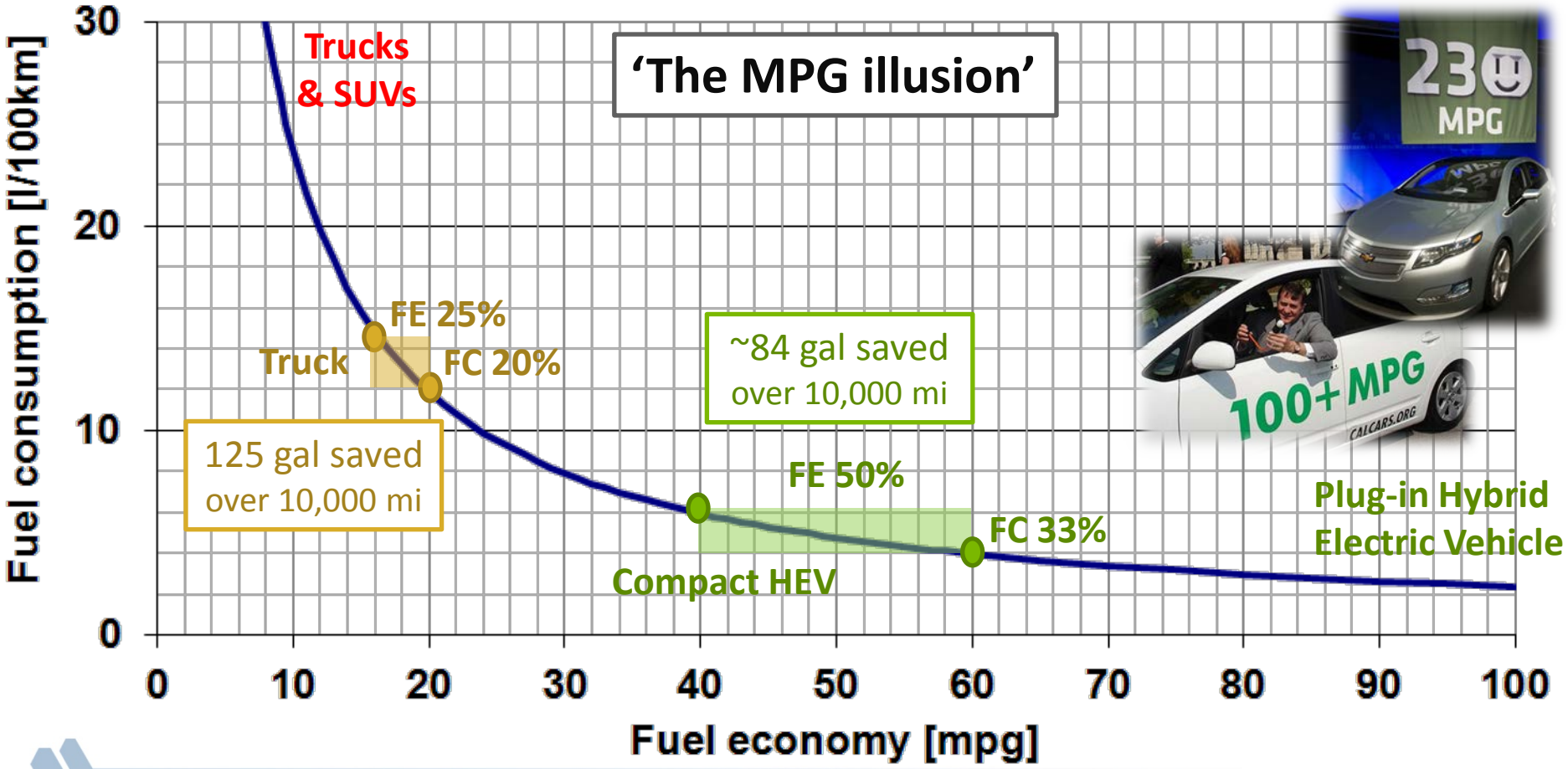
Psychology of Fuel Economy vs. Fuel Consumption

Fuel Economy = Distance / Fuel

If little fuel is used, FE *'explodes'* to a large number and becomes misleading

Fuel consumption= Fuel / Distance

FC is a better scale for very efficient vehicles!



Using Physics to Reduce Fuel Usage in Vehicles

- To reduce vehicle energy usage:
  - Reduce vehicle weight
  - Improve aerodynamics
  - Reduce friction losses (tires,…)
- Improve the powertrain efficiency:
  - Improve the engine efficiency
  - Improve transmissions (CVT, 6~8 gears, DCT)
  - Use a battery and electric motor(s) to improve average engine efficiency (Hybrid Electric Vehicle)
  - Displace petroleum by using electricity (Plug-in Hybrid Vehicle)
  - Use only electricity (Battery Electric Vehicle)

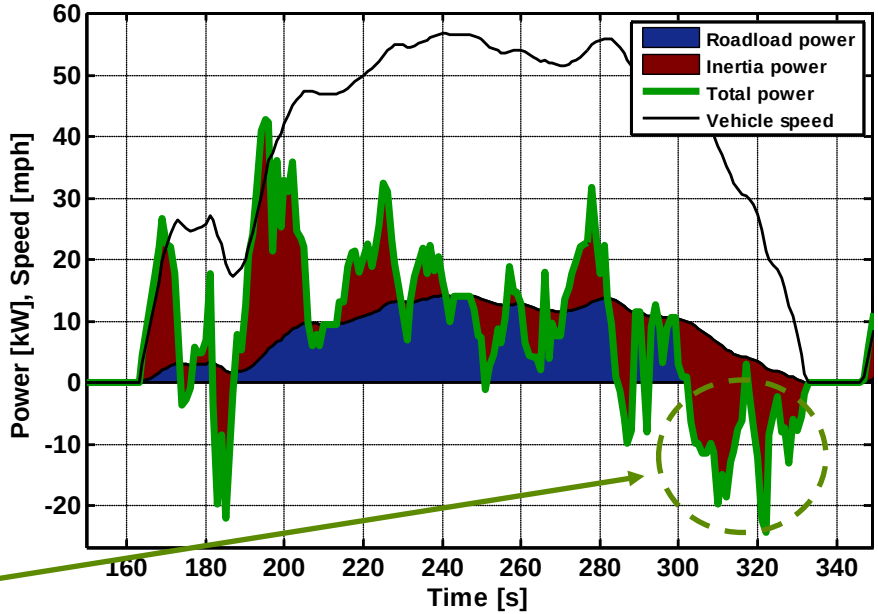
Regenerative braking possible for energy recovery

Inertia force: overcome change in momentum

Road load: caused by wind resistance and other vehicle level losses

$$Power_{propulsion} = \left(m \times \frac{\partial(V)}{\partial t} + F_{roadload} \right) \times V$$

(At the wheel)



The Conventional Vehicle

- In development for over a 110 years

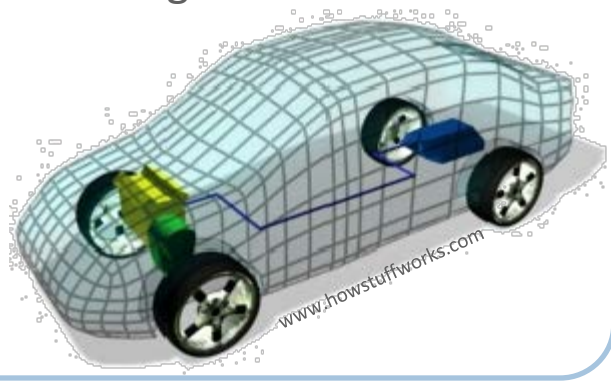
1886 → present

- Vehicles are evaluated on these criteria:
  - Fuel economy
  - Emissions
  - Performance
  - Cost / Consumer features
- Simple givens in a conventional:
  - Engine sized to meet performance, towing and gradability targets
  - Engine speed locked by transmission gear and vehicle speed

Conventional Vehicle

- Fuel: gasoline / diesel / ethanol
- Internal combustion engine
- Transmission

$\text{Power}_{\text{propulsion}}$ = Engine



Future Technology Improvements

Internal combustion engine

- Technology (DI, DFCO, engine down sizing, boosting, accessories electrification…)
- Renewable alternative fuels
- Engine idle stop feature

Transmission

- Increase in gear numbers
- Dual clutch, aggressive shift logic

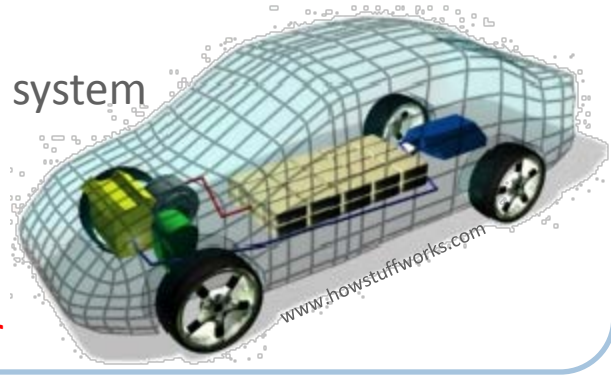
The Hybrid Electric Vehicles (HEV) and Plug In HEV (PHEV)

- Hybrid vehicles deliver improvements in fuel economy and reduction in emissions
- Additional degrees of freedom for hybrids
  - Engine operating regime
  - Engine down sizing
  - Regenerative braking
- Hybrid complication:
  - extra weight, packaging, losses and cost
- Additional complexity:
  - Hybrid architectures
  - Energy storage systems
  - Diversity of energy management and torque split management
- A PHEV has a larger battery which is discharged to displace fuel in a charge depleting mode. Once the battery is empty a PHEV behaves like an HEV. It requires charging to get fuel economy benefits.

Hybrid Electric Vehicle

- Fuel
- Internal combustion engine
- Electric motor
- Energy storage system
- Transmission

$\text{Power}_{\text{propulsion}}$
=
Engine + Motor



Future Technology Improvements

Engine and transmission
- HEVs enable different engine and transmission concepts

Hybrid system
- Energy storage systems (batteries, capacitors)
- Electric motor technologies
- Electrification of accessories

The Battery Electric Vehicle (BEV)

- The electric car is not new!

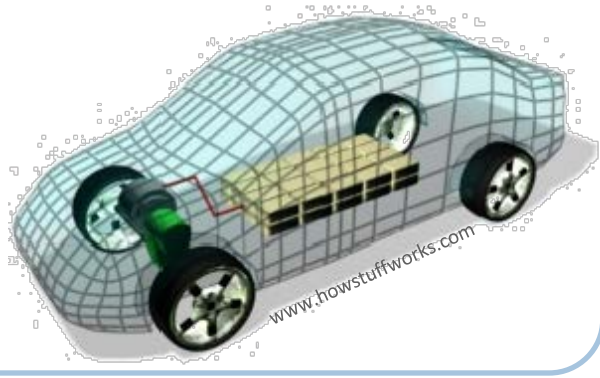
1904 present

- The recent EV revival is enabled by lithium ion batteries breakthrough in consumer electronics (cell phones, laptops, …)
- Electric vehicle complication:
  - 'Range anxiety'
  - Charge time for battery pack
- Additional complexity:
  - Zero tailpipe emissions, but upstream emissions in electric production exist
  - Large variability in energy consumption and range
  - Charger efficiency matters

Battery Electric Vehicle

- Electric motor
- Energy storage system

$\text{Power}_{\text{propulsion}}$
=
Motor



Future Technology Improvements

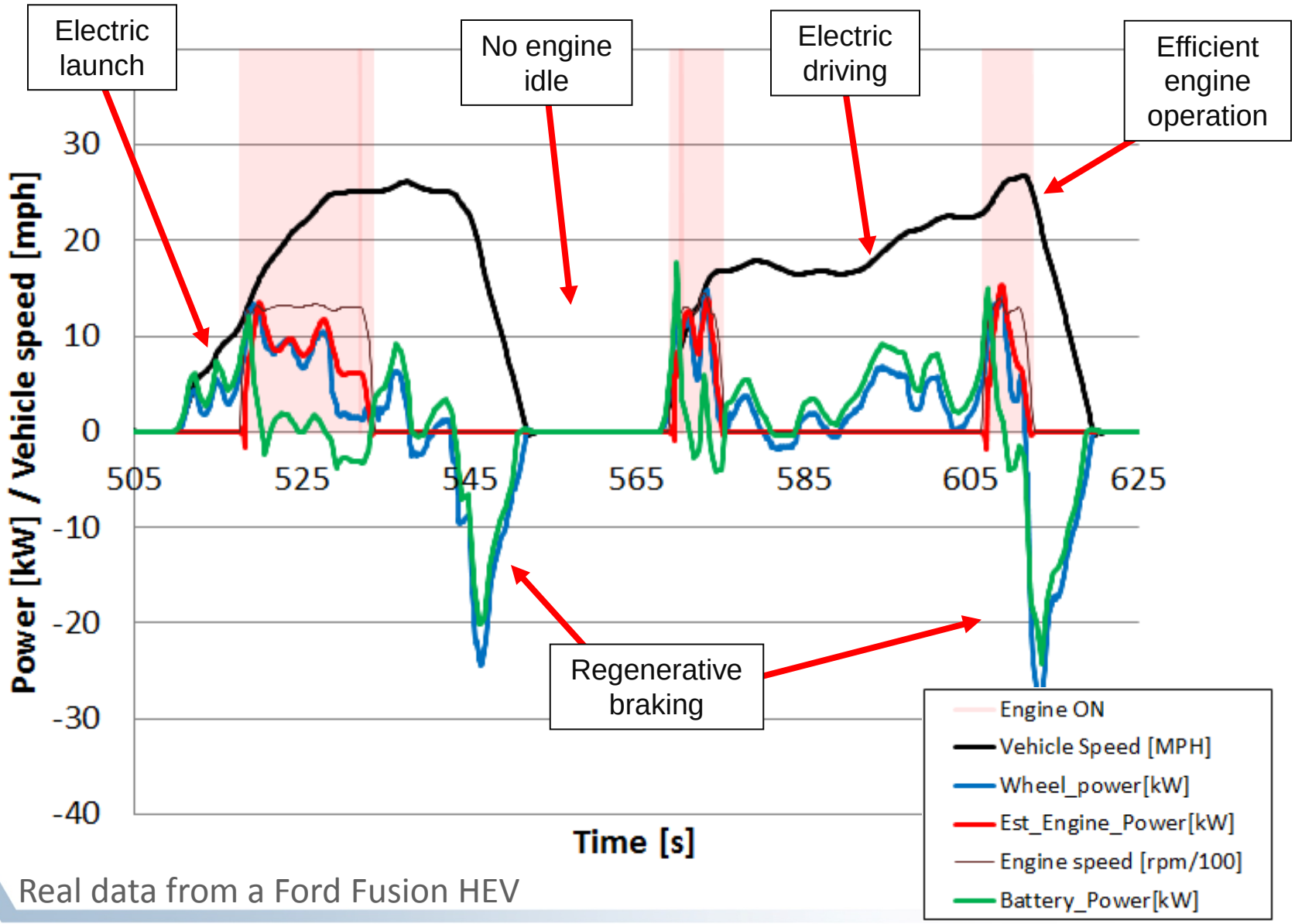
Batteries

- New chemistries, higher specific energy and power, lower cost, life and durability
- Monitoring and control algorithm

Charging

- Charging infrastructure
- Fast charging
- Wireless charging

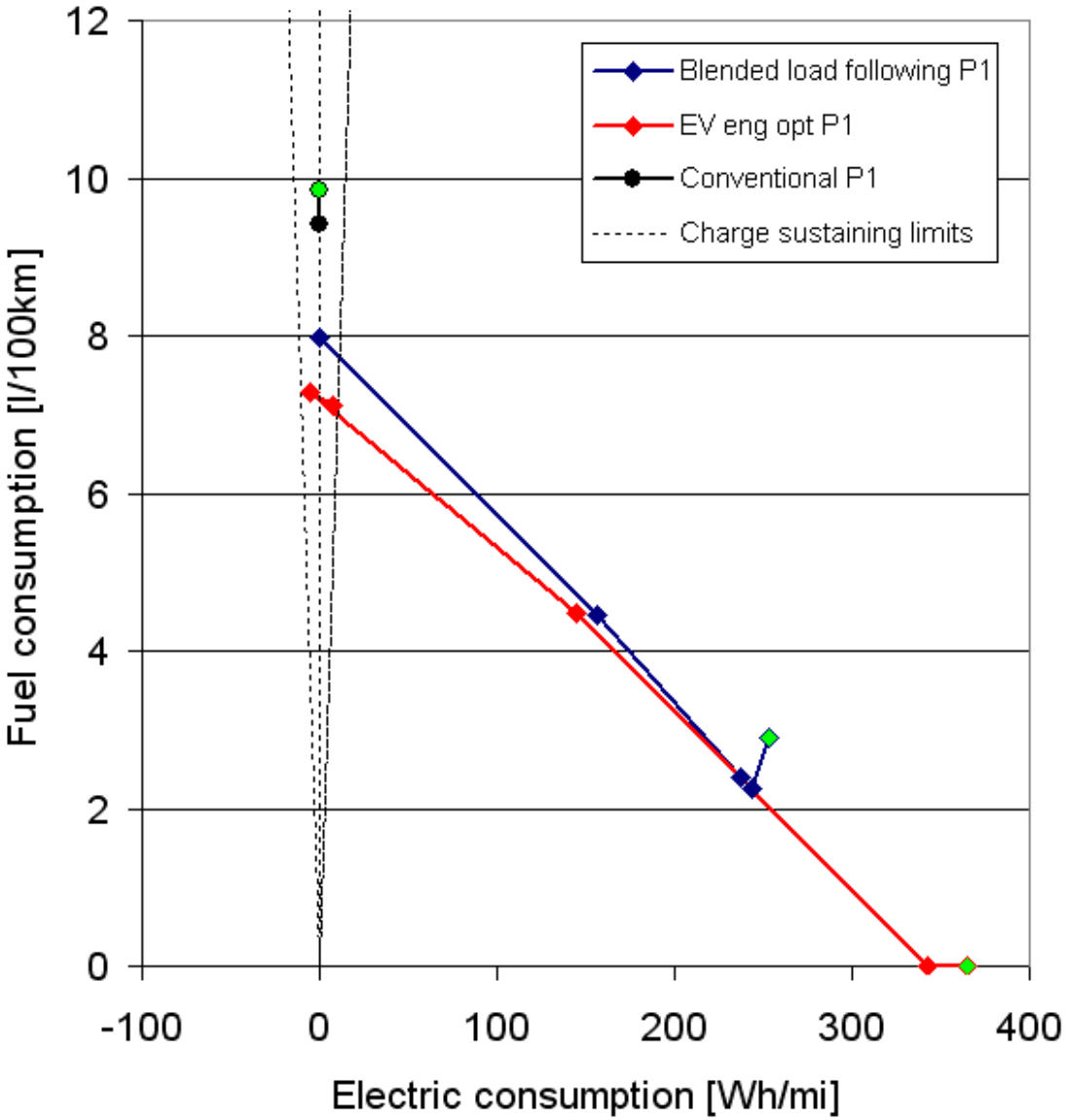
Fuel Saving Operations of Hybrid Electric Vehicle



Real data from a Ford Fusion HEV

How Do These Different Technologies Stack Up?

- Fuel consumption improvement of a conventional vehicle:
  - 16% mild HEV
  - 23% full HEV
  - 23% to 100% PHEV
  - 100% EV



Smart Grid – An Important Enabler for Success

Charge time: EV Range on a miles-per-minute

	Electric service	Charge rate	Miles per hour of charge*	Time to charge 70 mi*
Level 1	120V/20A	1.7 kW	~5	~14 hr
Level 2 (typical)	240V/20A	3.4 kW	~12	~6 hr
Level 2 (normal)	240V/40A	7.2 kW	~24	~3 hr
DC Level 2 (fast charging)	480V (3P)	50 kW	~165	~25 min
Gasoline	Fuel pump	22,000 kW	10,000 (15% avg eng eff)	

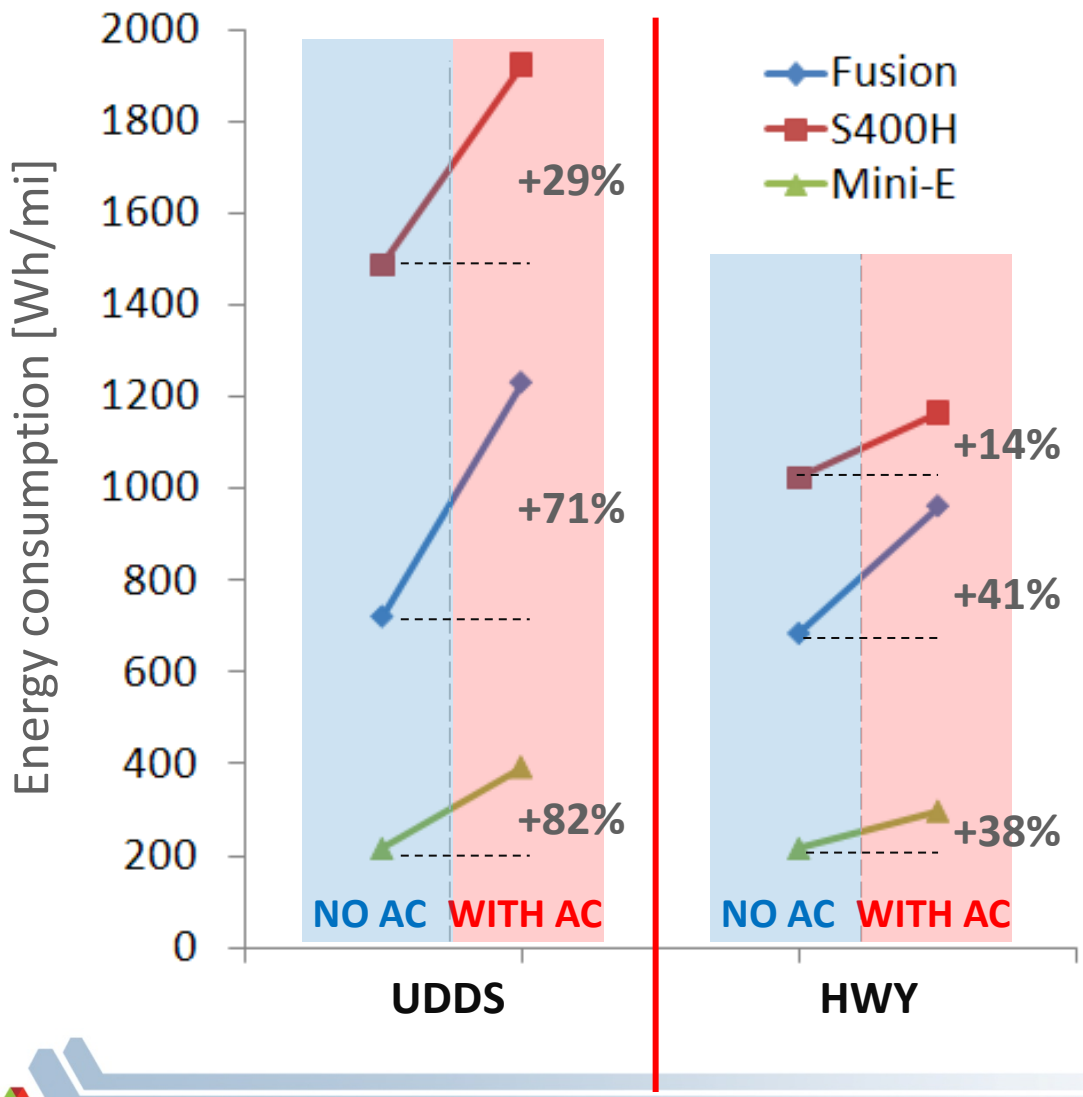
Slow

Over night charging

Charging while at the store

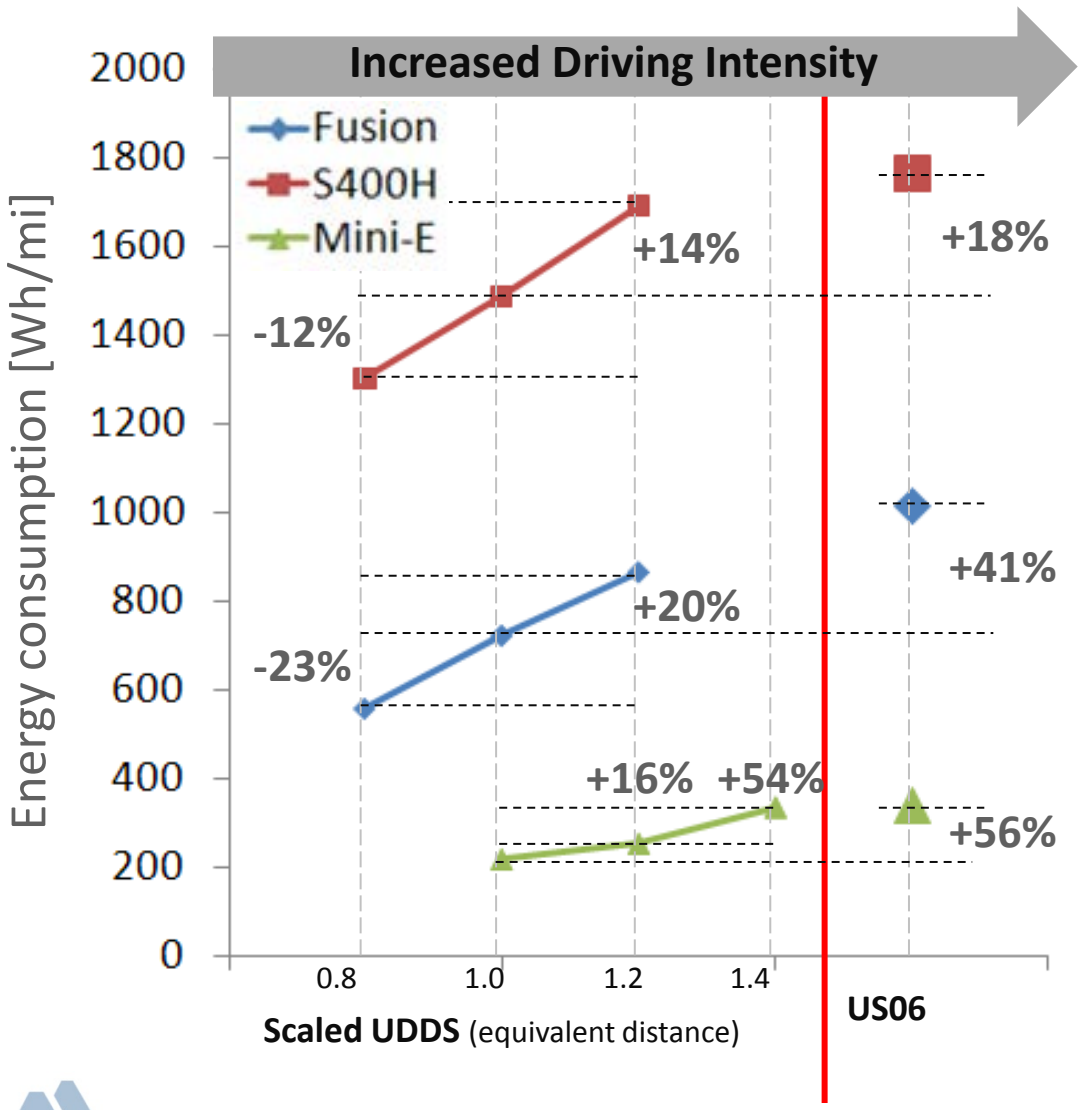
* Assumes 300 DC Wh/mi and does not include charging efficiency

Accessory use: Air Conditioning has the Biggest Impact



- The drive cycles are completed at 95 deg F (35 deg C)
- The AC impact can increase energy consumption by over 70%
- Impact of air conditioning usage is largest in city driving since extra energy is consumed during stops
- Electric vehicle energy consumption is most sensitive to air conditioning usage which has a direct impact on range

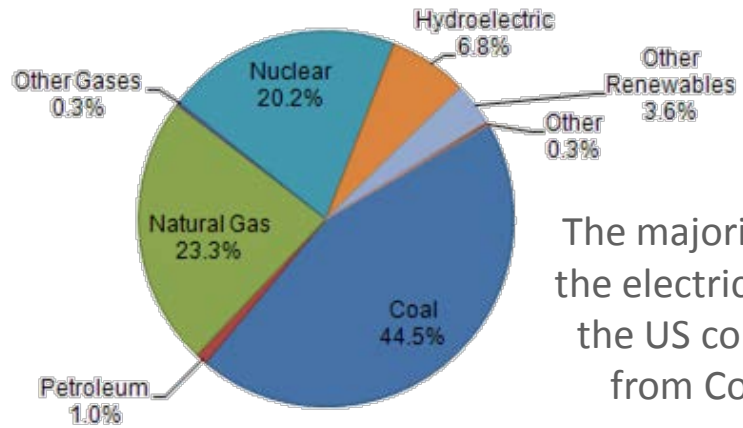
Aggressive driving: The more Aggressive You Drive the Worse Your Fuel Consumption



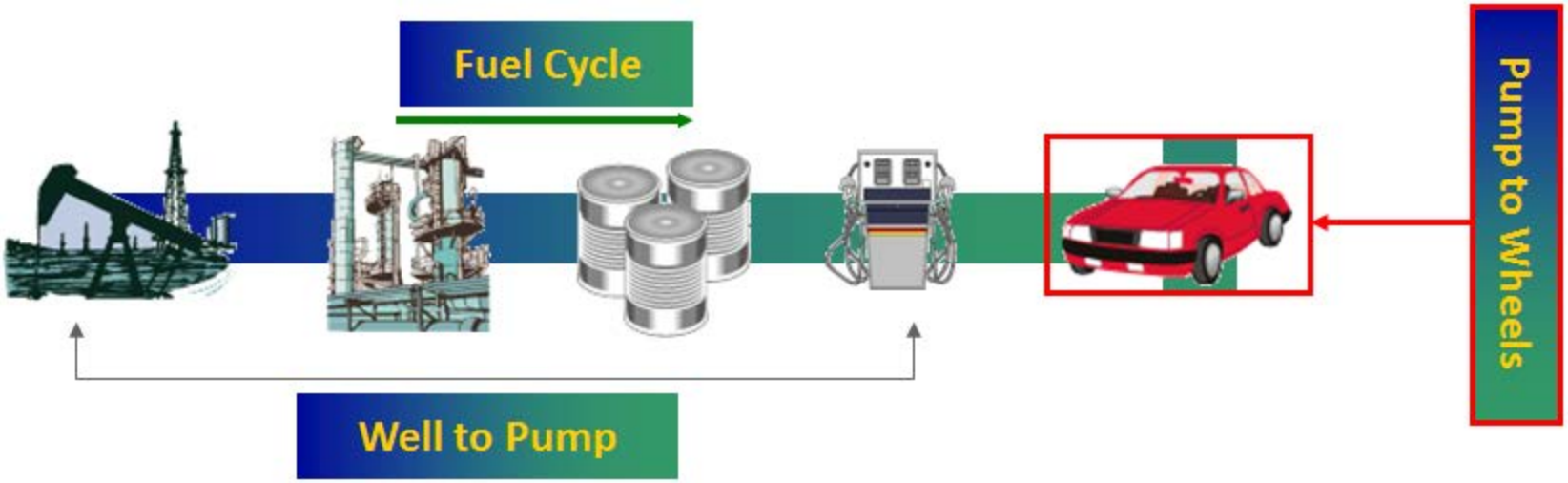
- Electric vehicle energy consumption is most sensitive to driver aggressiveness which has a direct impact on range
- Impact of driver intensity on energy consumption varies with vehicle type and powertrain

Production and Transportation of Fuel and Electricity costs Energy and Produces Emissions

- Fuels can be produced in different ways which all cost energy and produces emissions
- ANL's GREET Model Is Considered the "Gold Standard" for GHG and Total Life Cycle Analysis



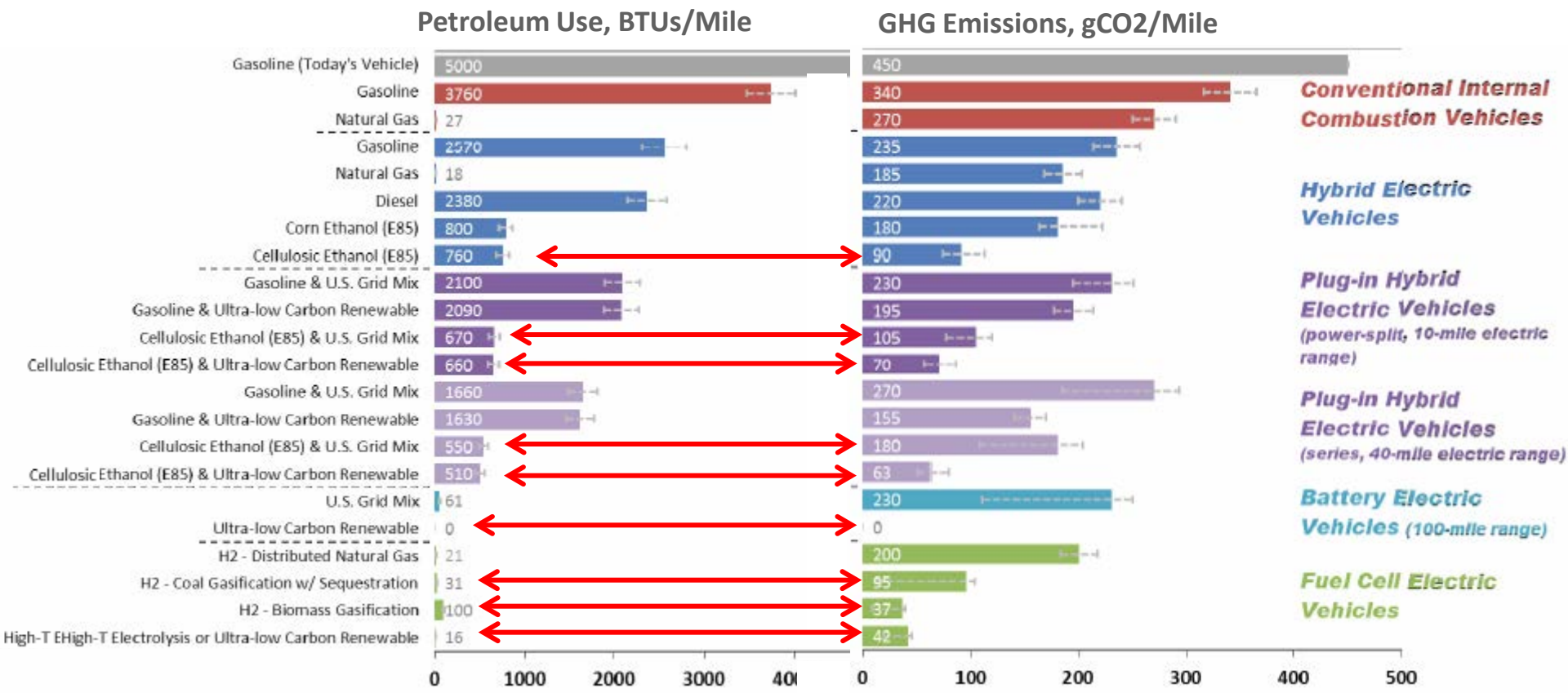
The majority of the electricity in the US comes from Coal



Results of Argonne's assessments of new fuels and advanced vehicles have been used by federal and state governments, auto industry, and energy industry in their decisions.

Environmental Footprint

Only Transportation Options That Achieve Very High Petroleum Reductions and Very Low Carbon Emissions Combine Electric Drive With Low Carbon Fuels



Conclusions:

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- In the near future there is no silver bullet, we'll just have many different bullets for a portfolio of vehicle technologies
- Advanced conventional vehicles, HEVs, PHEVs, BEVs and alternative fuel are these bullets which will help the US reduce their petroleum dependence
- PHEVs results are particularly difficult to explain to the consumer. More then every EPA's disclaimer is true: 'Your Fuel Economy May Vary' from 20 mpg to infinite!
- Air conditioning and driver aggressiveness have very large impact on fuel and energy consumption
- Upstream energy and emissions of fuel and/or electricity are essential to determine the impact of an advanced technology vehicles in terms of energy efficiency and environmental impact

Choosing the right vehicle for a consumer becomes difficult with the selection of more advanced, diverse and efficient the automotive technologies to obtain largest fuel consumption benefits