The STG Lecture Series

EV-01
Introduction to Vehicles & Transportation

Presented by

Don Hillebrand

April 22, 2014

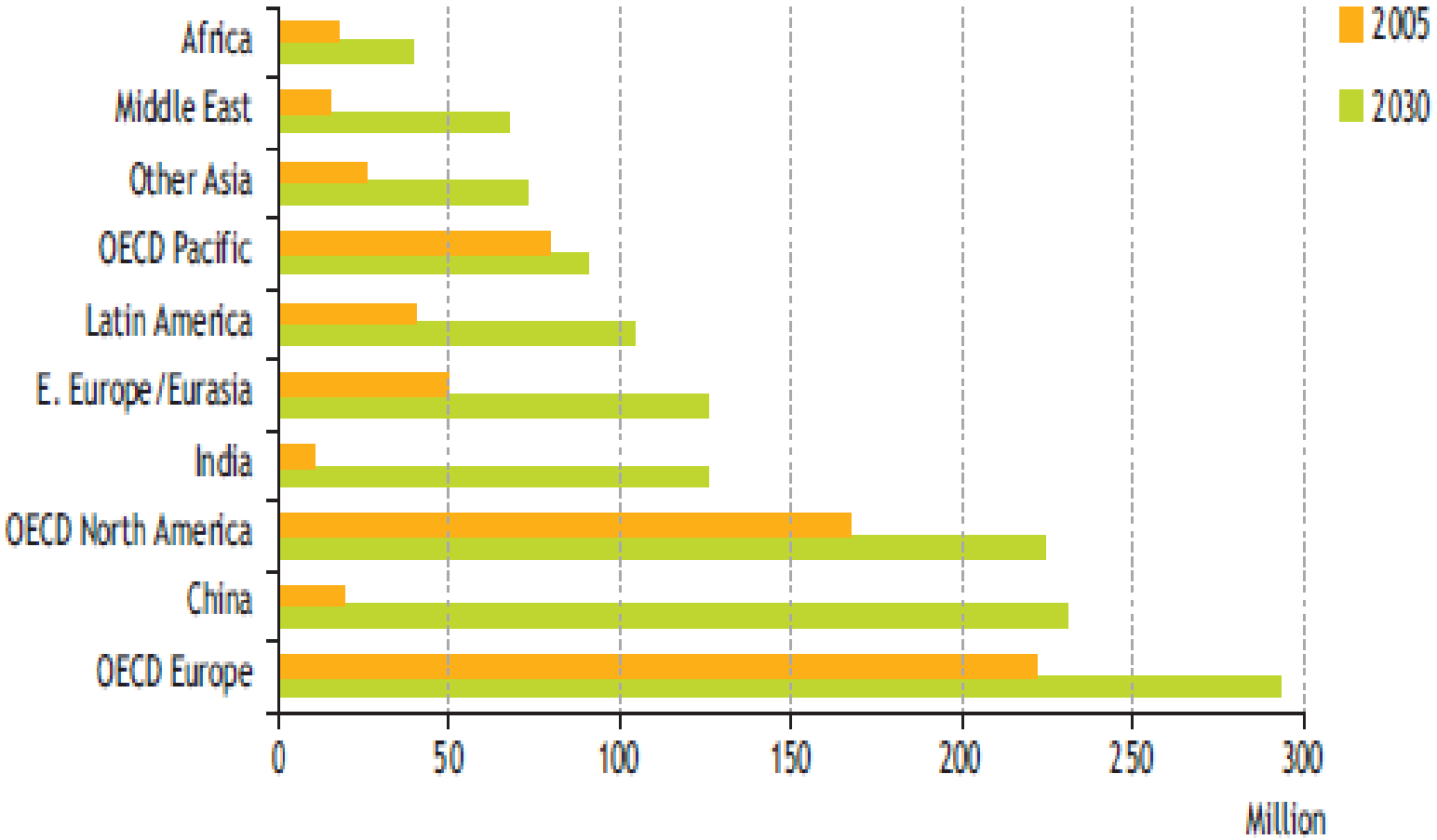
galvin center for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

The Jevons Paradox

The proposition that technological progress that increases resource-use efficiency… tends to increase the rate of consumption of that resource

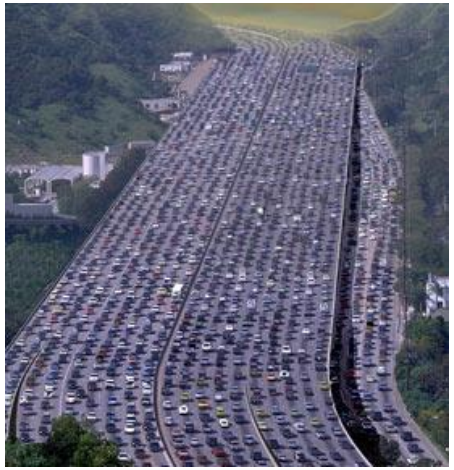
W. Stanley Jevons
The Coal Question
1865 English Economist

Worldwide Motor Vehicle Stocks Projected in International Energy Agency's World Energy Outlook

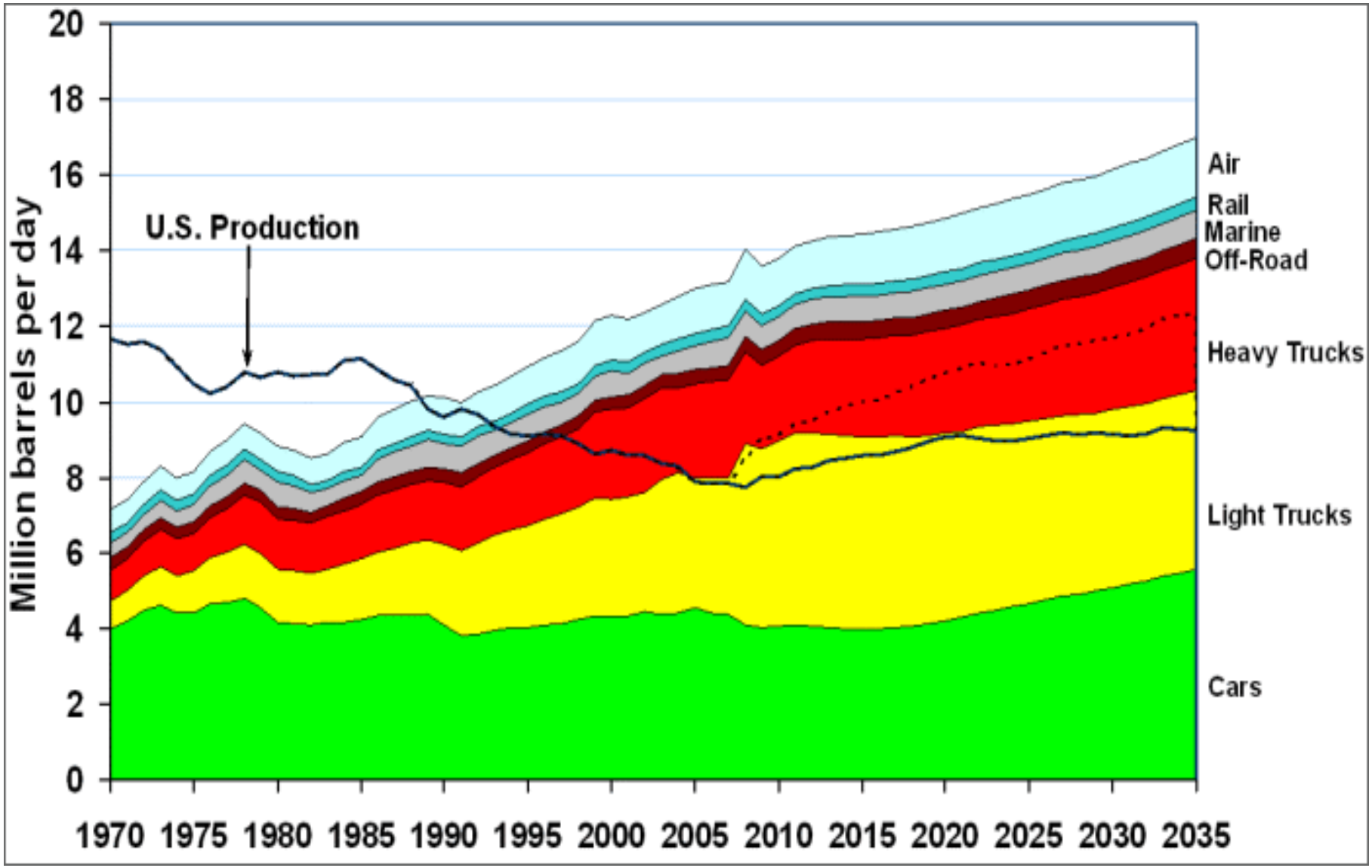


Urbanization, Energy and Transportation

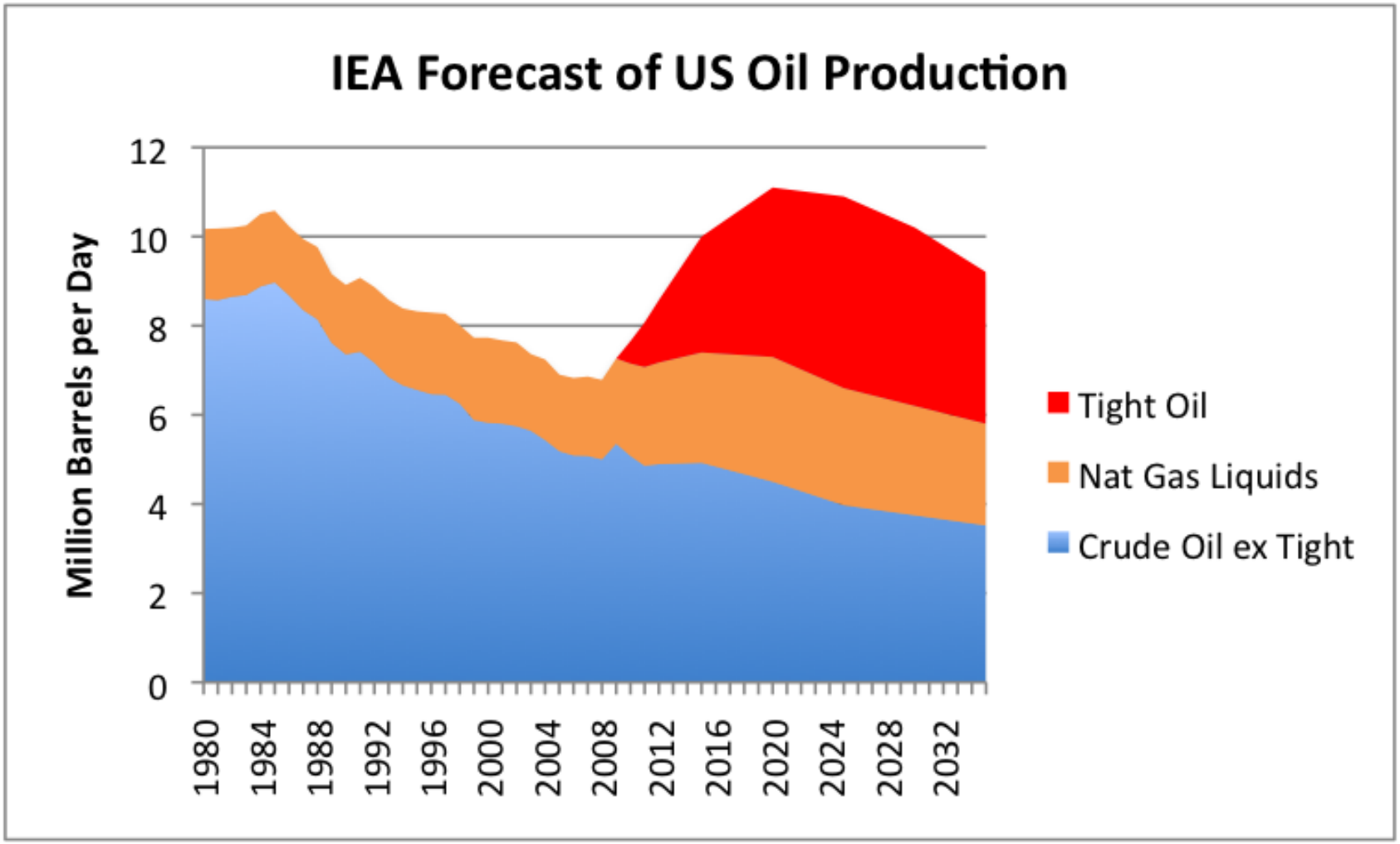
- **By 2020 60% of World Population in MegaCities**
- **Will Control 80% of Wealth**
- **Only 14% of World Population (1 B vehicle) have access to Personal Transportation**
- **Rest aspire to Personal Transportation**



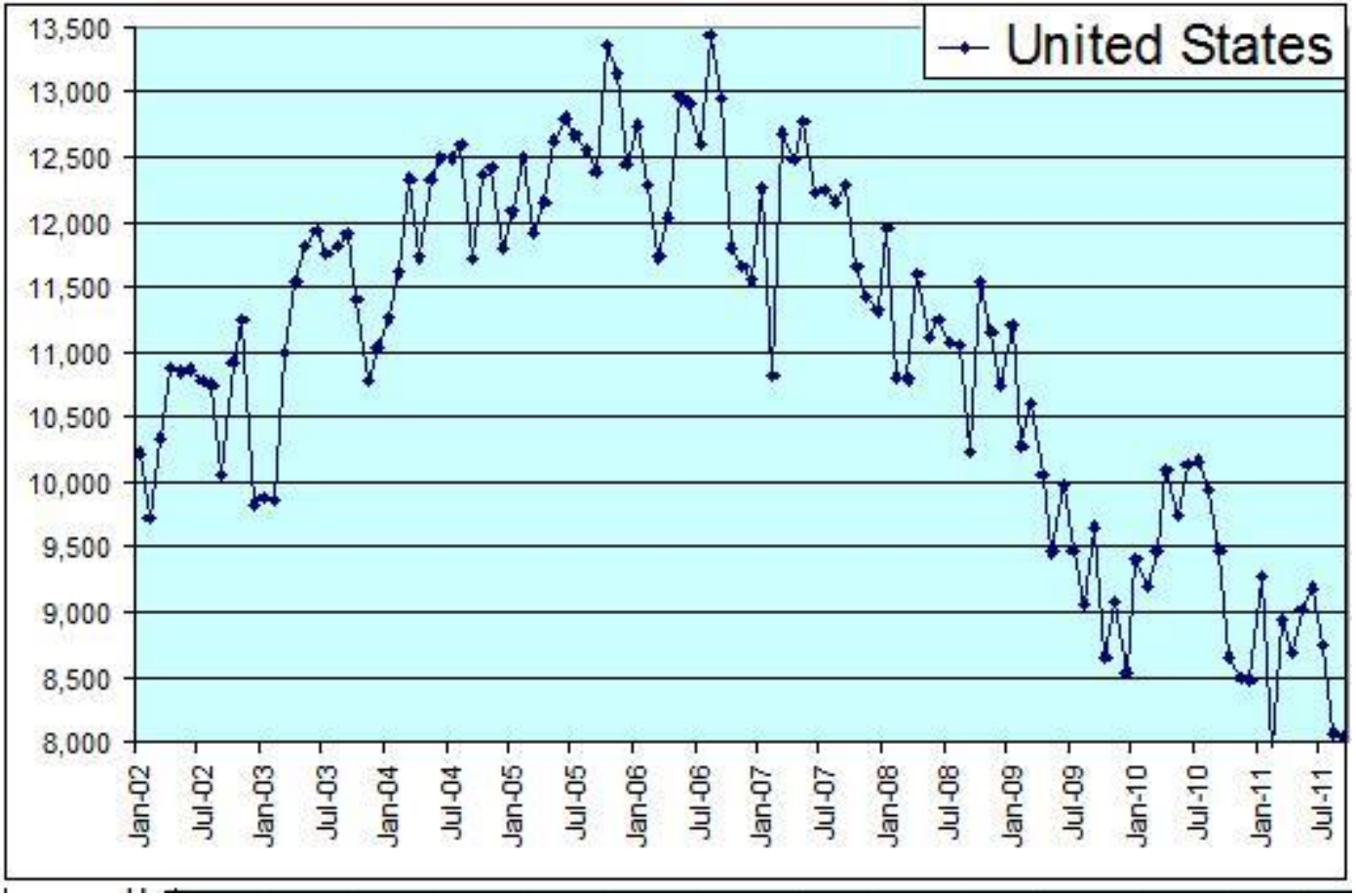
United States Transportation Petroleum Gap



United States Petroleum Production is Growing

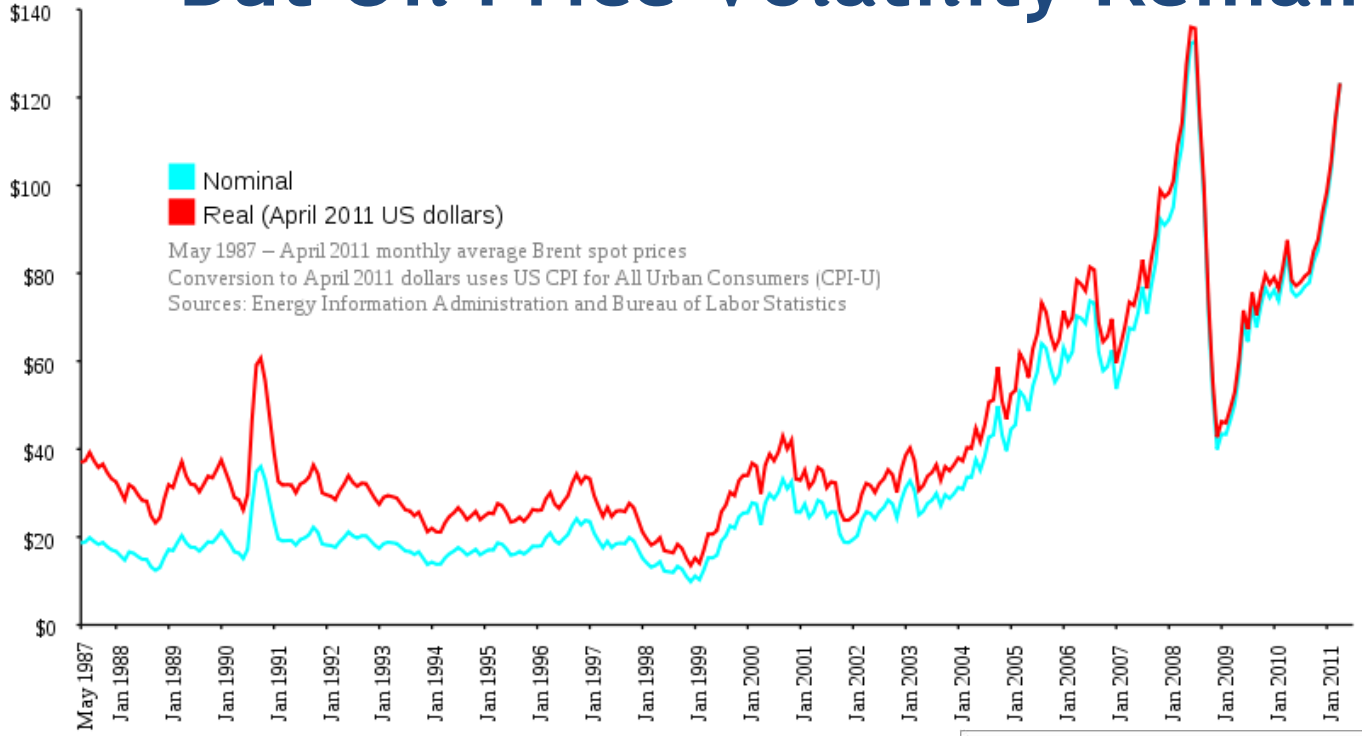


Oil Imports to the U.S. are dropping - Which could mean many things.

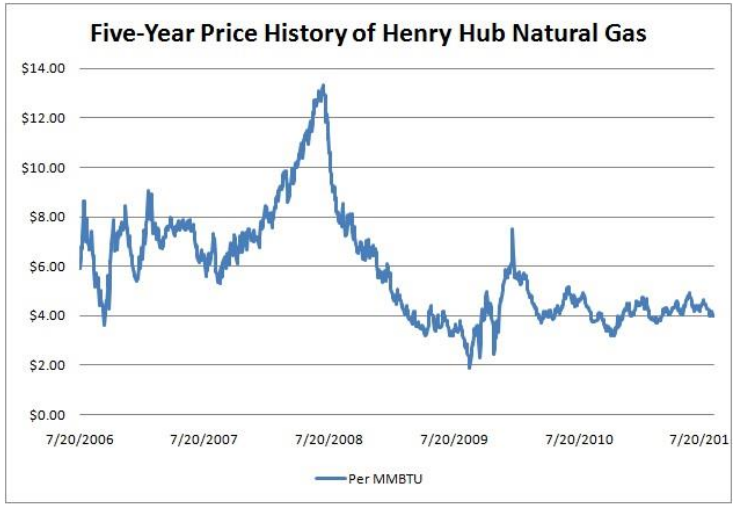


(And not all of them are good things)

But Oil Price Volatility Remains



(And Natural Gas appears to be heading down)



U.S. Research Programs for Advanced Technologies for High Efficiency Clean Vehicles

Batteries and Electric Drive
- Advanced Batteries
- Power Electronics
- Inverters
- Controllers & Motors

VSST
- Aerodynamics, Rolling Resistance & Accessory Loads
- Validation

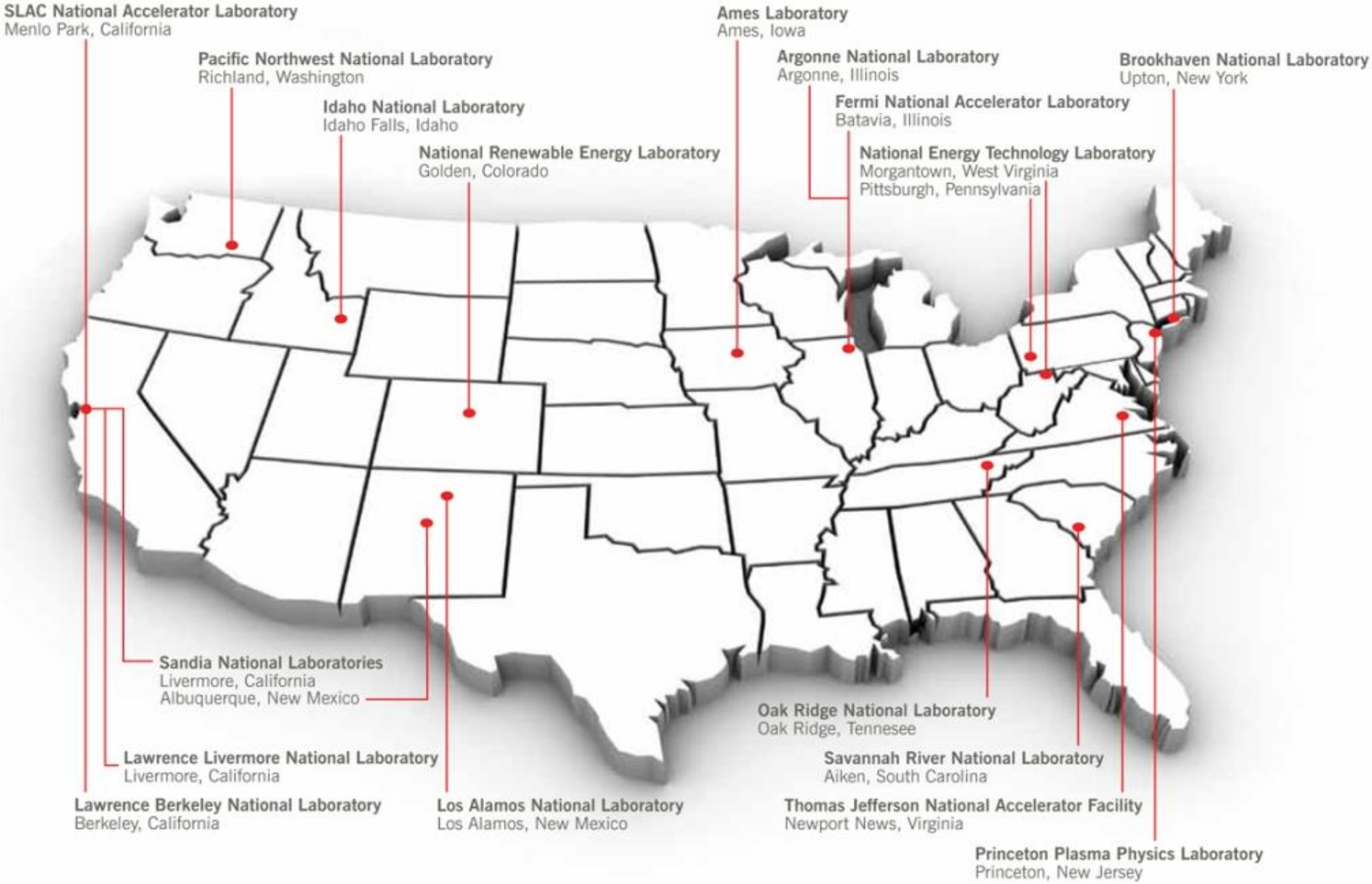
Outreach, Deployment and Analysis
- EPAct/EISA
- Rulemaking
- Deployment
- Student Competitions
- Graduate Automotive Technology Education
- Safety, Codes, & Standards

Advanced Combustion Engine R&D
- Low Temp. Combustion R&D
- Emission Controls
- Light- & Heavy-Duty Engines
- Solid State Energy Conversion
- Health Impacts

Fuels Technology
- Bio-Based Fuels
- Clean/Efficient Combustion Fuel Characteristics
- Fischer-Tropsch Fuels & Blendstocks
- Advanced Lubricants

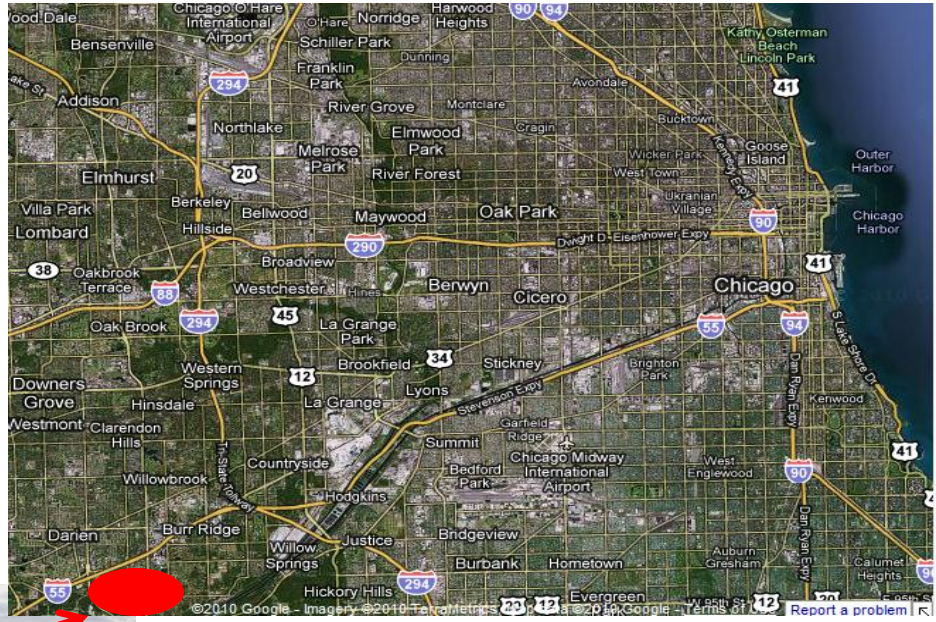
Materials Technology
- Lightweight Structures
- Composite Development
- Processing/Recycling/ Manufacturing
- Design Data Test Methods
- High Temperature Materials Laboratory

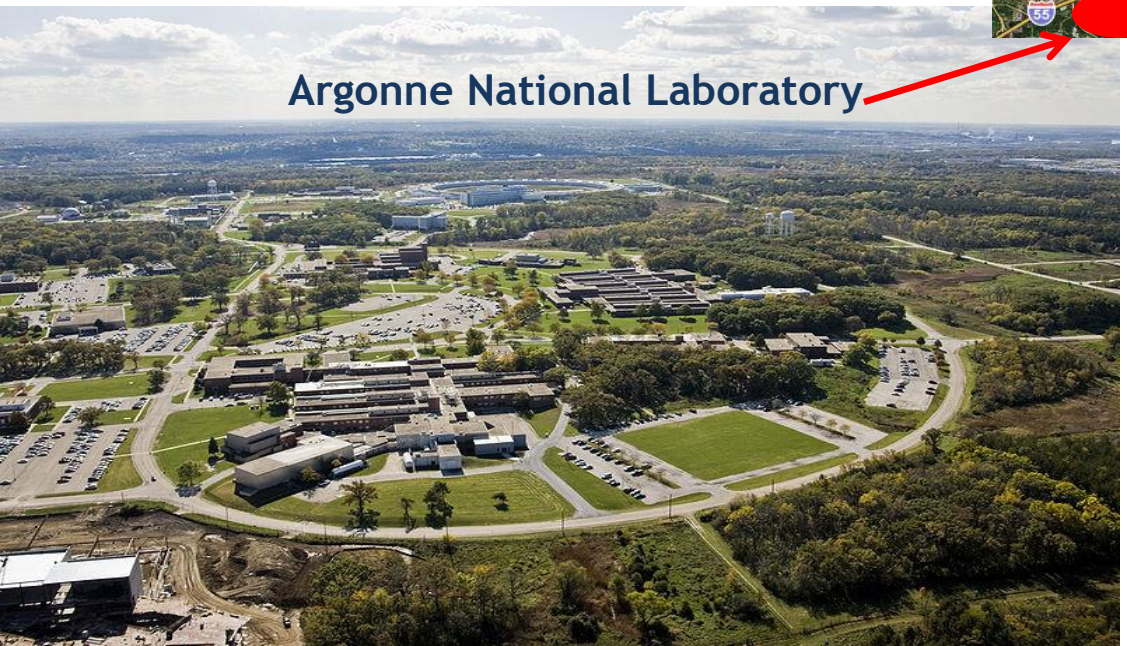
17 National Labs



Argonne: The Nation's First National Laboratory

- Basic science, applied technology and engineering research and development
- System Assessment Section, Energy System Division
- Assessment of transportation fuels and advanced vehicle technologies





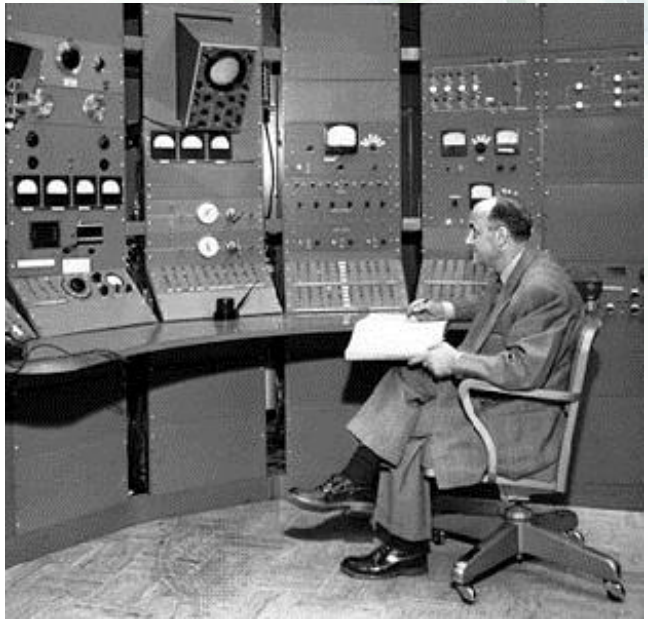
History of Argonne

Argonne found its home about 25 miles southwest of Chicago -- along what used to be the storied Route 66 and before that was a major Indian trail.

Argonne traces its origins to the World War II era, when Enrico Fermi and his colleagues were creating the first controlled self-sustaining nuclear chain reaction at the University of Chicago's Metallurgical Laboratory.

Peaceful use of the atom

Argonne Produced the First Atomic-Powered Electricity



"Experts would be mobilized to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities. A special purpose would be to provide abundant electrical energy in the power-starved areas of the world. Thus the contributing powers would be dedicating some of their strength to serve the needs rather than the fears of mankind."

Among the National Labs, Argonne Has the Lead R&D Role in Several Automotive Fields

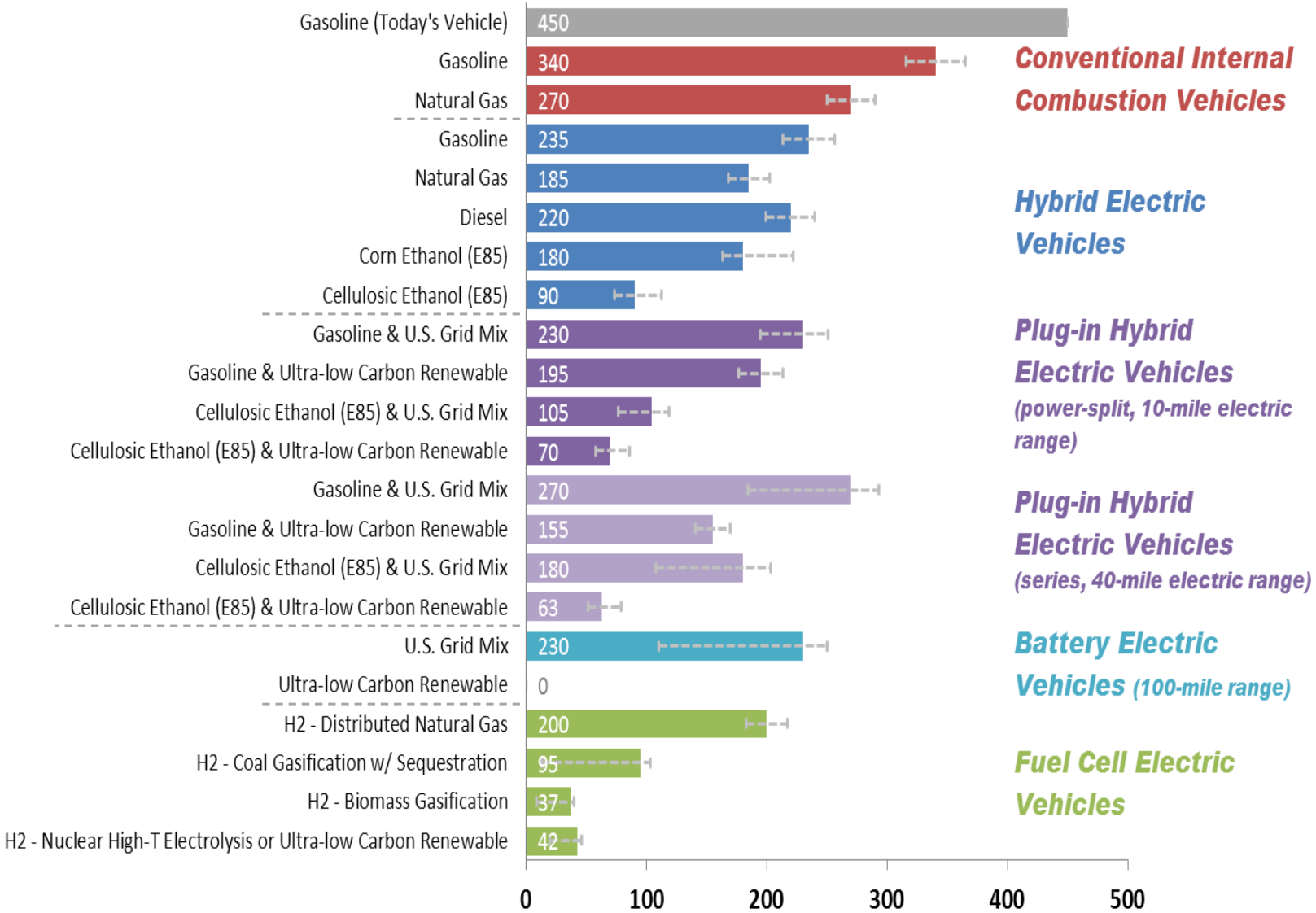
- **Hybrid vehicle systems, incl PHEVs**
  - Modeling
  - Benchmarking and evaluation
  - Component integration
- **Engine emissions control**
  - In-cylinder combustion
  - Bio-fuels
  - Natural gas engines
- **Batteries**
- **Fuel cells**
- **Vehicle recycling**
  - Rare Earths
  - Battery Reman
- **Applied materials research**
  - Tribology
  - Nanofluids
- **High-performance computing**
- **Analysis and assessments**

4-wheel drive dynamometer for hybrid vehicle evaluation

Hydrogen Engine Test Stand

MATT HIL
Mobile Automotive Technology Testbed Hardware-In-the-Loop

WTW Results: GHG Emissions of a Mid-Size Car (g/mile)



Low/high band: sensitivity to uncertainties associated with projection of fuel economy and fuel pathways

(DOE EERE 2010, Record 10001)

Samples of Advanced Technology Vehicles tested in the APRF

- Hybrid vehicles
- Plug-in hybrid vehicles
- Battery Electric vehicles
  - Mini E
  - Tesla
  - Auto X
  - Leafs
- Alternative fuel vehicles
  - Biofuels, Diesels, Hydrogen…
- OEM proprietary prototypes
- Plug-in hybrid conversion vehicles
- Conventional vehicles

BEV Tesla

Mini-E

ANL PHEV prototype

Prototype

Leaf

Many different EVs

PROGRESSIVE AUTOMOTIVE X PRIZE

Supplier BEV prototype

Ford TADA PHEV

Jetta TDI (bio-fuels)

Fuel cell

Hydrogen internal combustion engine

Major Technical Research Areas

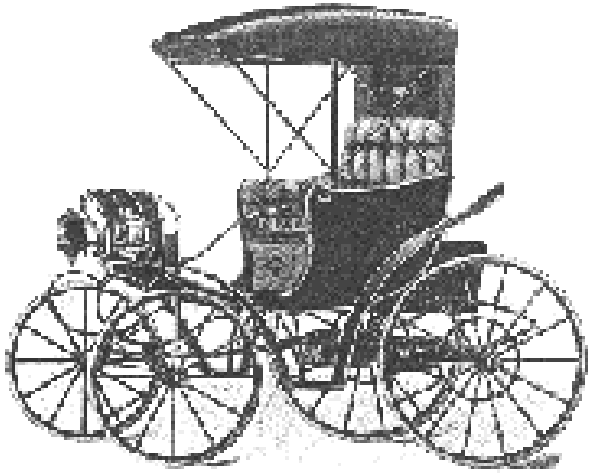
- Advanced Combustion
- Electric Vehicles
- Natural Gas
- Automated Driving

The first electric vehicles (EVs)

- First crude electric made between 1832 & 1839
- More practical & successful vehicles made around 1842
- Better battery storage invented in 1865 with further improvements in 1881

1918 Detroit

1909 Baker Suburban Runabout



1902 Wood's Electric Phaeton

There are Unique Capabilities and Charging Needs for Each Plug-in Car Type

– Plug in Hybrid Electric Vehicle (PHEV)

- Varying electric range – battery 5-10 kWh
- Blended mode operation on highways, hard acceleration
- Charge power presently 1.4 - 3.3 kW

– Extended Range Electric Vehicle (EREV)

- Increased electric range – medium battery 10-20 kWh energy
- Nearly exclusively electric operation in metro areas
- Charge power presently 1.4 to 3.3 kW

– Battery Electric Vehicle (BEV)

- All electric range – large battery >20kWh energy
- Exclusively electric operation
- Charge power presently 3.3 kW to 50 kW

– “Super” Battery Electric Vehicle (BEV)

- All electric range – large battery 85 kWh energy
- Charge power 10 or 20kW; DC Fast, 35 kW

Vehicle Testing and Evaluation

Before PHEV Test Standards…

Questions Arose, Are We Violating Laws of Thermodynamics?

MPG Claims:

"230 MPG"

"100+ HWY MPG"

"150+ MPG"

"UP TO 100 MPG"

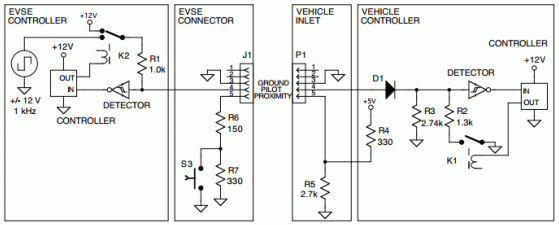
"+" = "with much uncertainty"..?

Test Standards

Uniform procedures to provide repeatable, representative test results.

Interoperability Standards

Different products work together.
Standard specifications for operation, performance, safety.



Test Standards

New Vehicles
New Test Challenges

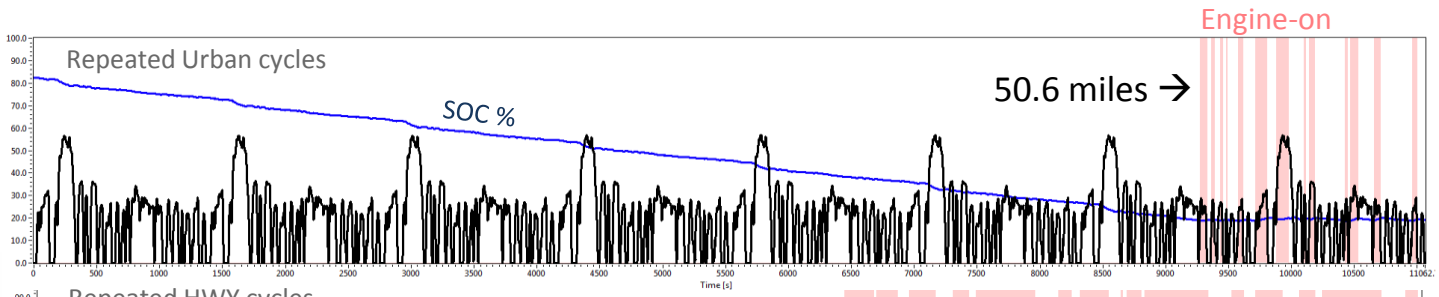
Legacy test methods

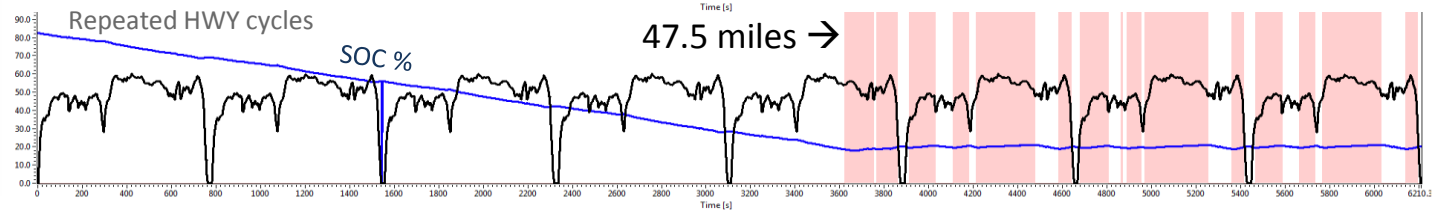
"square peg for a round hole"

- Longer test days
- More test days
- New instrumentation
- Safety of high voltage access
- New post-processing concepts
- Additional "fuel" → electricity
- For all vehicle types/designs *(even ones that don't make sense),*
  the same general test
- New Recharge procedures/equipment

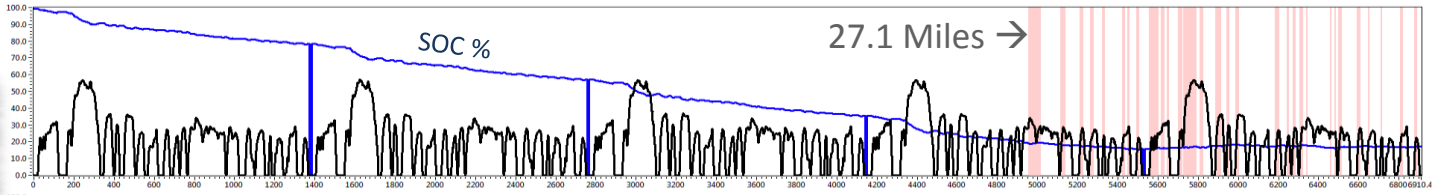
Argonne J1711 Dyno Testing

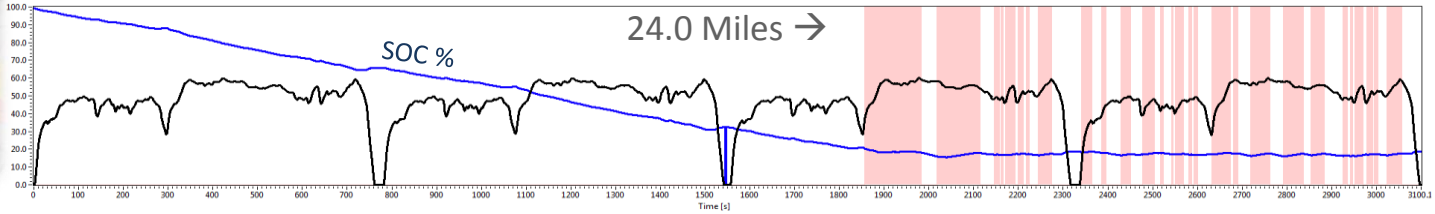
2012 Chevy Volt



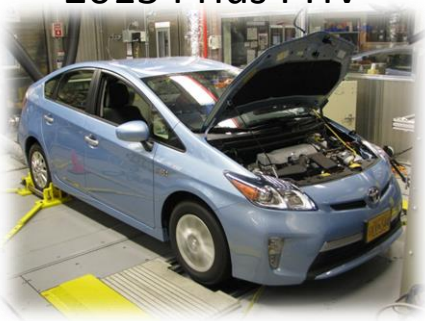


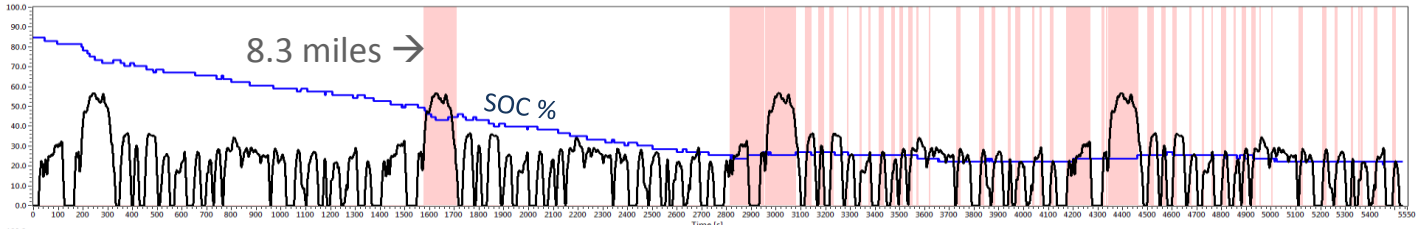
2013 Cmax PHEV

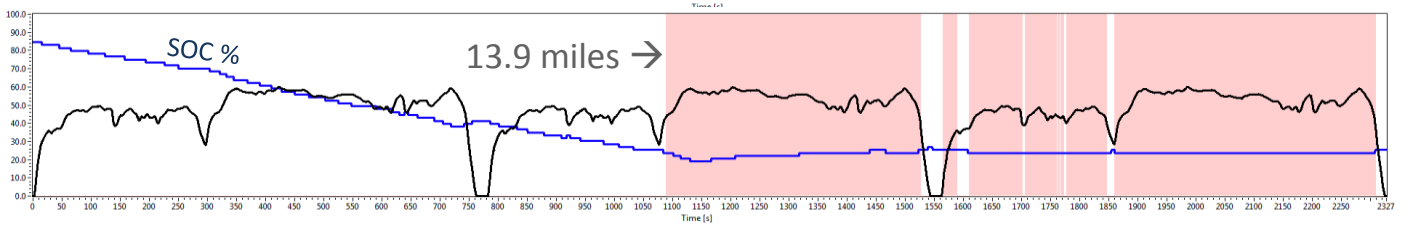




2013 Prius PHV







Lithium Ion Batteries Allowed a New Manufacturer, Tesla, to Actually See What Some Customers Would Pay

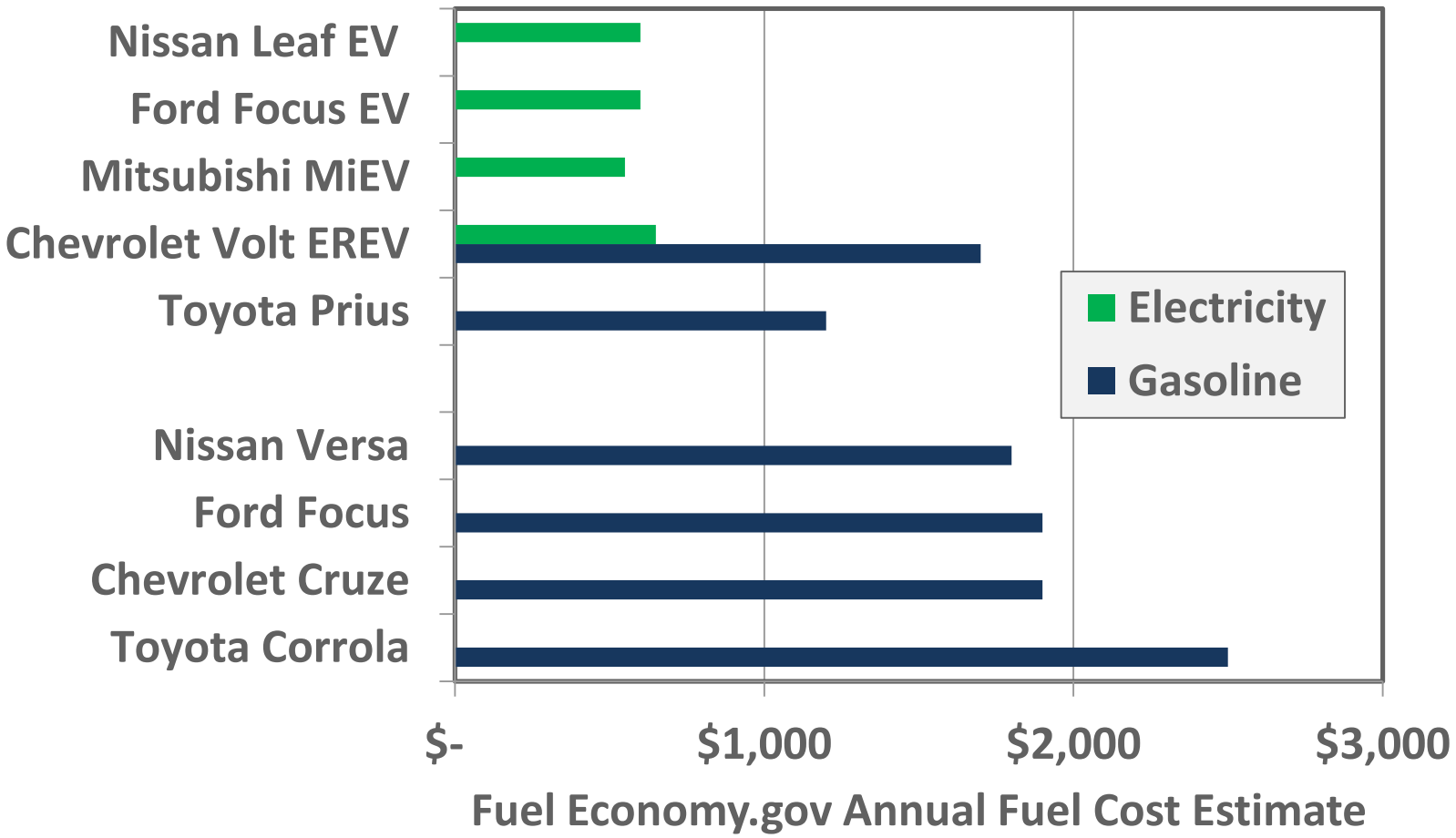
- 1990s, Nickel Metal Hydride Battery
- 6.5 sec 0-50 mph (yes, 50!)
- 80 mph top speed
- GM made it available only for lease, not purchase

- 2008, Lithium Ion Battery based on consumer cells
- 3.7-3.9 sec 0-60 (yes, 60!)
- 125 mph top speed
- $109,000+

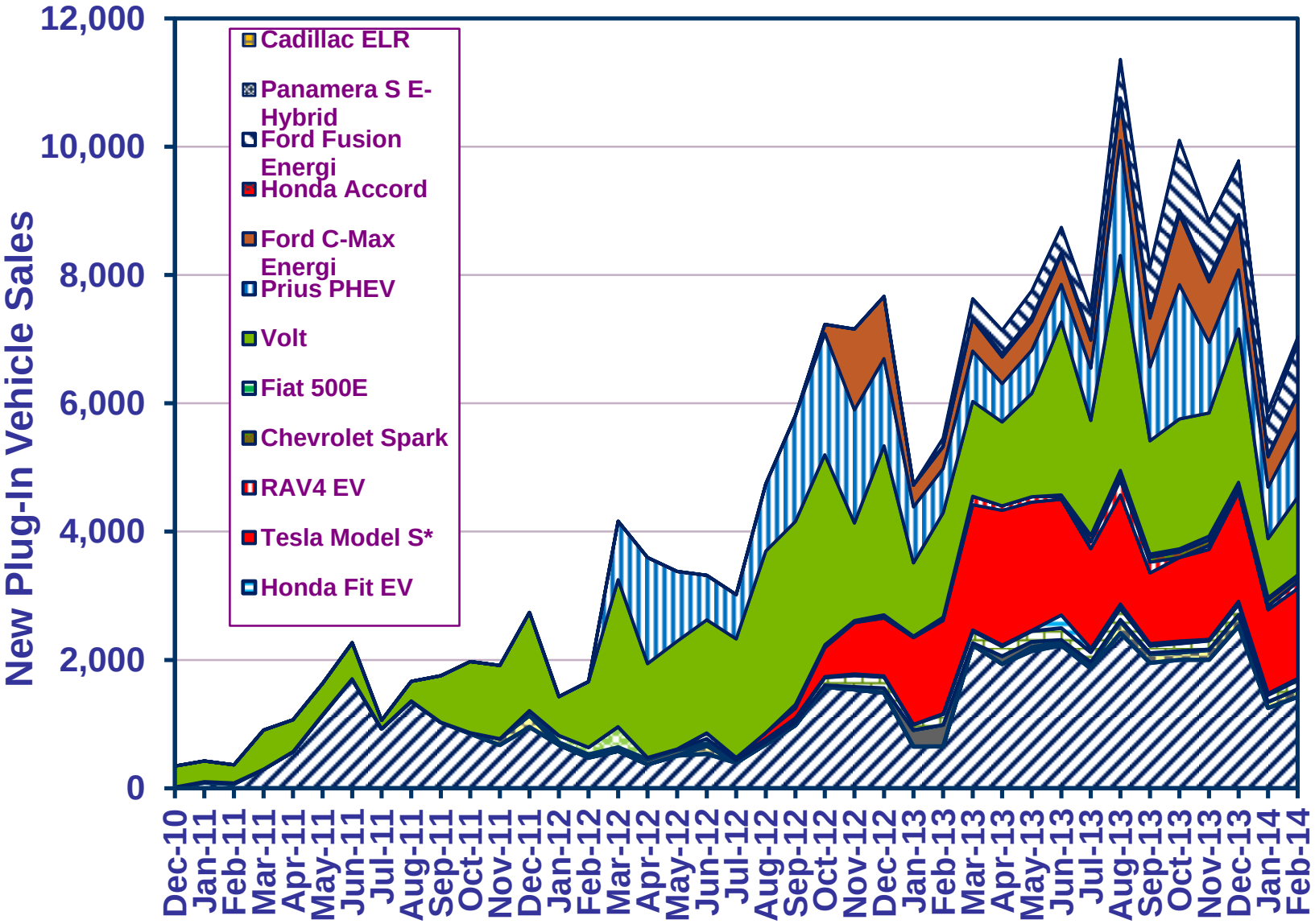
HEVs Have Proven to Require Less Maintenance than Conventional Vehicles. Plug-in Vehicles are Anticipated to Follow Suite.

- HEVs and PHEVs require slightly less maintenance than conventional vehicles
- Battery warranties are for 8 years or more
- EVs should also require less maintenance than conventional vehicles
  - Battery, motor, and associated electronics require no regular maintenance, or at very long intervals
  - Minimal fluids to change, coolant and brake fluid (one battery flush for Focus BEV however)
  - Regenerative braking reduces break wear
  - Fewer moving parts than a conventional vehicle

Annual Fuel Cost Can Be More Than $1000 Less For EVs vs. Conventional Gasoline



Plug-In Vehicle Sales – What is Happening?



Battery Electric Vehicles have “Obstacles”
Range Anxiety is probably Foremost

- Battery Swaps
- Fast Charging
- Really Big Batteries
- Research on better Batteries

Battery Swaps – Back of the Envelope

- Need standardized or interchangeable batteries
- Need sufficient vehicles to justify the infrastructure
- Need a cost model that can work

Current EV Battery Pack is listed as costing $12,000 for replacement

(Which we all believe to be wildly optimistic)

$12000 x 5% annual return on investment = $600

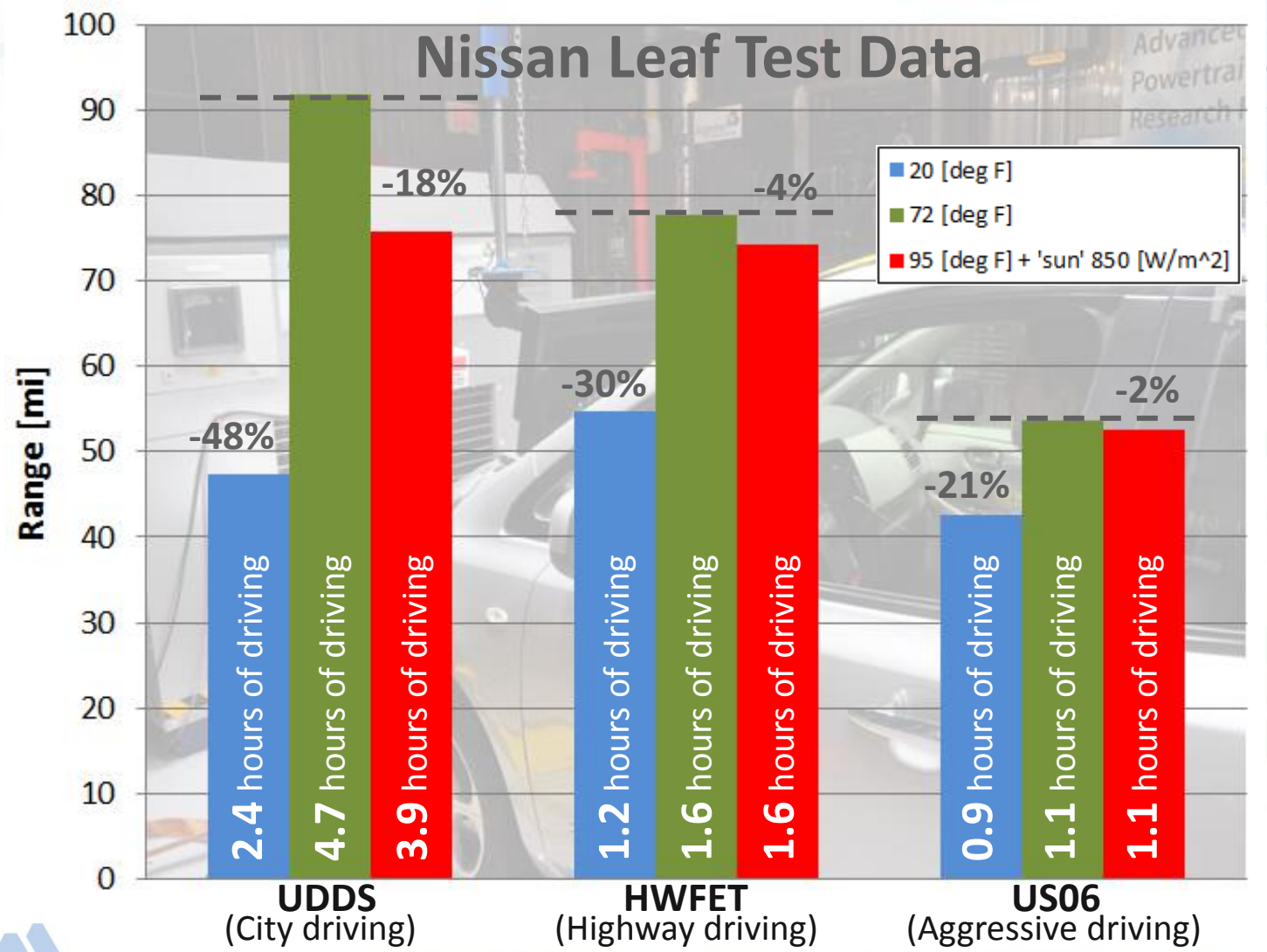
3 year battery life means amortizing cost is $4000

Annual Return for each pack must surpass $4600 per year

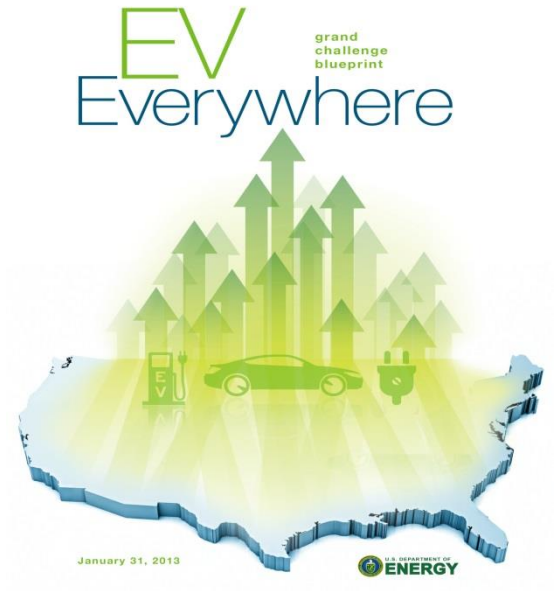
For battery swapping profit, must drive 1300 miles per day per battery pack!

Conclusion: The EV Battery is twenty times too expensive for the swap model.

Temperature Extremes and Drive Style Affect the Electric Range Dramatically



EV Everywhere



A Clean Energy Grand Challenge

- Enabling plug-in vehicles to be as affordable and convenient for the American family as conventional gasoline-powered vehicles by 2022
- Bring together America's best and brightest scientists, engineers, and businesses to produce EVs at lower cost, with improved vehicle range and increased fast-charging ability

President Obama announced EV Everywhere during a visit to Daimler Trucks in North Carolina, March 2012

EV Everywhere Goal

Enable the U.S. to be the first in the world to produce plug-in electric vehicles that are as affordable and convenient as today's gasoline-powered vehicles within the next 10 years

For a copy of the Blueprint, visit electricvehicles.energy.gov

Infrastructure

L1 Charge Equipment Goes With the Vehicle; L2 Is Placed at Usual Parking Spots; and L2 and DC at "Stations"

Level 1 (L1) with Vehicle

Level 2 (L2) on House Wall

Level 1 or 2 in Parking Lot

L2 & DC Fast in "Stations"

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

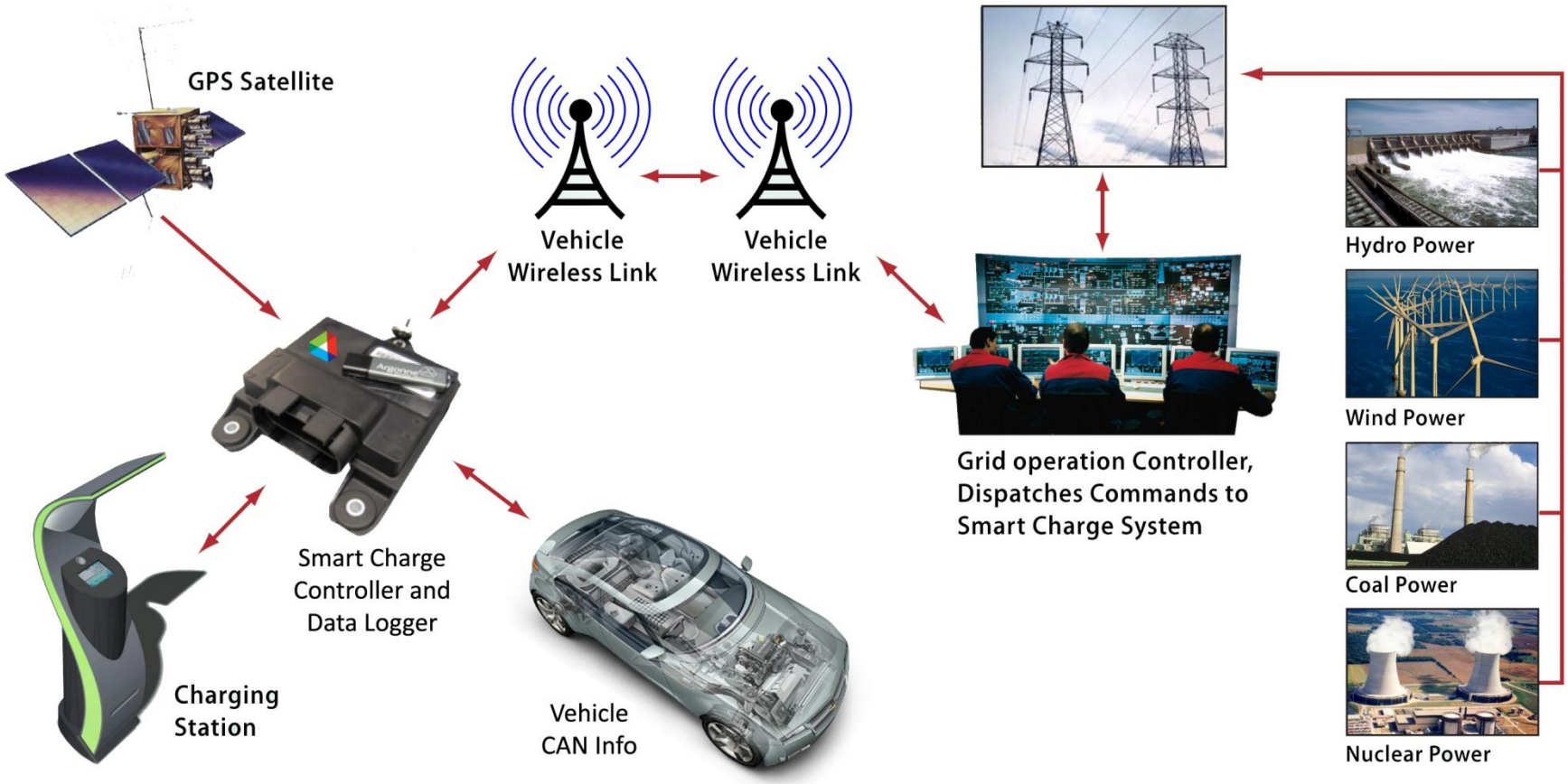
	Electric service	Charge rate	Miles per hour of charge*	Time to charge 70 mi*
Level 1	120V/20A	1.7 kW	~5	~14 hr
Level 2 (typical)	240V/20A	3.4 kW	~12	~6 hr
Level 2 (normal)	240V/40A	7.2 kW	~24	~3 hr
DC Level 2 (fast charging)	480V (3P)	50 kW	~165	~25 min
Gasoline	Fuel pump	22,000 kW	10,000 (15% avg eng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

Slow

Good for over night charging

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

Vehicle-Grid Interoperability



Requires standard connectivity/communication protocols to minimize impact on automotive industry and utilities/grid operators (cost, complexity, reliability)

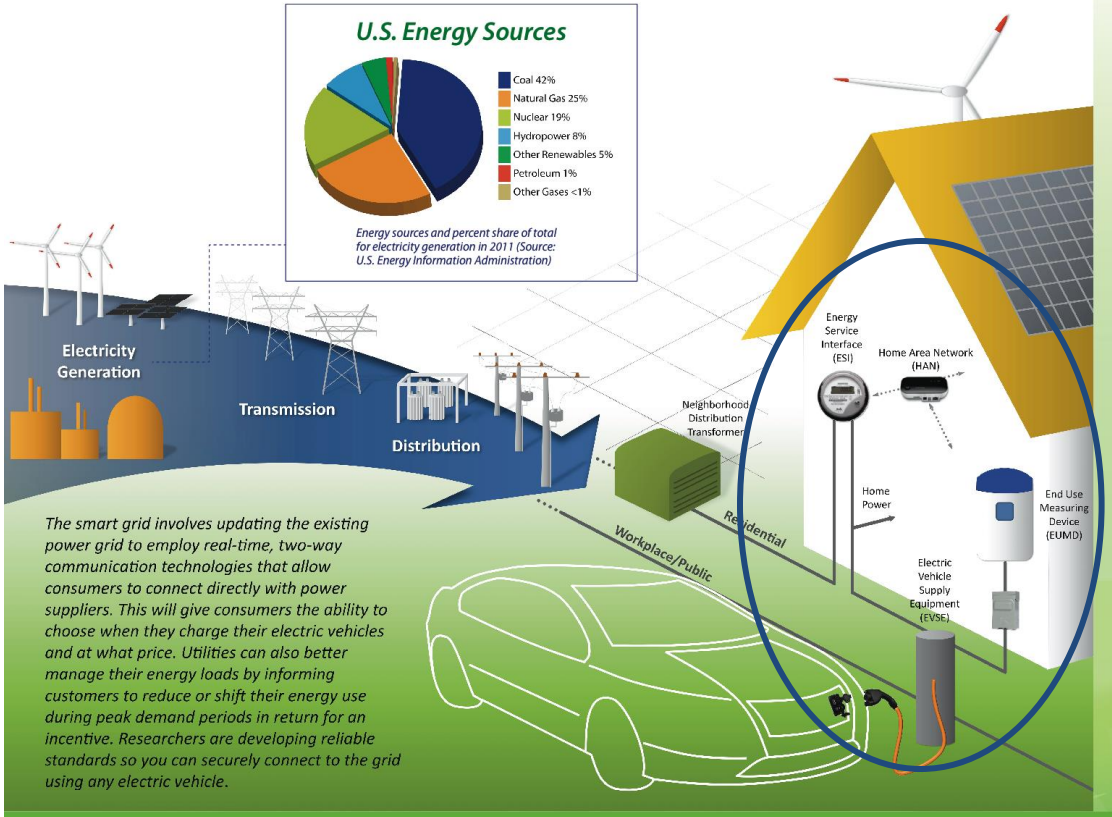
Interoperability: Vehicle - EVSE - Home - Utility

Argonne NATIONAL LABORATORY

HOW YOU WILL CONNECT TO THE SMART GRID

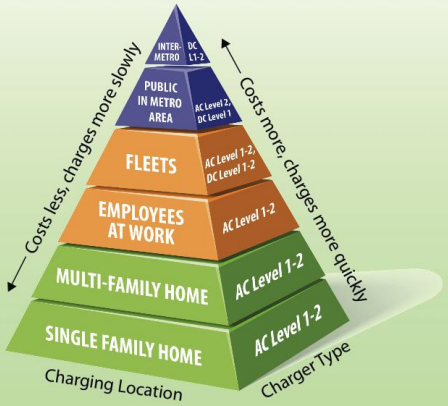
U.S. Energy Sources

Energy sources and percent share of total for electricity generation in 2011 (Source: U.S. Energy Information Administration)



The smart grid involves updating the existing power grid to employ real-time, two-way communication technologies that allow consumers to connect directly with power suppliers. This will give consumers the ability to choose when they charge their electric vehicles and at what price. Utilities can also better manage their energy loads by informing customers to reduce or shift their energy use during peak demand periods in return for an incentive. Researchers are developing reliable standards so you can securely connect to the grid using any electric vehicle.

Electric Vehicle Charging Options



Cars charge most often where they are parked most often.

Types of Chargers

Level	Volts	Amps	kW
AC-1	120	20	2.4
AC-2	240	<80	<19.2
DC-1	<450	<80	<36
DC-2	<600	<400	<240

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Visit www.transportation.anl.gov to learn more!

U.S. DEPARTMENT OF ENERGY

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by U Chicago Argonne, LLC.

es_openhouseGridPyramidgsi_0812

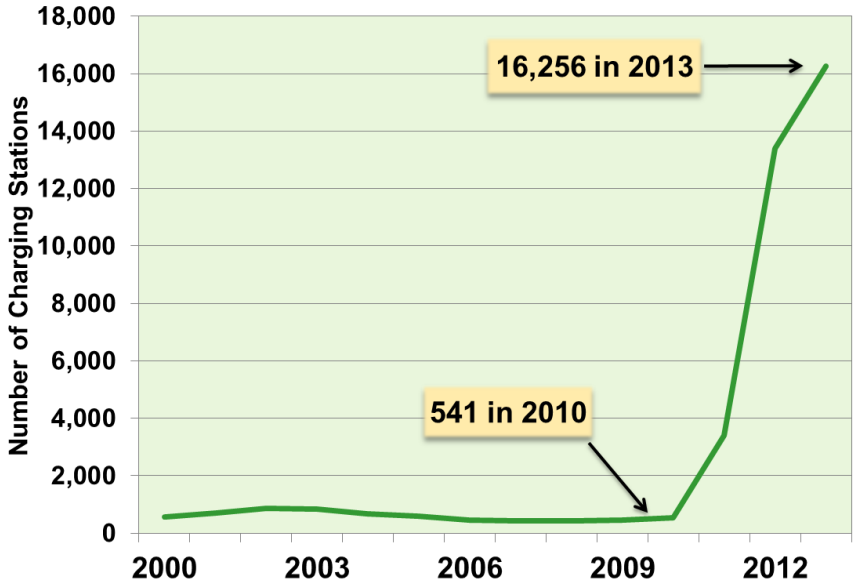
U.S. DEPARTMENT OF ENERGY

Due to Costs of Trenching and Rewiring, Costs Behind the Plug Can Vary Significantly. New Construction Can Be Far Less Expensive, But Most Will Involve Retrofits.

- **Most owners will charge vehicles at home, making Level 1 and Level 2 the primary options. Workplace seems to be the next highest priority.**
- **Level 2 charging equipment now costs $1,500 to $2,500 when owners choose to install.**
- **Old dwellings with limited kW capacity could require rewiring, or investment in much more efficient appliances and/or lighting to create capacity for the PEV**
- **Level 2 at work is generally more expensive, with longer runs to parking spots, needing trenching and paving replacement.**
- **Each of these installations requires permitting and licensed contractors.**

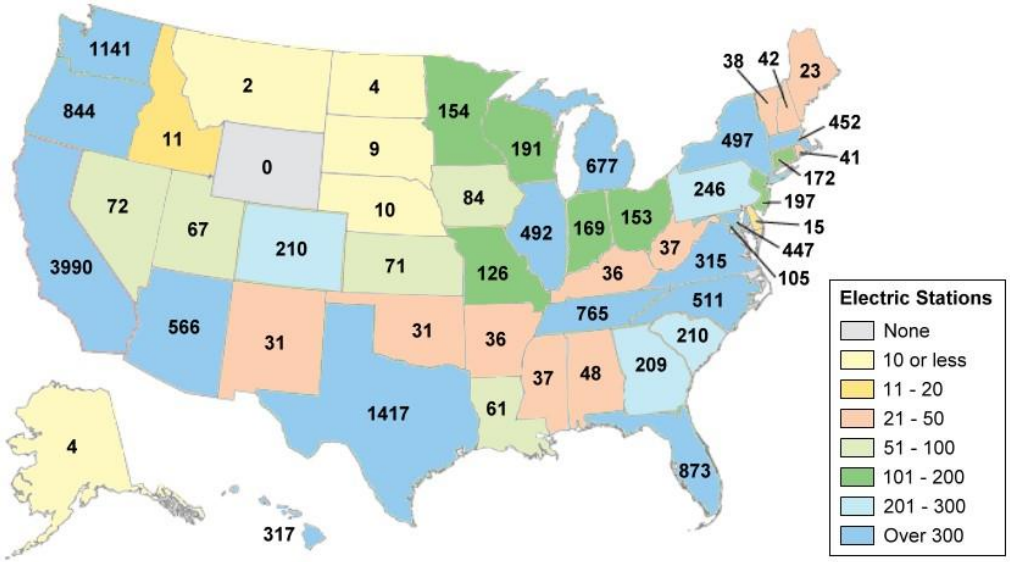
Market Drivers

Electric Charging Stations



There are 30 times more charging stations in 2013 than there were in 2010.

The top three states with electric charging stations are California, Texas, and Washington State. Currently, 15 states have more than 300 electric charging stations.



Note: Electric charging stations are counted once for each outlet available, even when multiple outlets are present at a single location. Does not include residential electric charging infrastructure.

Source: Alternative Fuels Data Center. Website. Accessed April 9, 2013. http://www.afdc.energy.gov/

Zero Emission Vehicle Mandates (ZEV)

- **California** and the States that have adopted California emission regulations ZEV Mandates have established a *Zero Emission Vehicle mandate*, which requires the automotive OEMs to sell clean energy vehicles including ZEVs
- Requirements are only for Large Volume Manufacturers (3 year average California sales greater than 60,000 units)

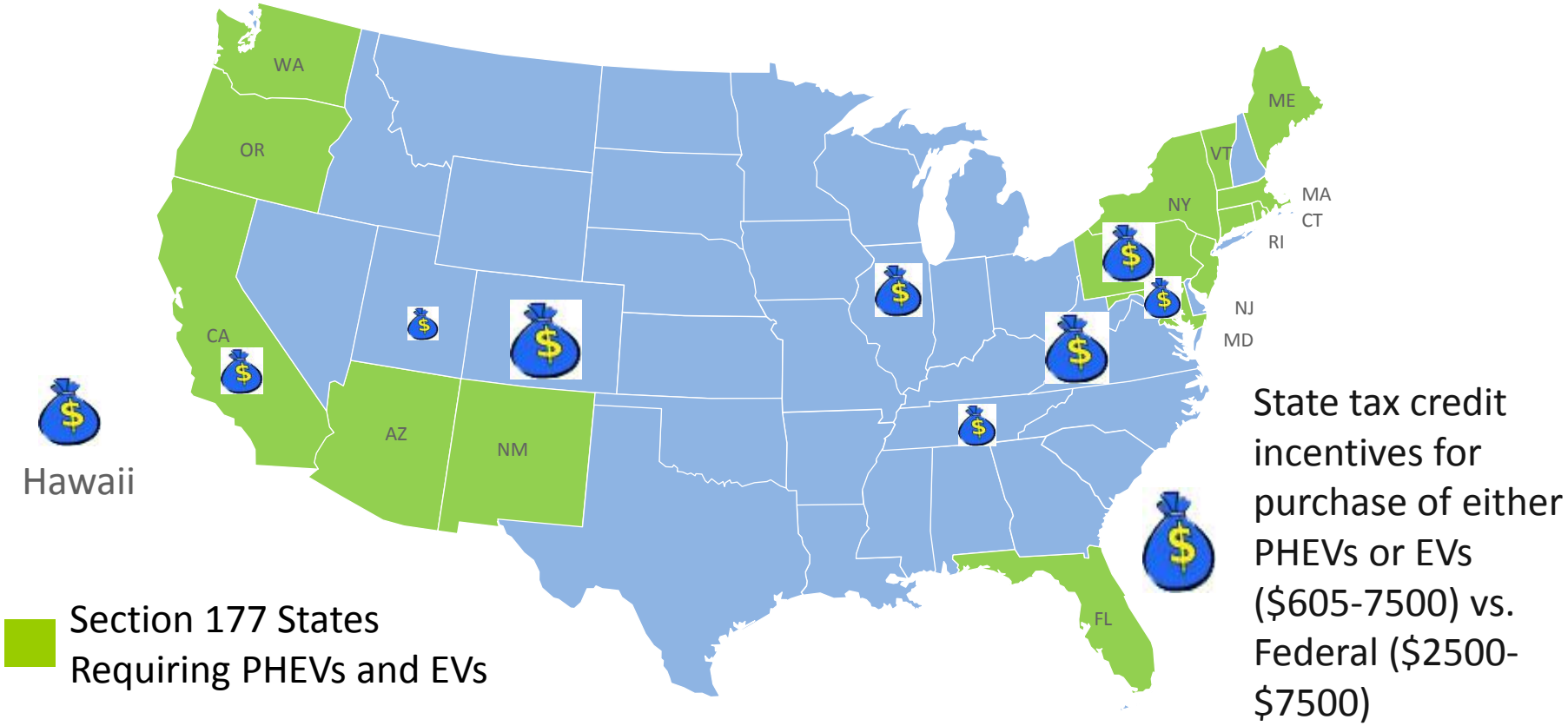
ZEV target requirements

	Percent of California Sales Volume	
Year	Total	ZEV requirement
2009-2011	11%	0.82%
2012 - 2014	12%	0.79%
2015 - 2017	14%	3.00%
2018+	16%	TBD

Financial Incentive May Enhance PEV Rollout

- Driven by incentives and deployment initiatives the majority of the EV market growth will be in the West Coast in the near term – particularly in the **highly incentivized markets**

- In the medium to Long term EV deployment will likely gain momentum in the States that have adopted California emission regulations ZEV Mandates (Section 177 States)



Note: Nissan's site lists more states with at least EV credits

Federal Income Tax Credit Incentives for PEV

Vehicles which qualify for a Federal income tax credit in the amount of:			
$7,500	$3,751	$3,626	$2,500
AMP GCE Electric Vehicle AMP MLE Electric Vehicle BYD E6 Electric Vehicle Chevrolet Volt CODA Sedan EVI MD Electric Truck EVI WI Electric Truck EMC E36 7 Passenger Wagon EMC E36t Pick-up Truck EMC E36v Utility Van Ford Focus EV Ford Transit Connect Fiat 500e Fisker Karma Sedan Mitsubishi i-MiEV Nissan Leaf Smart fortwo EV Tesla Model S Tesla Roadster Think City EV Toyota RAV4 EV Wheego LiFe	Ford C-Max Energi Ford Fusion Energi	Honda Accord Plug-in Hybrid	Toyota Prius Plug-in Hybrid

Plug-in vehicles (PEV) purchased in or after 2010 are eligible for a Federal income tax credit. For plug-in hybrid-electrics, the amount of the credit will vary depending on the capacity of the battery used to fuel the vehicle.

All Federal income tax incentives for hybrid-electric vehicles (HEV) were phased out by the end 2010.

Source: Internal Revenue Service. Website. Accessed April 10, 2013.
http://www.irs.gov/Businesses/Qualified-Vehicles-Acquired-after-12-31-2009

Other State and Private Incentives for PEV

Many states offer their own incentives, such as HOV lane exemptions and tax credits/rebates. Utility companies offer lower electric rates in some areas for those with a separate meter for PEV charging.

State and Private Incentives Summary Table	
Incentive	**State**
High Occupancy Vehicle (HOV) Lane Exemption	AZ, CA, CO, FL, GA, HI, MD, NJ, NY, NC, TN, UT, VA
PEV Purchase Incentives: Tax Credits and Rebates	CA, GA, IL, MD, OK, SC, TN, TX, UT, WV
Lower Electric Rates for Residents with a Separate Meter for PEV Charging	AL, AZ, GA, HI, IN, KY, MI, MN, NV, VA
Charging Equipment/Installation Incentive	AZ, CA, CO, IL, IN, MD, MI, TN, TX
Vehicle Inspection/Emissions Testing Exemption	ID, MI, MO, NV, NC, VA
Parking Incentives	AZ, CT, HI, NV
Sales Tax Exemption	NJ, WA
Fuel Tax Exemption	WI, UT
Reduced License and/or Use Tax	AZ, WA
Reduced Registration Fee	IL, IA
Conversion Tax Credit	MT
Vehicle-to-Grid Energy Credit	DE
Idle Reduction Technology Tax Credit	CO
Weight Limit Exemption	CO
Title Tax Exemption	DC
Reduced Toll Road Rates	NJ

Source: Alternative Fuels Data Center. Website. Accessed April 9, 2013.
http://www.afdc.energy.gov/

Federal CAFE/GHG Regulation

- The new CAFE/ GHG standard requires all vehicle manufacturers to meet an estimated combined average mile per gallon (mpg) level of 34.1 mpg by 2016 – ***about a 45% increase in only 5 years***
- Manufacturers earn credits for each mpg over achieved, which can be banked and traded between cars and trucks and between vehicle manufacturers
- ZEV manufacturers earn maximum credits for each vehicle sold, which can be traded to other manufacturers

CAFE standards for each model year in miles per gallon

	2010	2011	2012	2013	2014	2015	2016
Passenger Cars	27.5	30.2	33.3	34.2	34.9	36.2	37.8
Light Trucks			25.4	26.0	26.6	27.5	28.8
Combined	23.5	24.1	29.7	30.5	31.3	32.6	34.1

a 45% increase

GeoEVSE Forum

Government-industry collaboration committed to establishing a repository of public EVSE location data for consumers and industry.

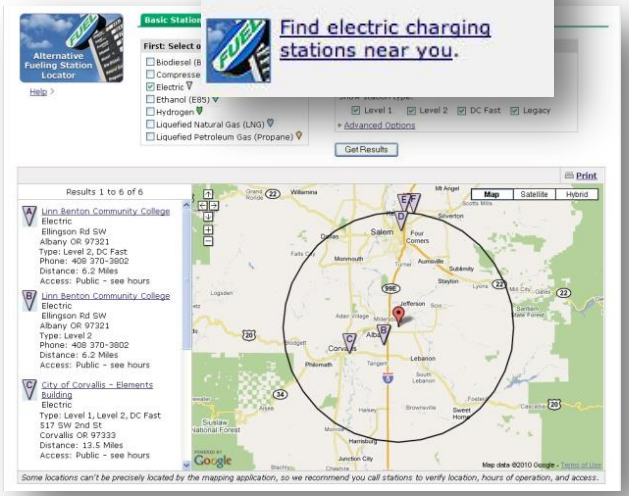
Goals

- Avoid duplication of data collection efforts for EVSE locations
- Enhance the EVSE data in the AFDC station locator
- ***Ensures that DOE continues to collect and provide the most comprehensive collection of EVSE location data***
- Strengthen relationships and improve communication with new industry stakeholders

http://www.afdc.energy.gov/afdc/vehicles/geoevse.php

How fast a vehicle charges depends on the battery type and the type of charging equipment used.

Level 1 = 8 to 20 hours
Level 2 = 3 to 8 hours
DC Fast Charging = < 30 minutes



Workplace Charging Challenge

Goal

Increase number of U.S. employers offering workplace charging by tenfold in five years.

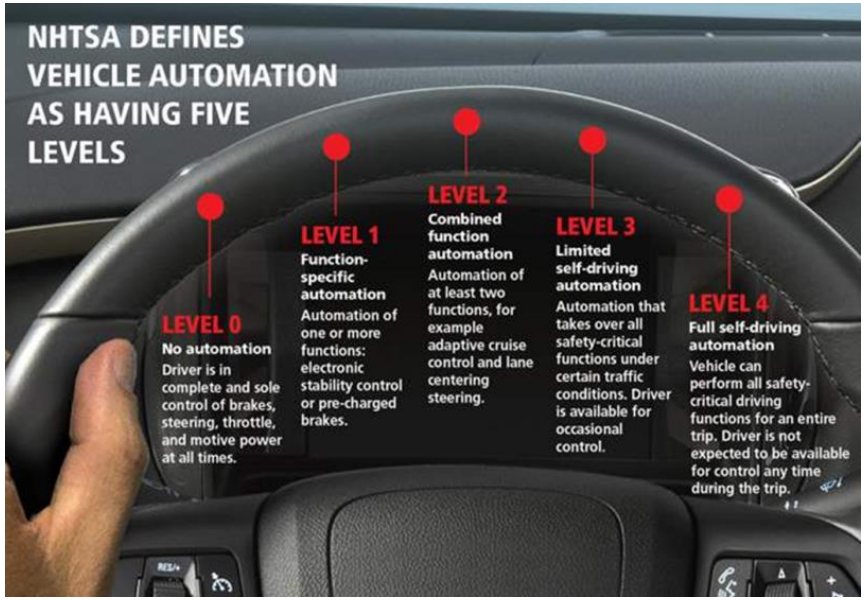
Automation is one key area to overcoming future problems with safety and Efficiency

- Fuel Economy Gains from Automated Driving
- Accident avoidance (zero accidents)

But also:

- Concerns with lawsuits related to accidents
- Terrorism, security, threats, loss of privacy
- They might be really boring – but no major infrastructure is expected.

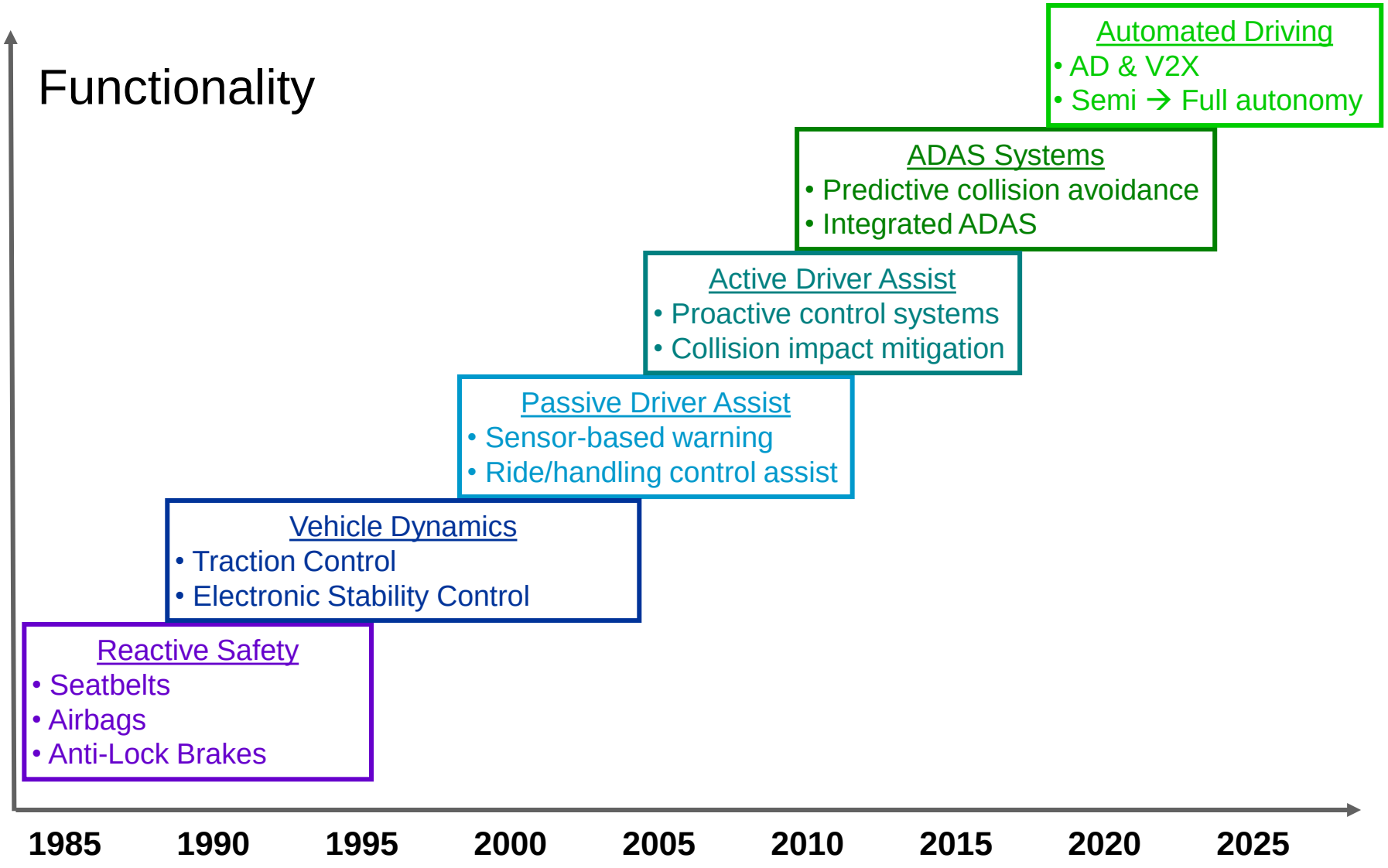
Automated driving… to what degree



Source: www.nhtsa.gov

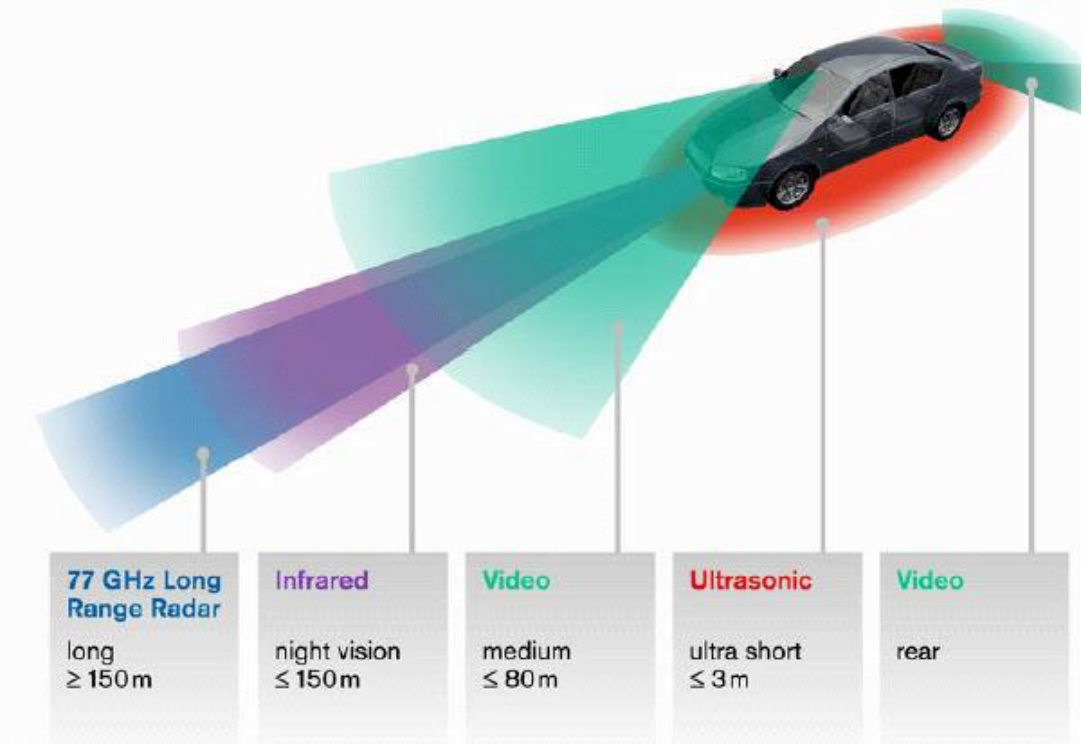
Source: www.ford.com

Driver assist trends
Enablers for automated driving – fusion of technologies



Macro Technology Trend – Integrated Safety

- Combined Active and Passive Safety (CAPS)
- Right on track to the sensitive car
- - New concept by Bosch: CAPS combines active and passive safety systems
- - Fewer serious traffic accidents with new assistance systems
- - Electronic surround vision with the “sensitive car”



Conclusions

- Electric vehicle sales difficulties
  - Infrastructure is not free, and is not ready
  - Need time for the energy storage technology to develop and prices to drop
- Fuel Infrastructure
  - Bane of all promising technologies – Ethanol, DME, Natural Gas, Hydrogen and Especially Electricity
- Electric Vehicles will have to compete with very efficient new technologies – And combustion has always won.
- Automated Driving is coming, but how far can it go?
- Remember Jevon's Paradox