Advanced Vehicle Technologies; Outlook for Electrics, Internal Combustion, and Alternate Fuels

Don Hillebrand

Energy Usage

Tesla Electric Car – Advanced Vehicle?

- Top speed 130mph
- 182-kilowatt AC-induction motor
- 6800 lithium ion batteries
- 13,500rpm top speed
- 3.5 hours recharge
- 250 miles range
- Cost $100K

Tesla’s “Batteryless: Electric Car

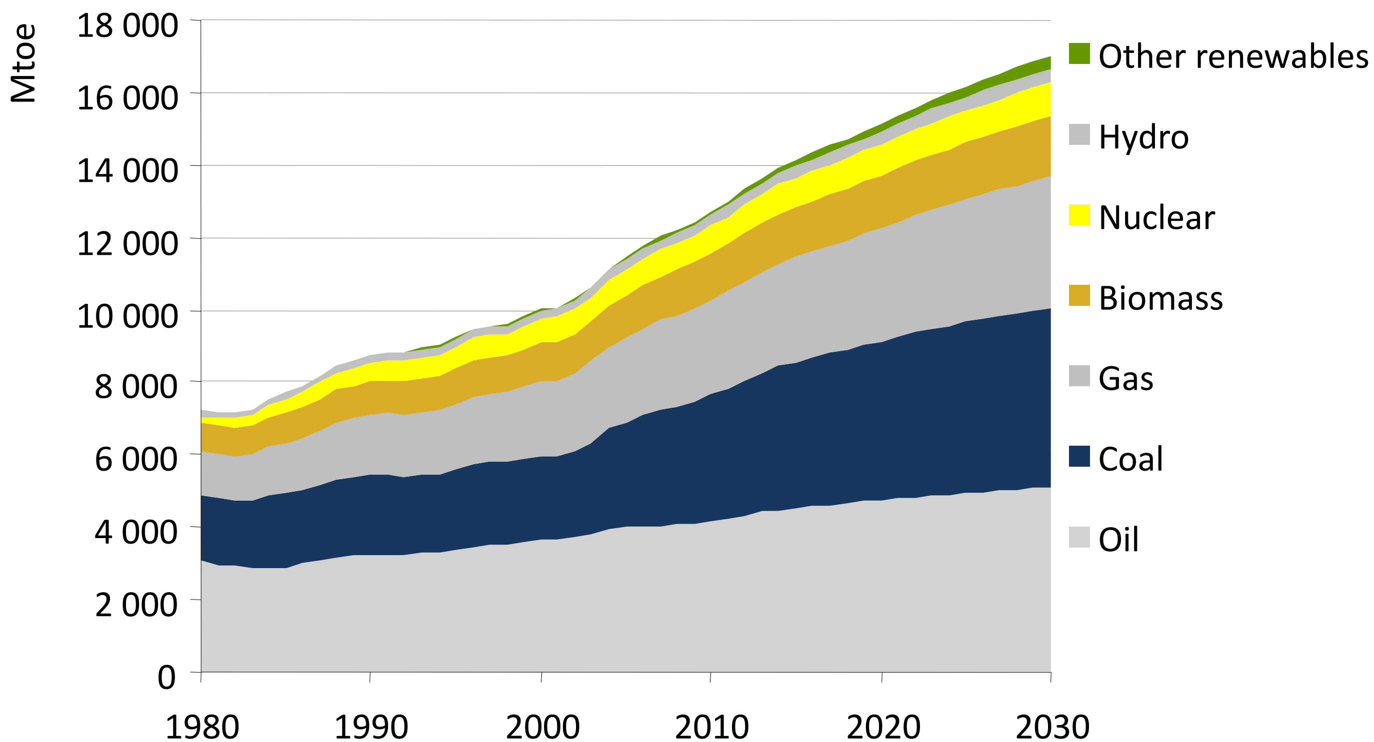
1931 Pierce Arrow
80 hp AC machine

- Supported by the Pierce-Arrow Co. and General Electric in 1931, Tesla replaced the engine with an 80-horsepower alternating-current electric motor with **<u>no external power source.</u>**
- Tesla bought vacuum tubes, some wires and assorted resistors, and assembled them in a circuit box 24 inches long, 12 inches wide and 6 inches high, with a button sticking out.
- Getting into the car, Tesla pushed a button and announced, "We now have power," and proceeded to test drive the car for a week, often at speeds of up to 90 mph.

(Quote from Texas Newspaper)

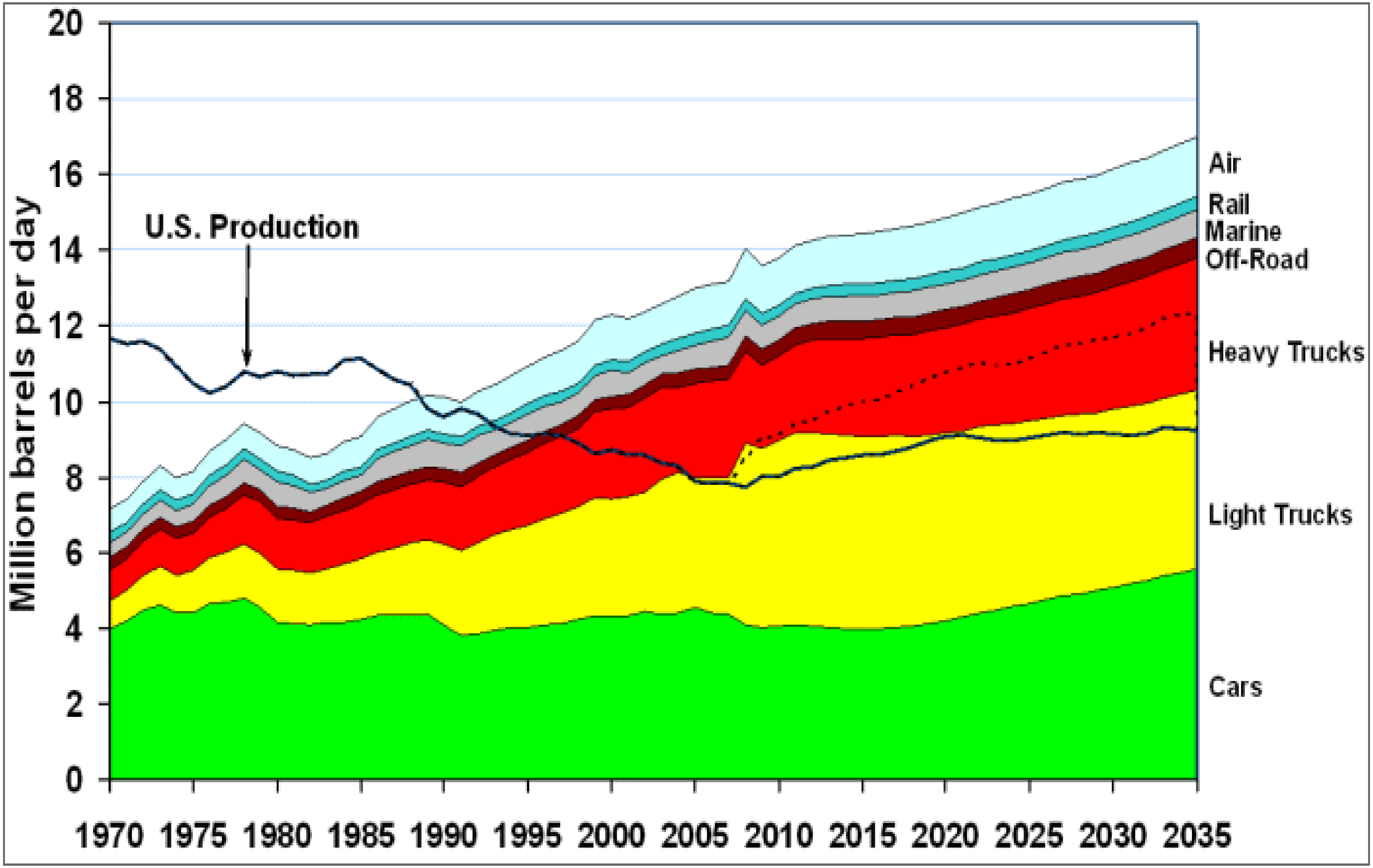
International Energy Agency's World Energy Outlook

World primary energy demand in the Reference Scenario:

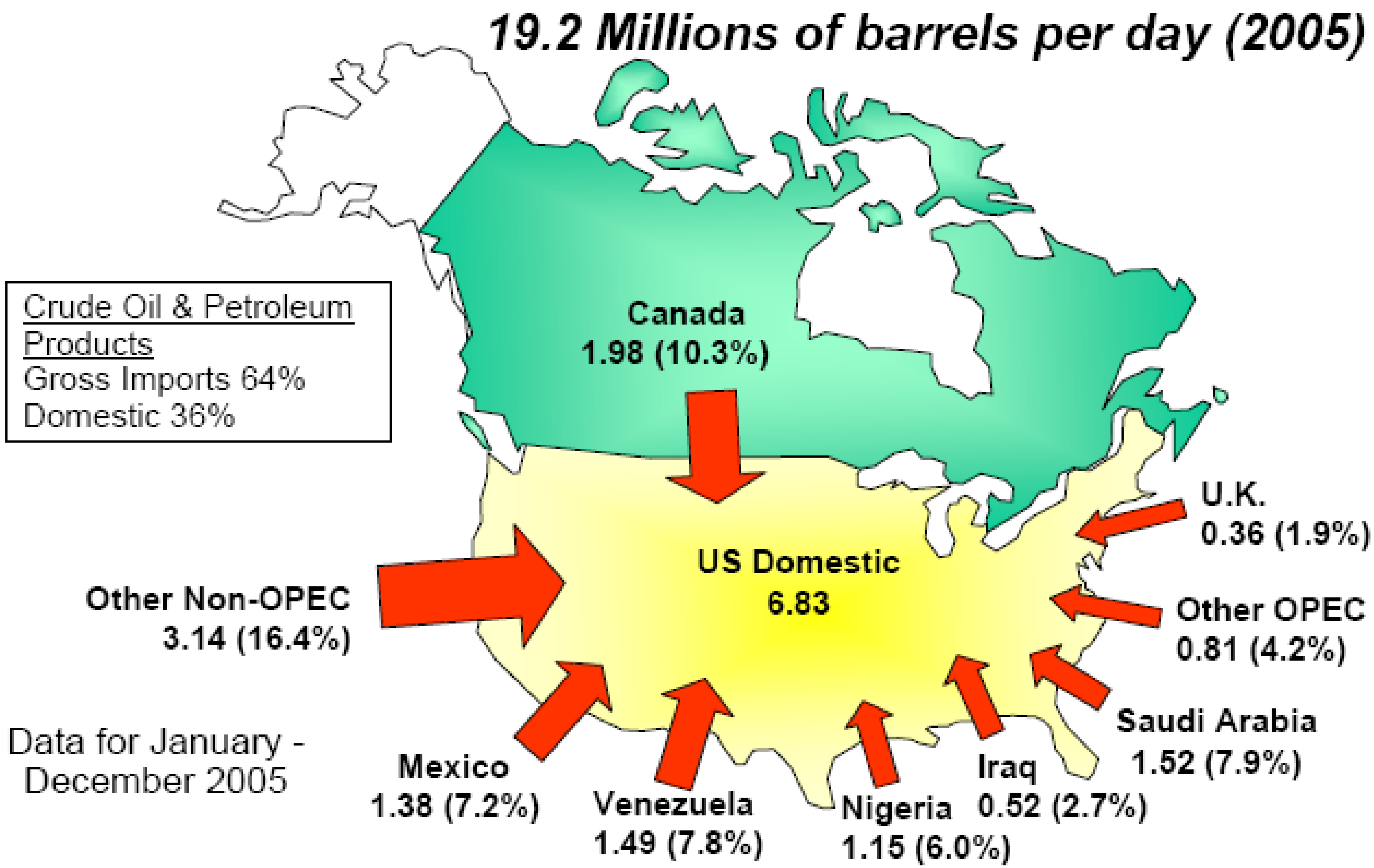


World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise

United States Transportation Petroleum Gap

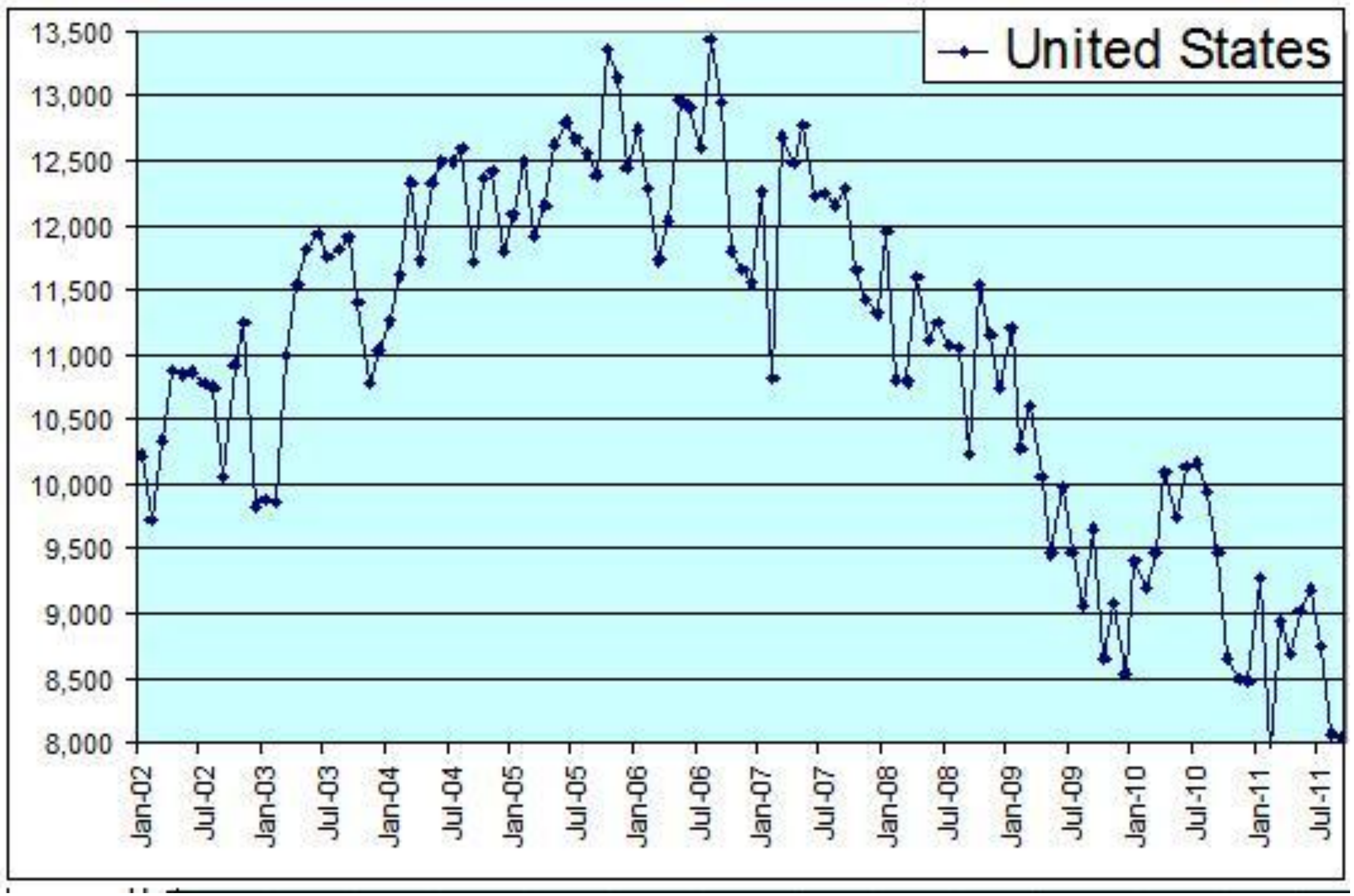


Changing U.S. Oil Import Situation



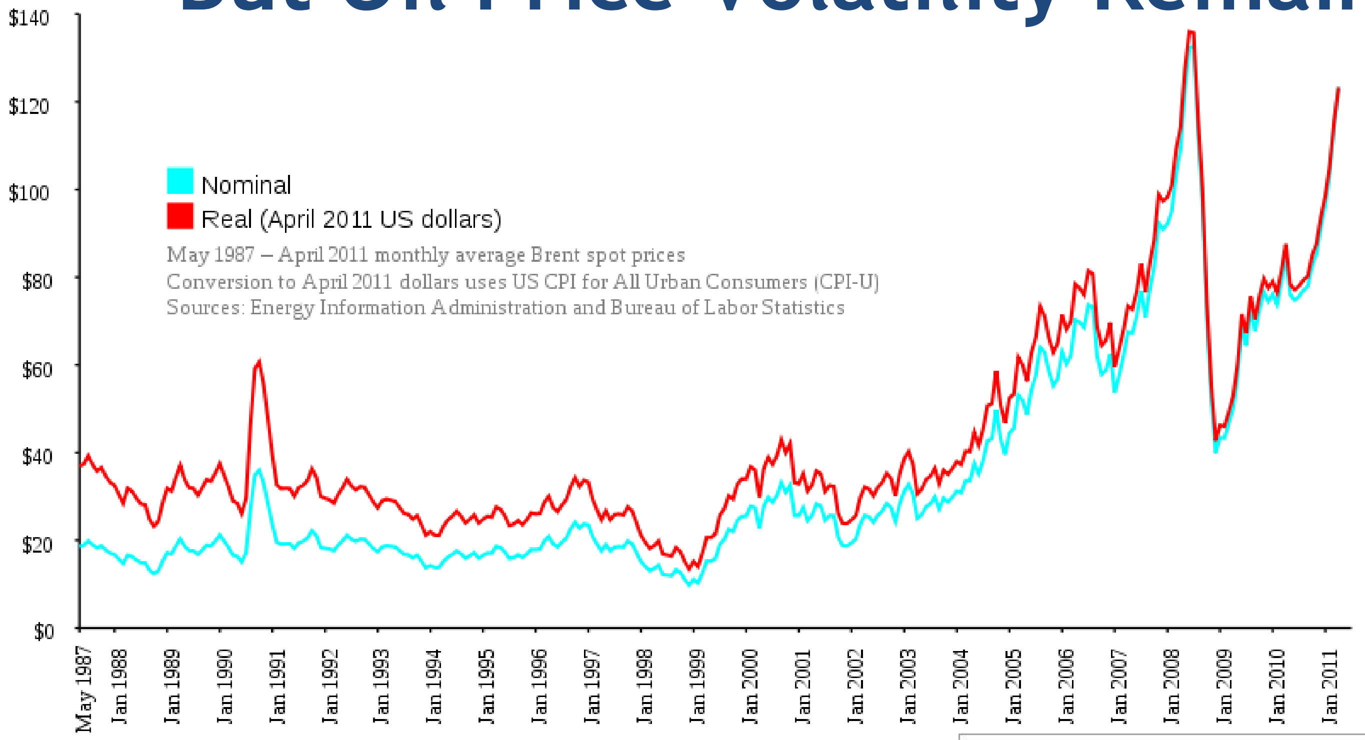
Source: Crude Oil and Petroleum Products, *EIA Petroleum Supply Monthly, February 2006.*

Oil Imports are dropping – Which could mean many things.

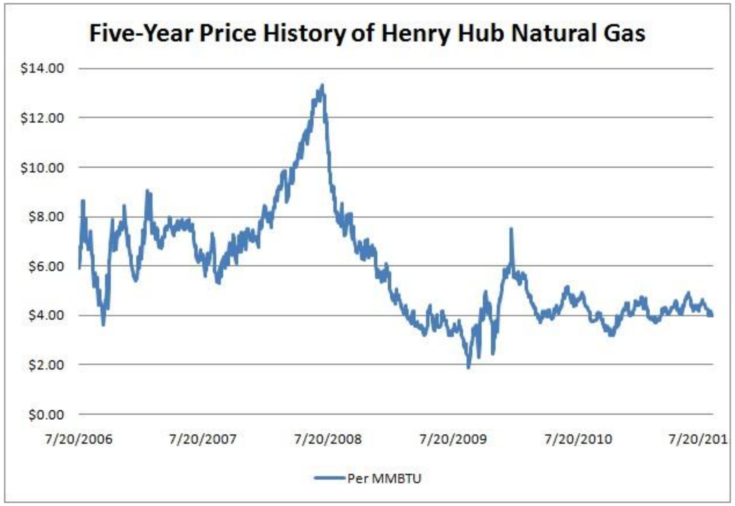


(And not all of them are good things)

But Oil Price Volatility Remains



(And Natural Gas appears to be heading down)



Worldwide Motor Vehicle Stocks Projected in International Energy Agency's World Energy Outlook 2008

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 an 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

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

Argonne has Examined and Evaluated More Than 80 Vehicle/Fuel Systems for Efficiency

Conventional Spark-Ignition Engine Vehicles
- Gasoline
- Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
- Gaseous and liquid hydrogen
- Methanol and ethanol

Spark-Ignition, Direct-Injection Engine Vehicles
- Gasoline
- Methanol and ethanol

Compression-Ignition, Direct-Injection Engine Vehicles
- Diesel
- Fischer-Tropsch diesel
- Dimethyl ether
- Biodiesel

Fuel Cell Vehicles
- On-board hydrogen storage
  - Gaseous and liquid hydrogen from various sources
- On-board hydrocarbon reforming to hydrogen

Battery-Powered Electric Vehicles
- Various electricity generation sources

Hybrid Electric Vehicles (HEVs)
- Spark-ignition engines:
  - Gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel

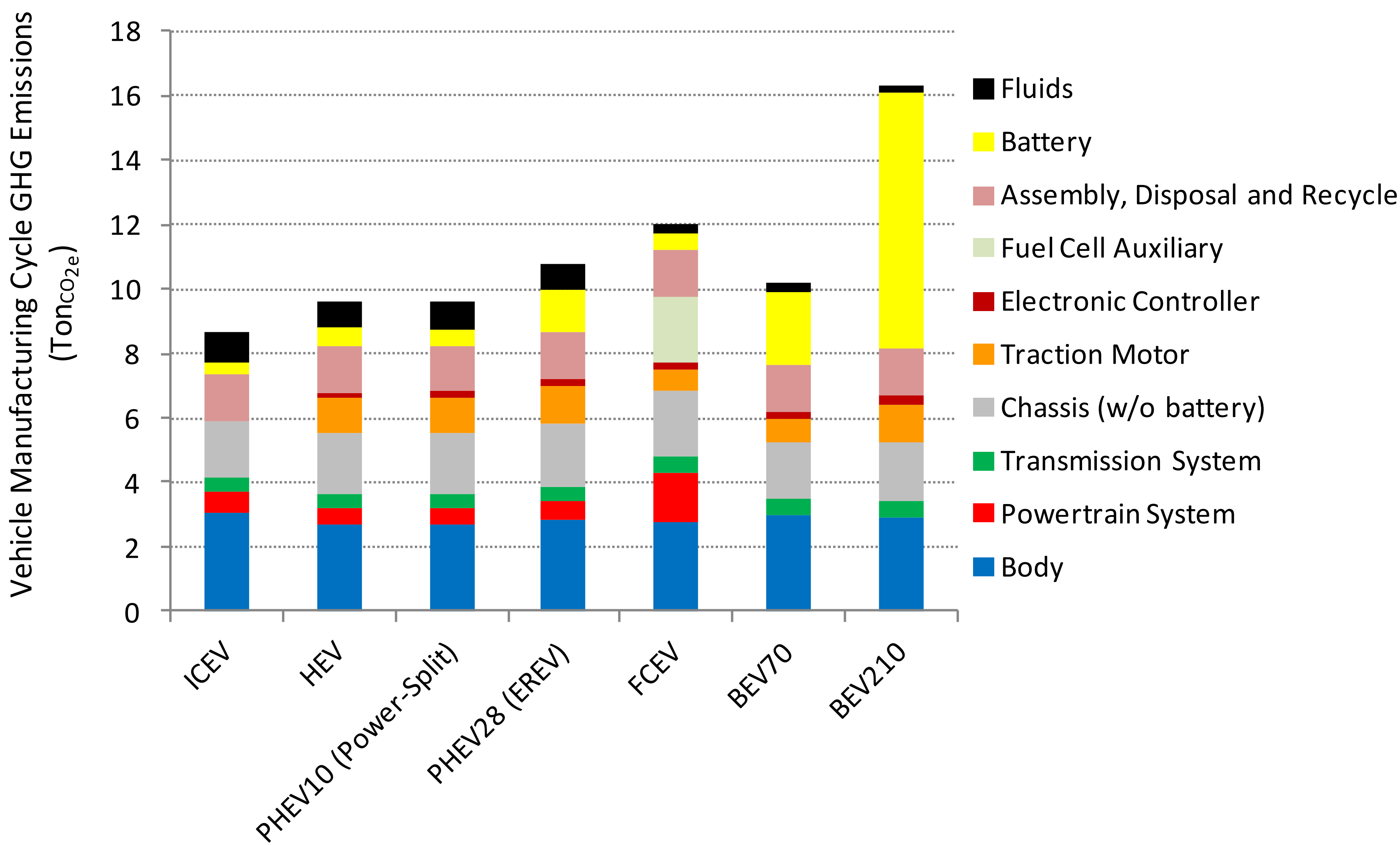
Plug-in Hybrid Electric Vehicles (PHEVs)
- Spark-ignition engines:
  - Gasoline
  - Compressed natural gas, liquefied natural gas, and liquefied petroleum gas
  - Gaseous and liquid hydrogen
  - Methanol and ethanol
- Compression-ignition engines
  - Diesel
  - Fischer-Tropsch diesel
  - Dimethyl ether
  - Biodiesel

More Than 100 Fuels are Available - Production Pathways from Various Energy Feedstocks

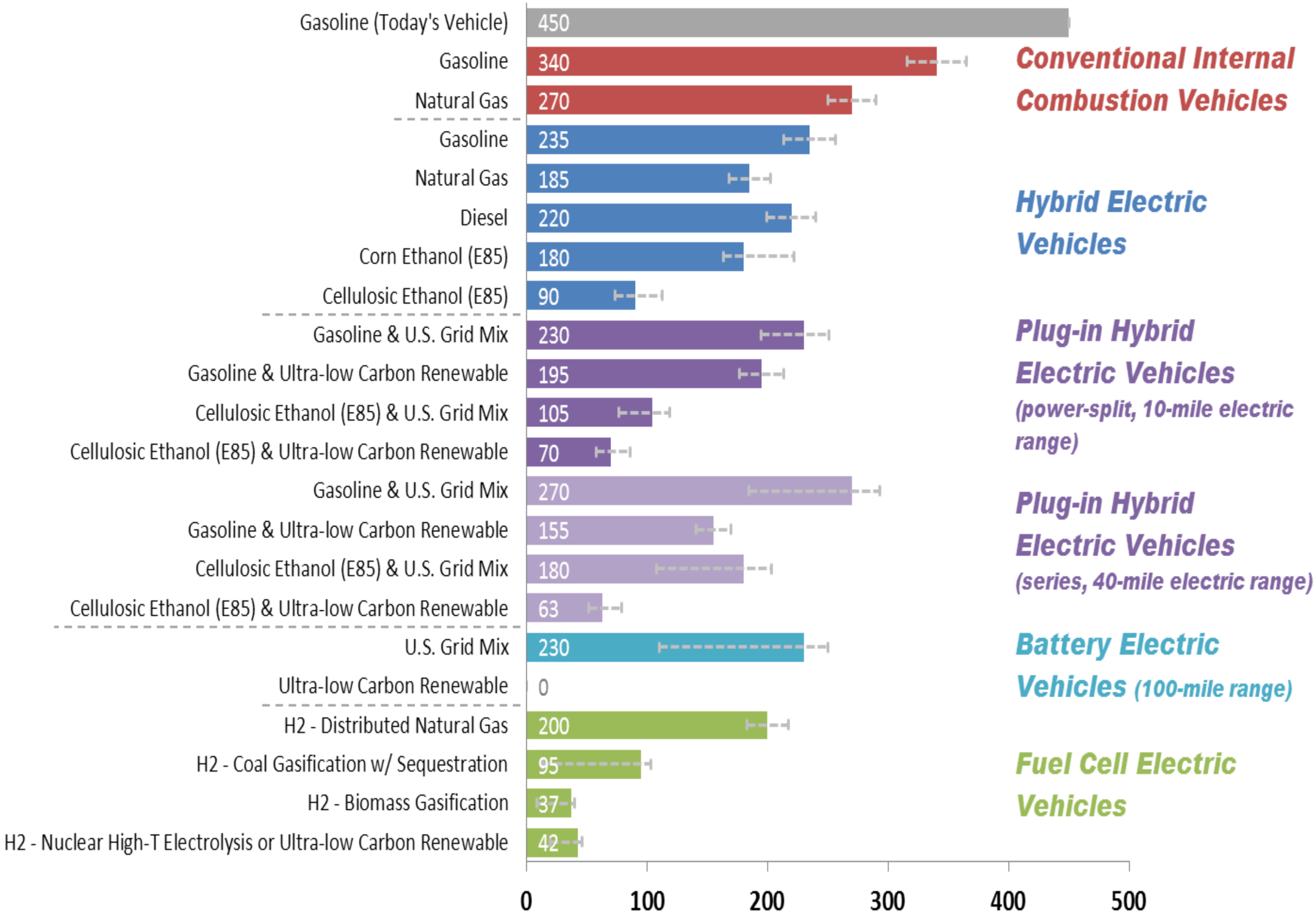
Petroleum Conventional Oil Sands	Gasoline Diesel Liquefied Petroleum Gas Naphtha Residual Oil Jet Fuel
Natural Gas North American Non-North American	Compressed Natural Gas Liquefied Natural Gas Liquefied Petroleum Gas Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Naphtha Fischer-Tropsch Jet Fuel
Corn	Ethanol Butanol
Sugarcane	Ethanol
Soybeans	Biodiesel Renewable Diesel Renewable Jet Fuel
Coke Oven Gas Petroleum Coke Nuclear Energy	Hydrogen
Coal	Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fuel
Renewable Natural Gas Landfill Gas	Compressed Natural Gas Liquefied Natural Gas Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Naphtha Fischer-Tropsch Jet Fuel
Cellulosic Biomass Switchgrass Fast Growing Trees Crop Residues Forest Residues	Ethanol Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fuel
Residual Oil Coal Natural Gas Biomass Other Renewables	Electricity

The yellow boxes contain the names of the feedstocks and the red boxes contain the names of the fuels that can be produced from each of those feedstocks.

Per-Vehicle Life-Cycle GHG Emissions of Different Vehicle Technologies



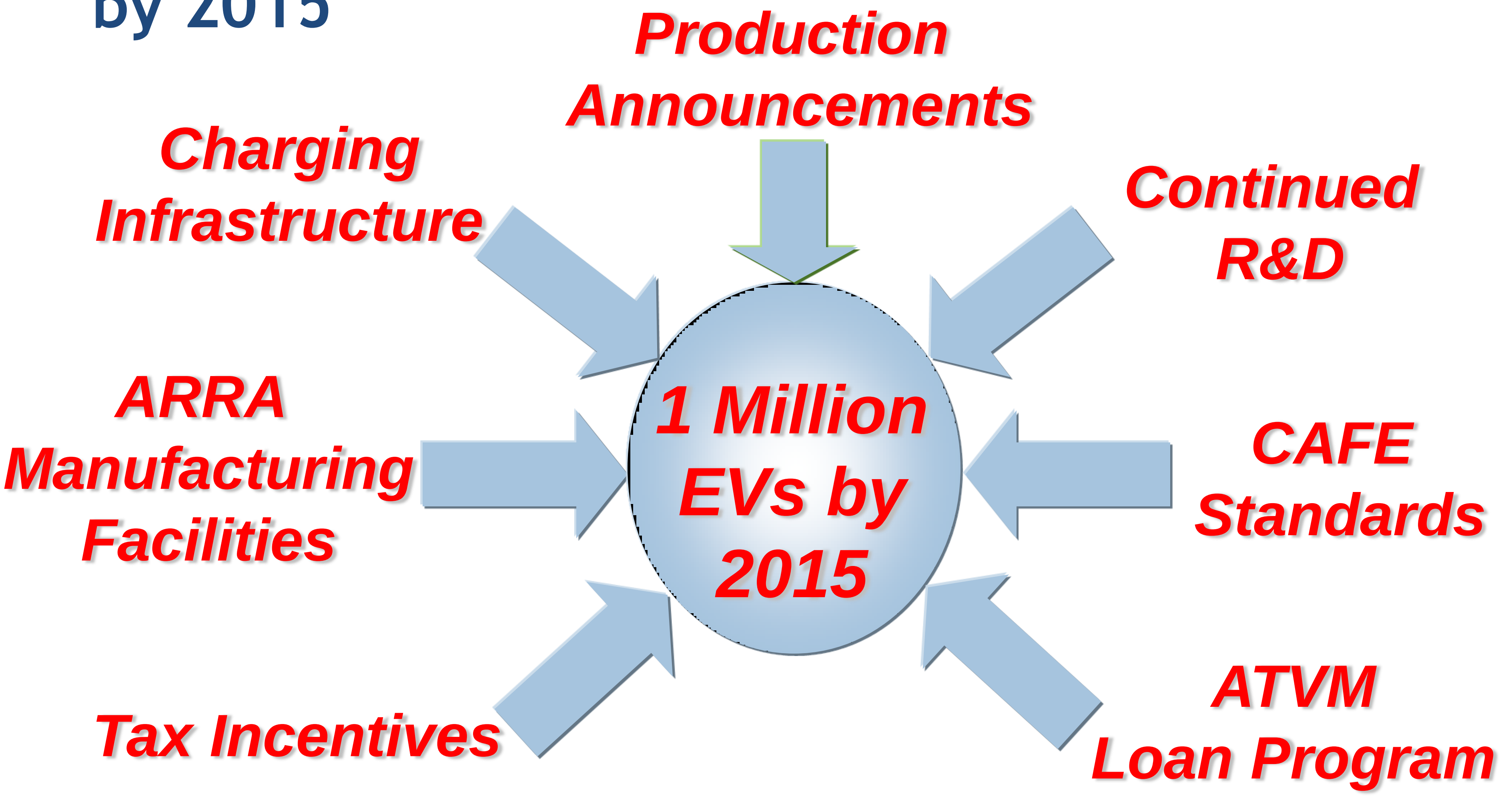
WTW Results: GHG Emissions of a Mid-Size Car (g/mile)



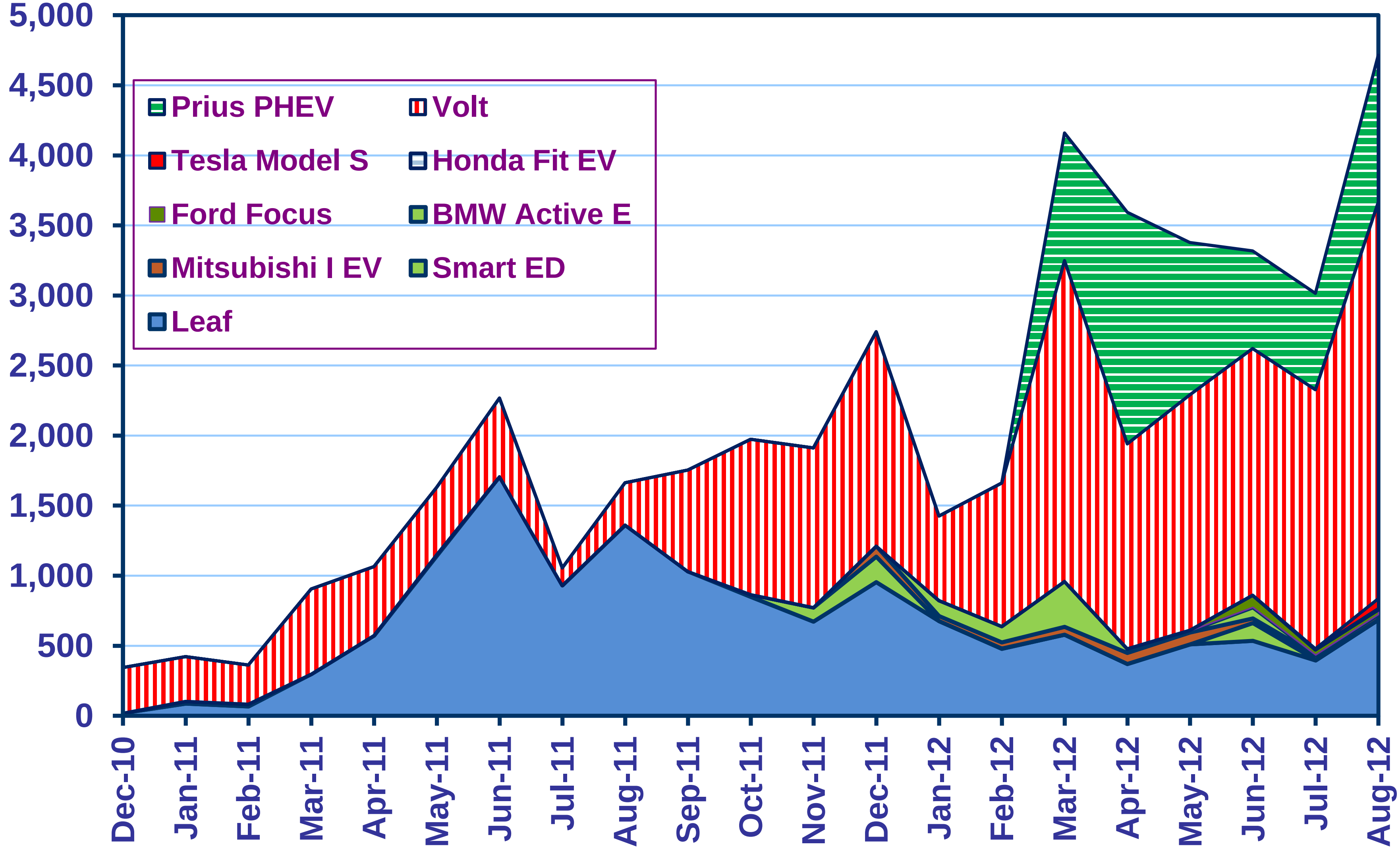
Low/high band: sensitivity to uncertainties associated with projection of fuel economy and fuel pathways

(DOE EERE 2010, Record 10001)

The Stated Goal was to Produce 1 Million EVs by 2015



New Plug-In Vehicle Sales – Battery Electrics will not meet Objectives



Battery Electric Vehicles have "Obstacles"
Range Anxiety is probably Foremost

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

In Perspective:

•A major electric vehicle company produced 700 vehicles last year.

•In 1985 - Sterling Height Assembly Plant made 700 vehicles in half a day.

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.

Fast Charging - Back of the Envelope
To make the economics work will require Subsidies

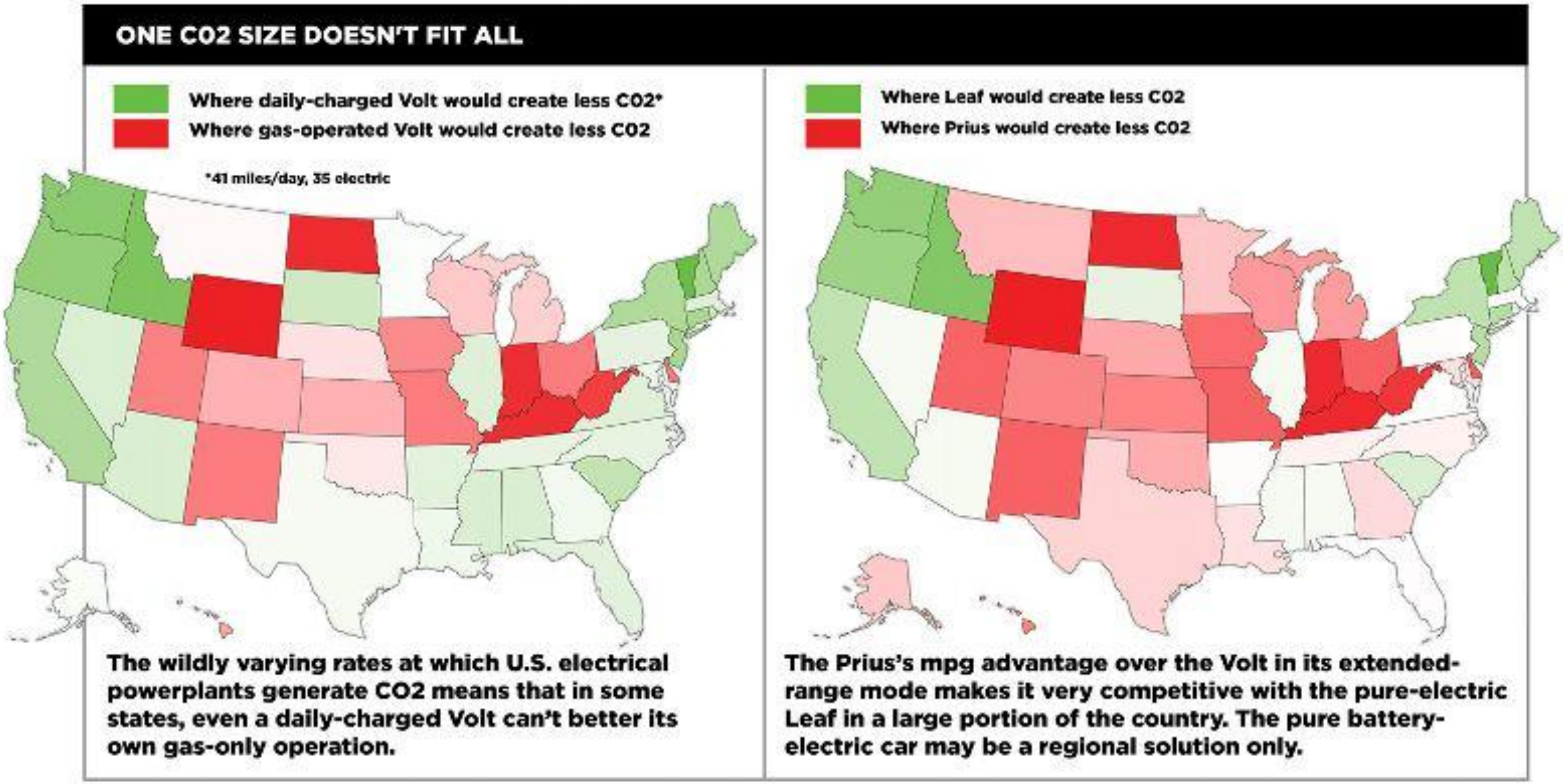
- Need to handle Thermal Loads and power distribution
- Massive investment in infrastructure required – similar to hydrogen
- Fast Charging will not be the first resort, because there will be other options, so the gasoline forecourt model will not hold.

Cost of level three charger is $15K – $60K

Value of electricity is about $5 per car

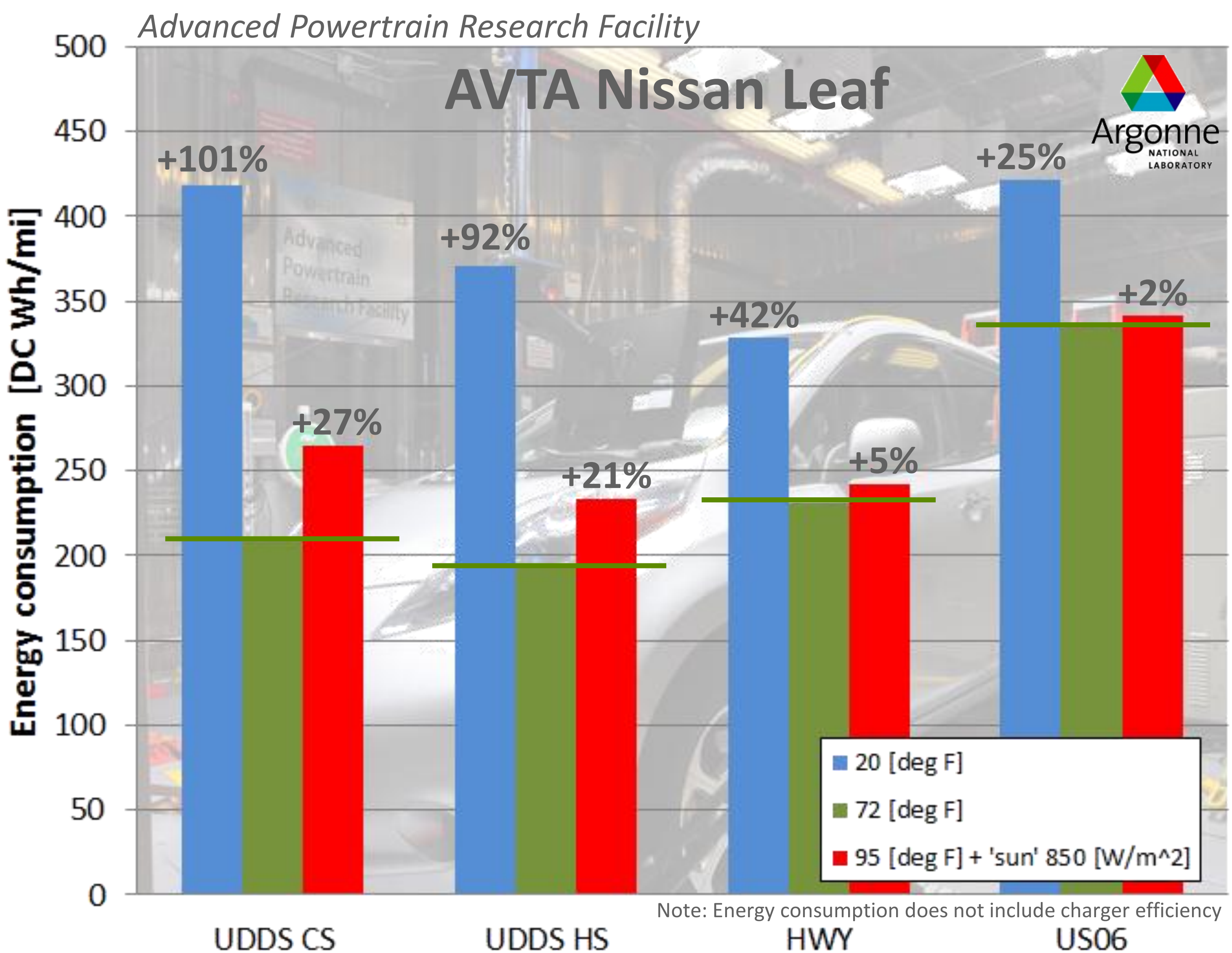
- EDF estimate: $15,000 charger is estimated to return a profit of $60 per year
- Scottish power estimates that a break even cost for electricity is 60 cents/ kW-h (making fast charge electric vehicles more expensive per mile than gasoline.)

Going electric doesn't necessarily reduce CO_2



Source:
http://www.motortrend.com/roadtests/alternative/1108_2011_chevrolet_volt_vs_2011_nissan_leaf_vs_2011_toyota_prius_comparison/

Impact of Temperature on Energy Consumption



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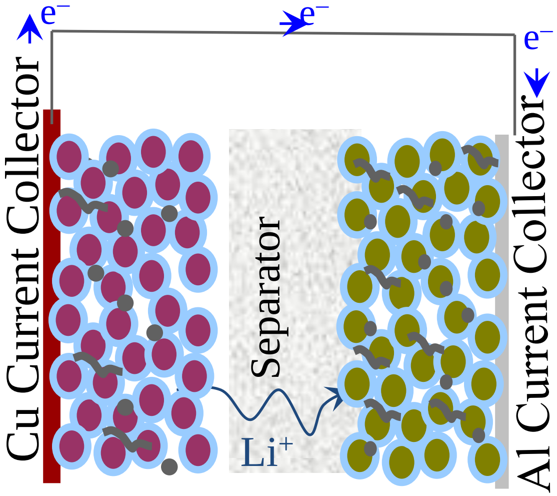
Next Generation Lithium-Ion

Next generation lithium-ion can increase the power and energy by 2X while decreasing cost by 70%

Anode

Today's Technology (300 mAh/g)
-Graphite
-Hard carbon

Next Generation (600 mAh/g)
-Intermetallics and new binders
-Nanophase metal oxides
-Conductive additives
-Tailored SEI



Electrolyte

Today's Tech (4 volt)
Liquid organic solvents & gels

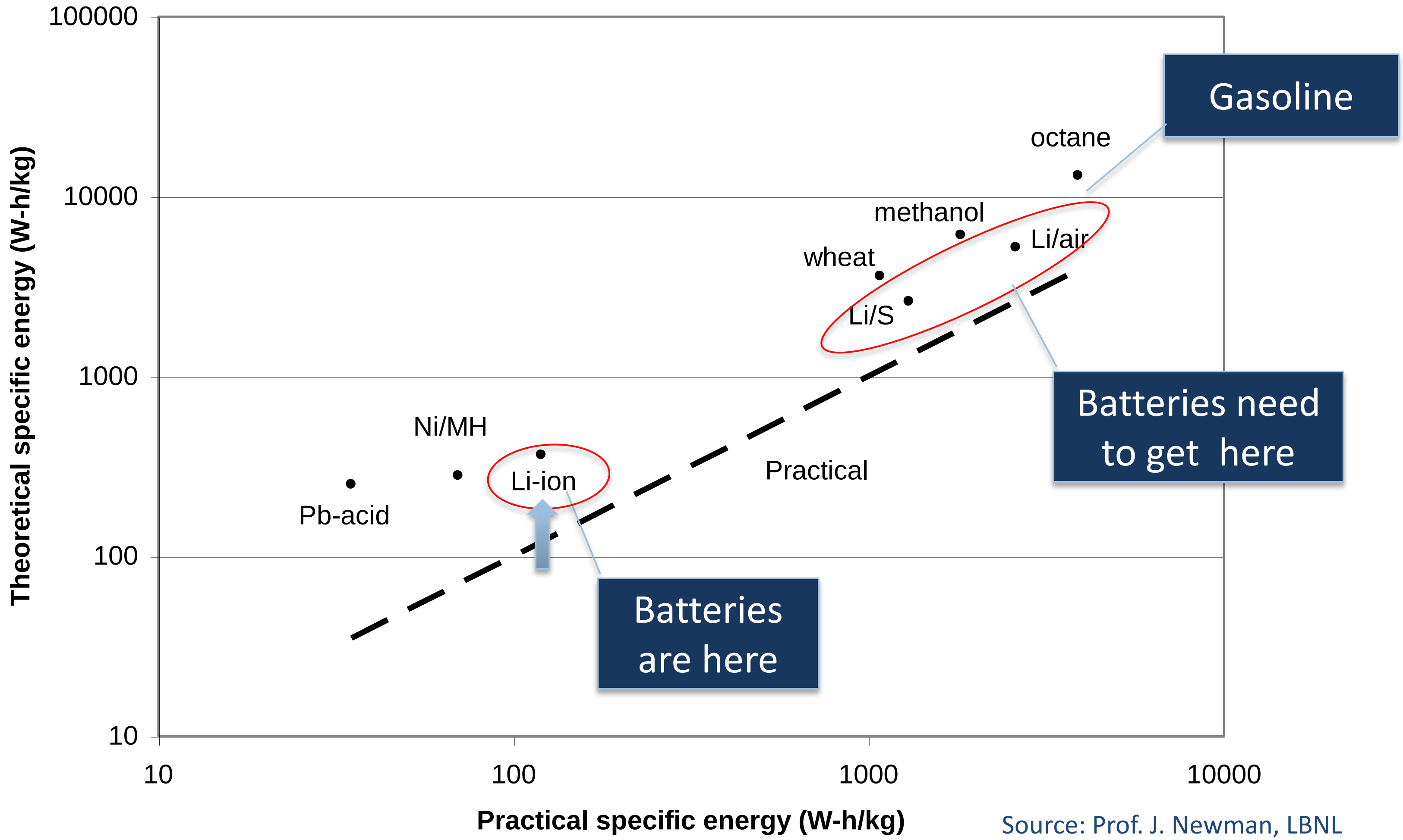
Next Generation (5 volt)
-High voltage electrolytes
-Electrolytes for Li metal
-Non-flammable electrolytes

Cathode

Today's Technology (120-160 mAh/g)
-Layered oxides
-Spinels
-Olivines

Next Generation (300 mAh/g)
-Layered-layered oxides
-Metal phosphates
-Tailored Surfaces

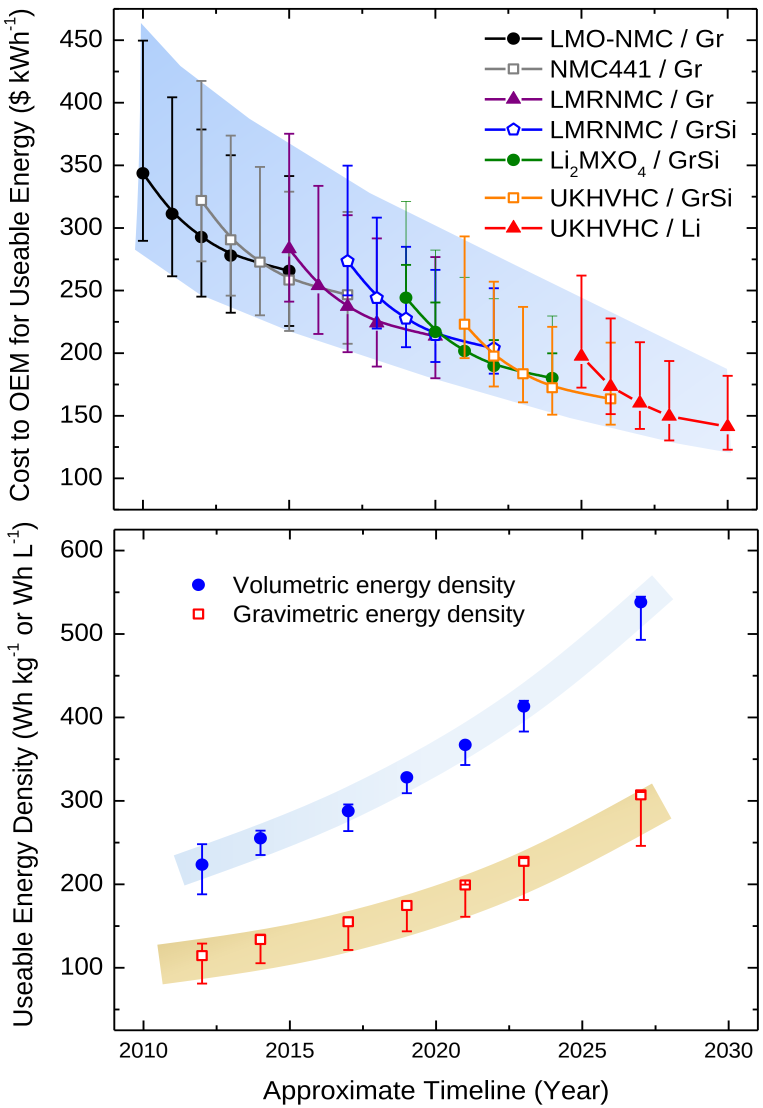
Energy storage technology gap



Source: Prof. J. Newman, LBNL

Game-changing technology is on the map, but only now being developed in the United States. We have a long way to go to meet technology demands.

Path Forward for Lithium Based Batteries



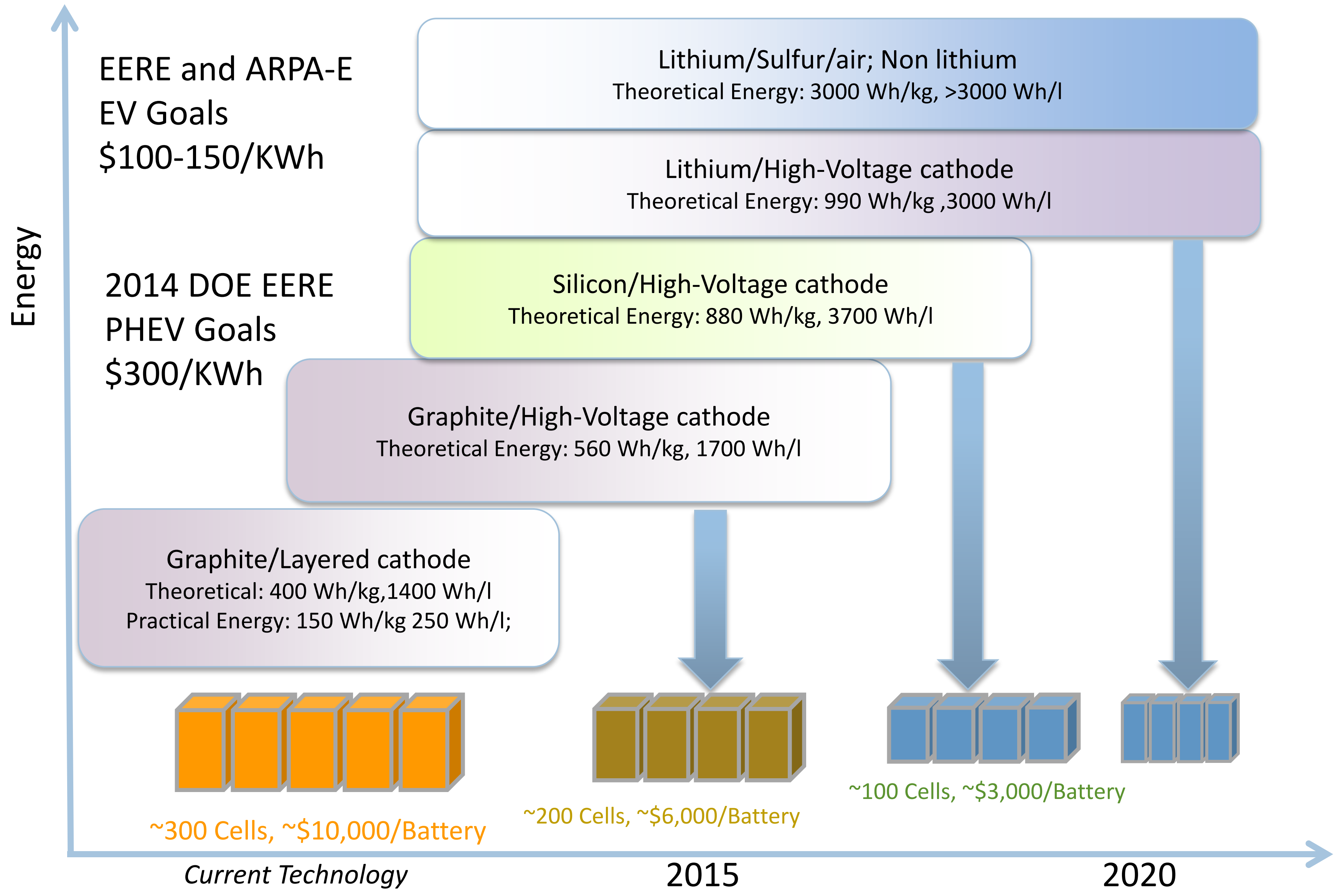
If high-risk research is successful, material advances may lead to a 60% reduction in cost and 250% increase in energy density

Calculations for a **EV100**: 30 kWh, 80 kW 360V

Barriers to overcome

- Stabilizing LMR-NMC, $xLi_2MnO_3 \cdot (1-x)LiMO_2$
- Stabilizing silicon composite (GrSi)
- Reversible multi-Li^+ per transition metal
- Discovery of high voltage electrolyte >4.8 V
- Discovery of high voltage, high capacity cathode
- Stabilization of Li metal

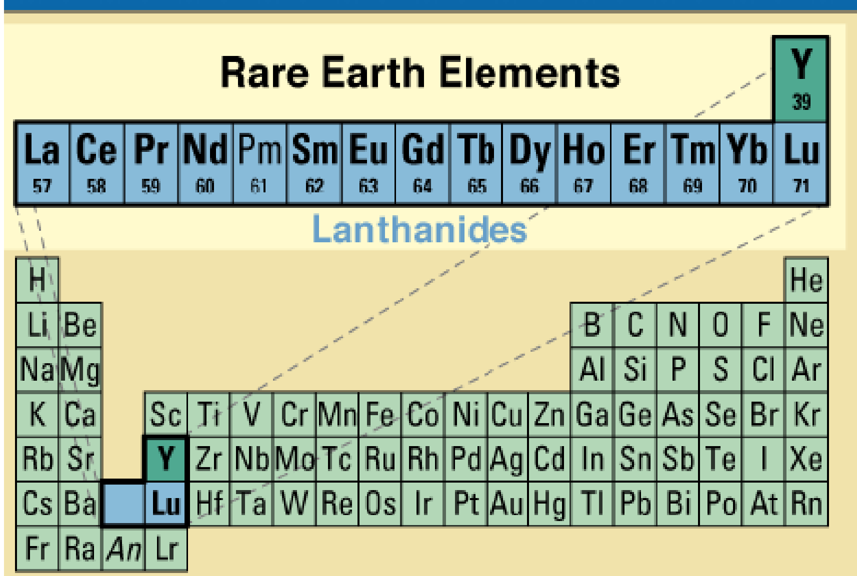
Research Roadmap for 2015 and Beyond

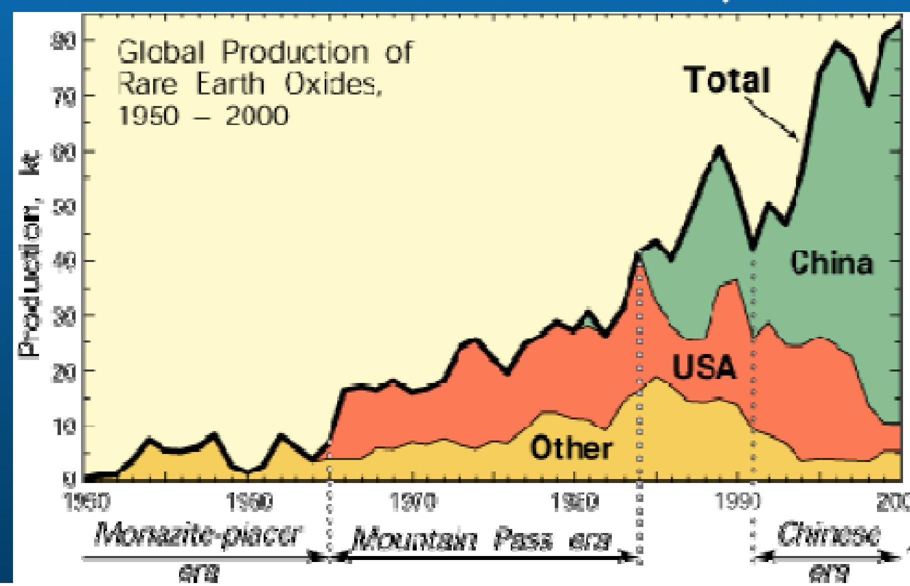


Rare earths are a strategic concern

NiMH battery slag

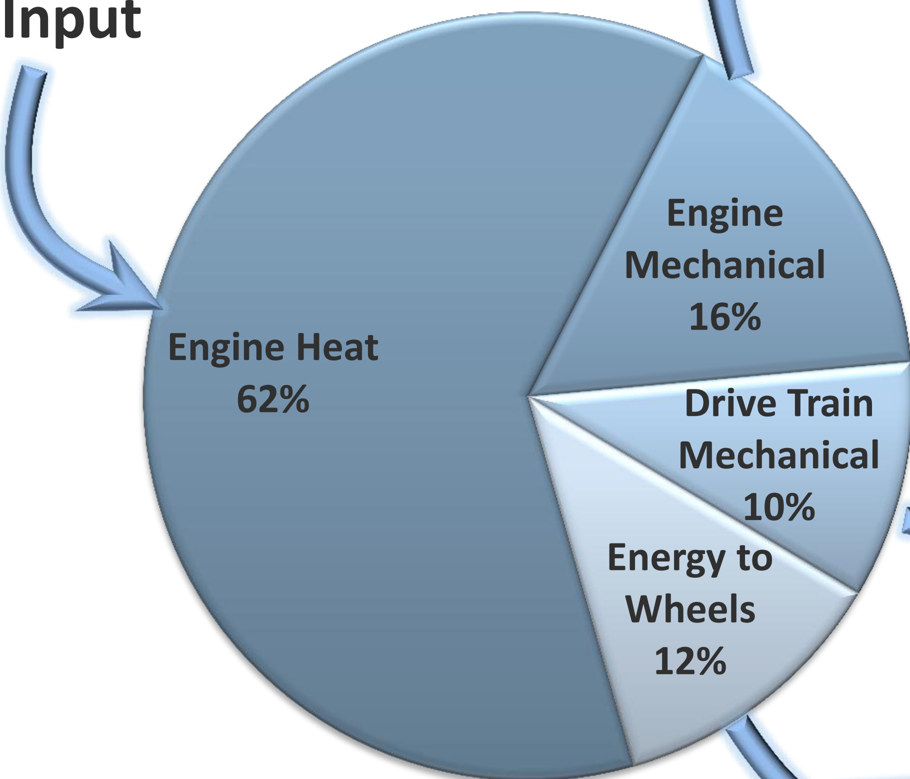
- Target: valorization of REE's
  - REE's are not 'rare'
  - Supply controlled by China; export quota: price ↗





Advanced Combustion Engine R&D

100 %
Energy
Input



- **Engine Mechanical Losses**
  - Pumping Work
  - Overcoming Friction
    - Rings and piston skirt
    - Valvetrain
    - Bearings & Seals
  - Accessories
- **Drive Train Mechanical Losses**
  - Overcoming friction
    - Transmission
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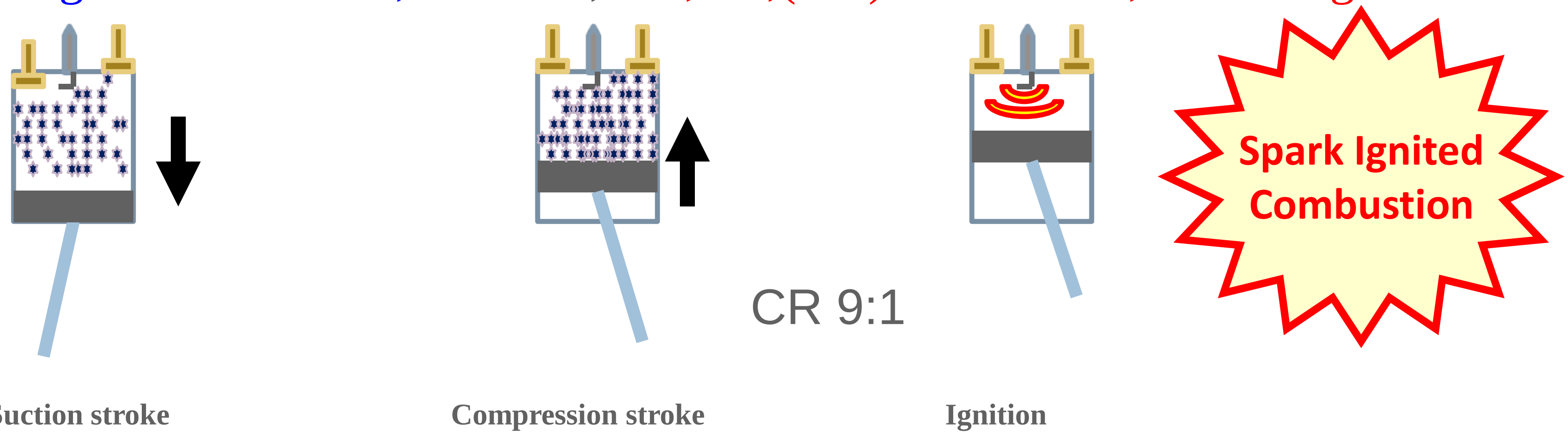
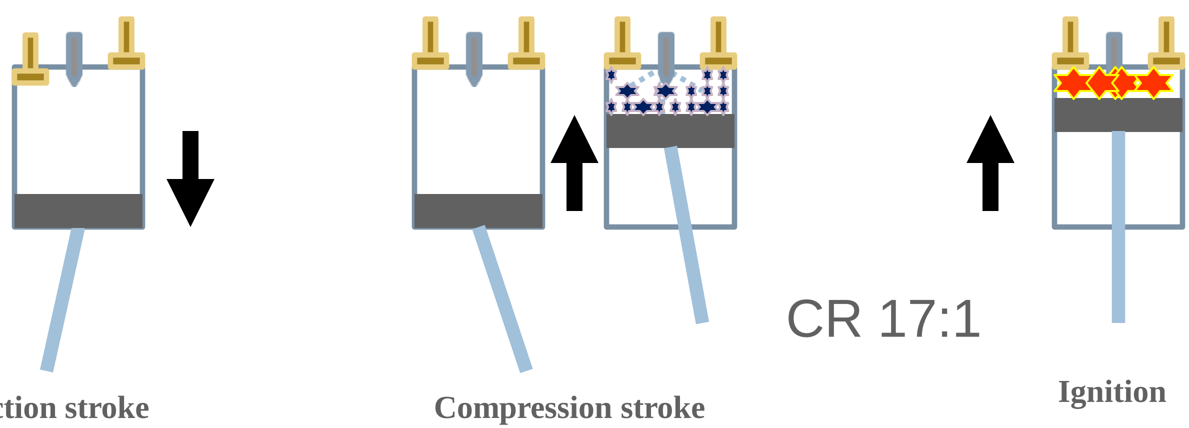
  - Coasting and Idle Work
  - Braking Work
- **Energy at Wheels**
  - Inertia, Rolling Resistance, Air Resistance, Gravity (grades)

Conventional Combustion Process

SI –Homogeneous Mixture, No soot ; HC,CO,(NO) –Emissions; Throttling losses

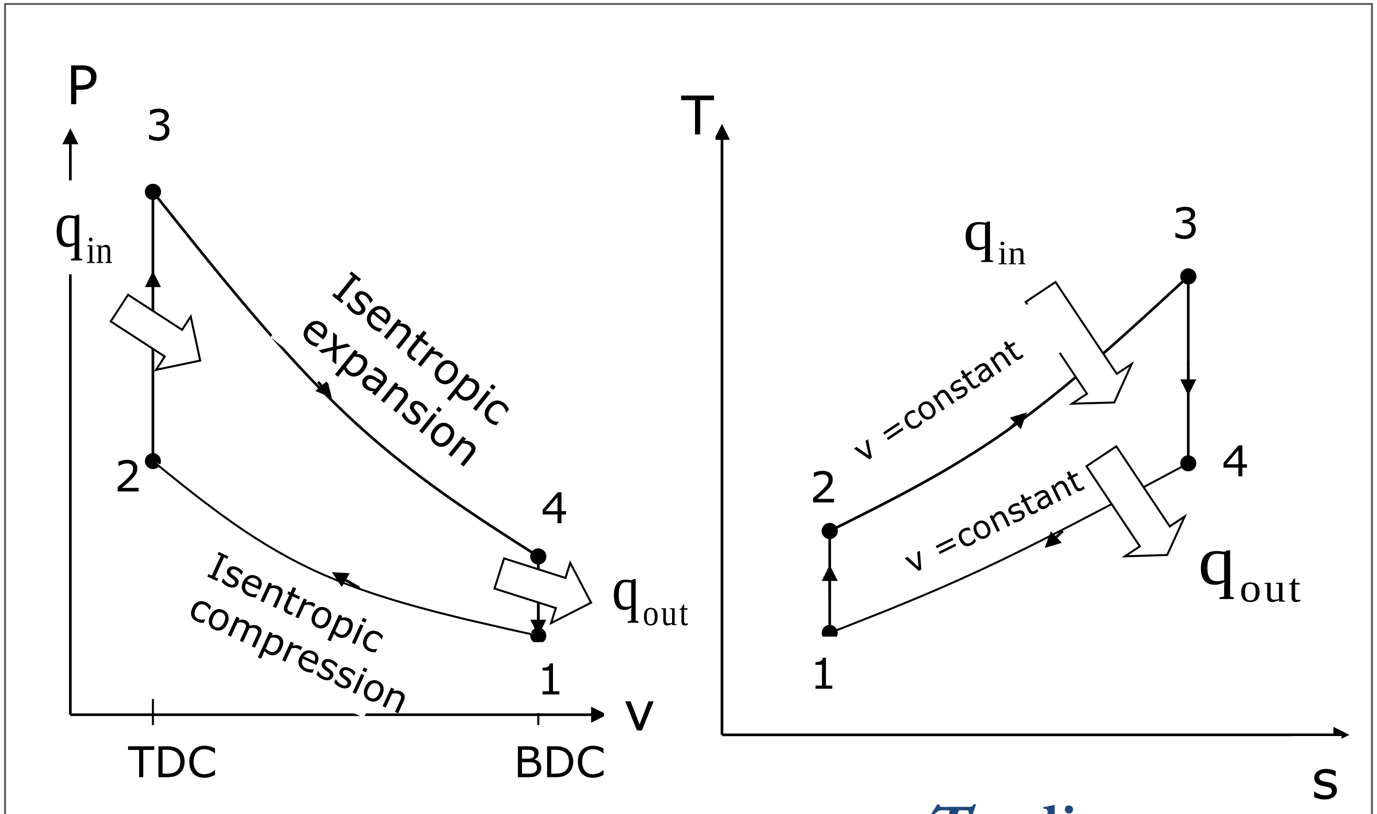


CI –Diffusion combustion, Fuel Efficient; High Smoke and NOx



Argonne National Laboratory

Otto-cycle: The traditional cycle for spark-ignition (SI) engines



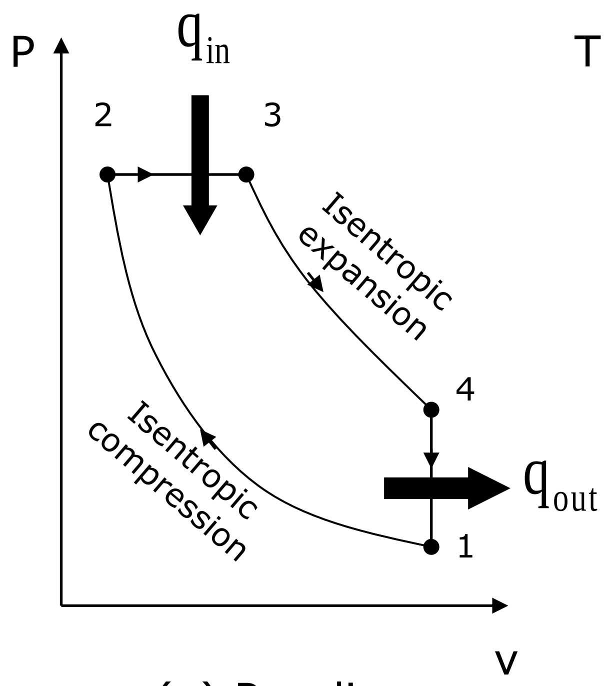
***P-v* diagram** ***T-s* diagram**

Diesel Cycle: The ideal cycle for compression-ignition (CI) engines

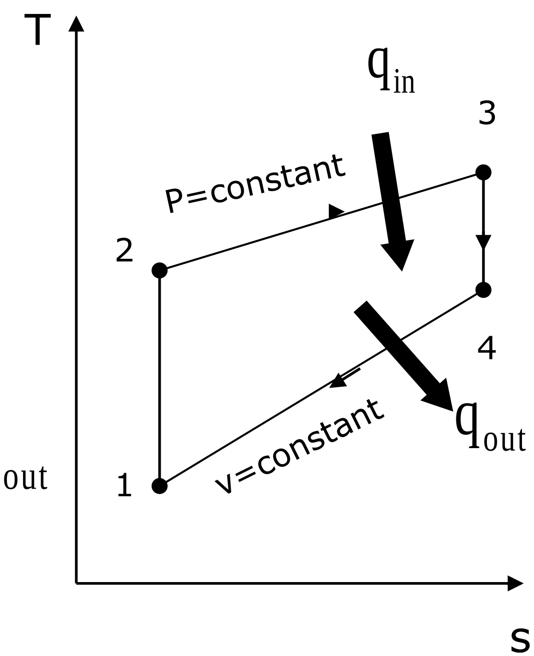
Diesel designed his engine in response to the heavy resource consumption and inefficiency of the steam engine, which only produced 12% efficiency.

Processes:
1-2 Compression
(s = Const)
2-3 Combustion
(P = Const.)
3-4 Expansion
(s = Const)
4-1 Exhaust
(V = Const)

The combustion process in CI engines takes place over a **longer interval** and is approximated as constant-pressure heat addition process.

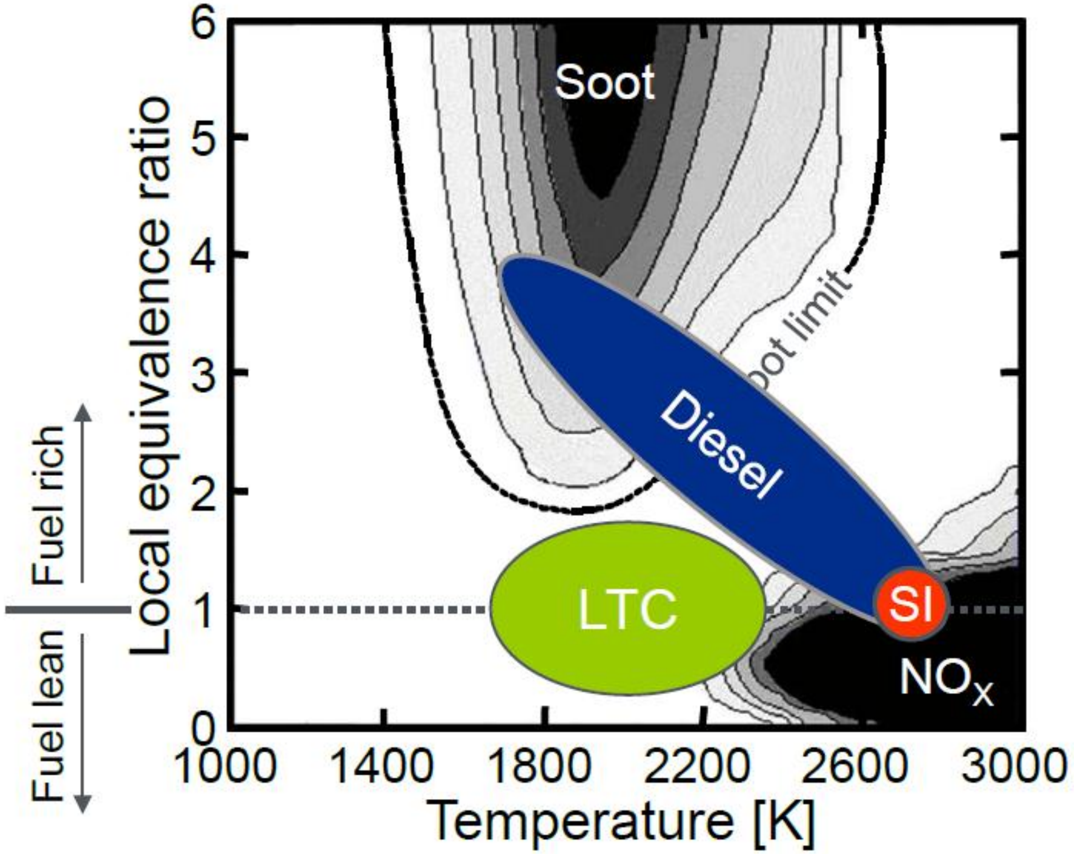


(a) P-v diagram



(b) T-s diagram

What are the efficiency and emissions challenges?

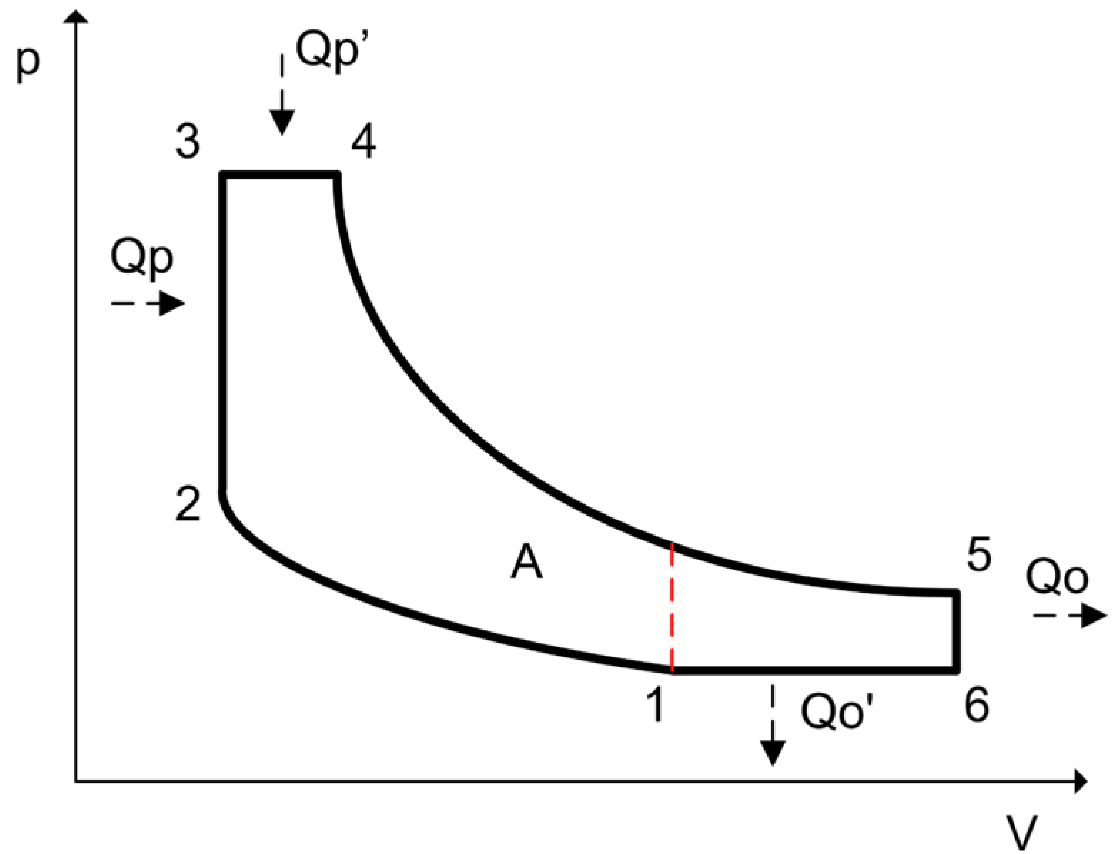


Ref. SAE 2003-01-1789 , Takaaki Kitamura et.al

Atkinson Cycle Engine is a bit of a cycle Cheater Used in the Toyota Prius - enabled by Hybridization

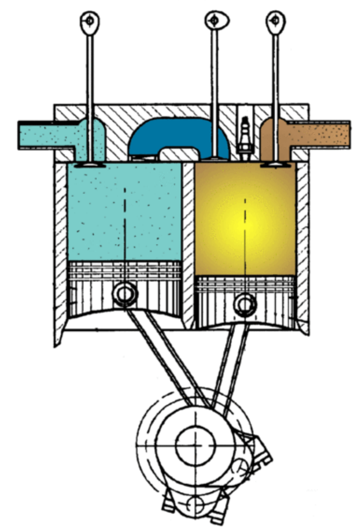
The disadvantage of the four-stroke Atkinson cycle engine versus the more common Otto cycle engine is reduced power density.

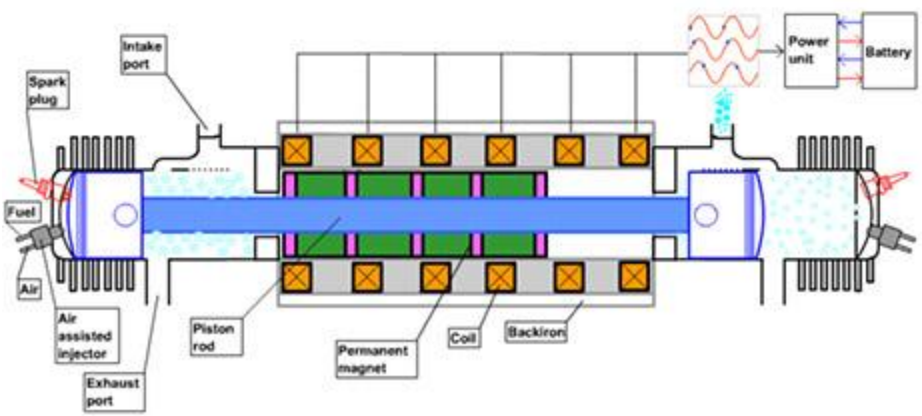
Keeping the intake valve open just a little longer



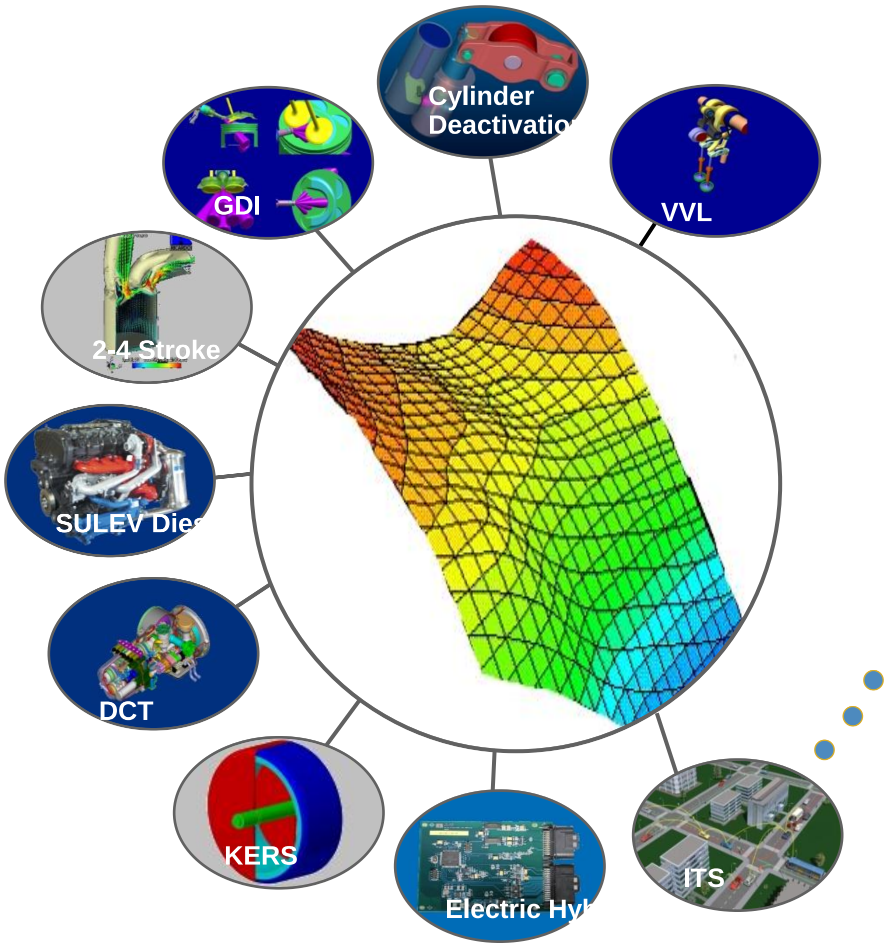
What was old – is new again
Advanced controls have enabled many “new” engine concepts

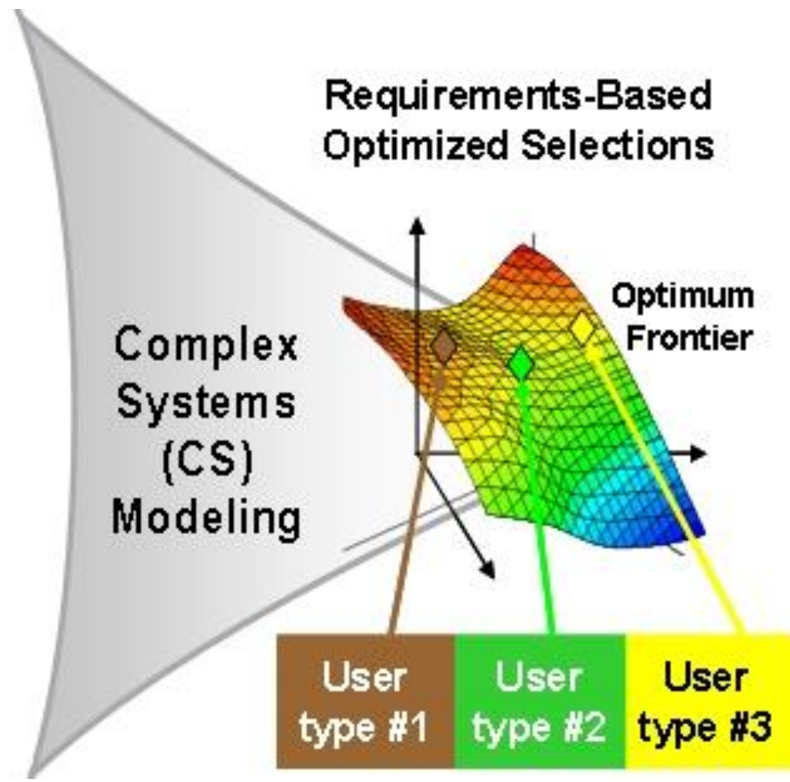
- Series Hybrid Engines
- Atkinson Cycle Engines
- External Combustion Engines (Steam Engines, Stirling Engines)
- Turbine Engines
- 6-Stroke Engines
  - Crower, Bajulaz, Velozeta Six-Stroke Engines, Beare, Griffin
- Scuderi Air Engine
- Free Piston Engines



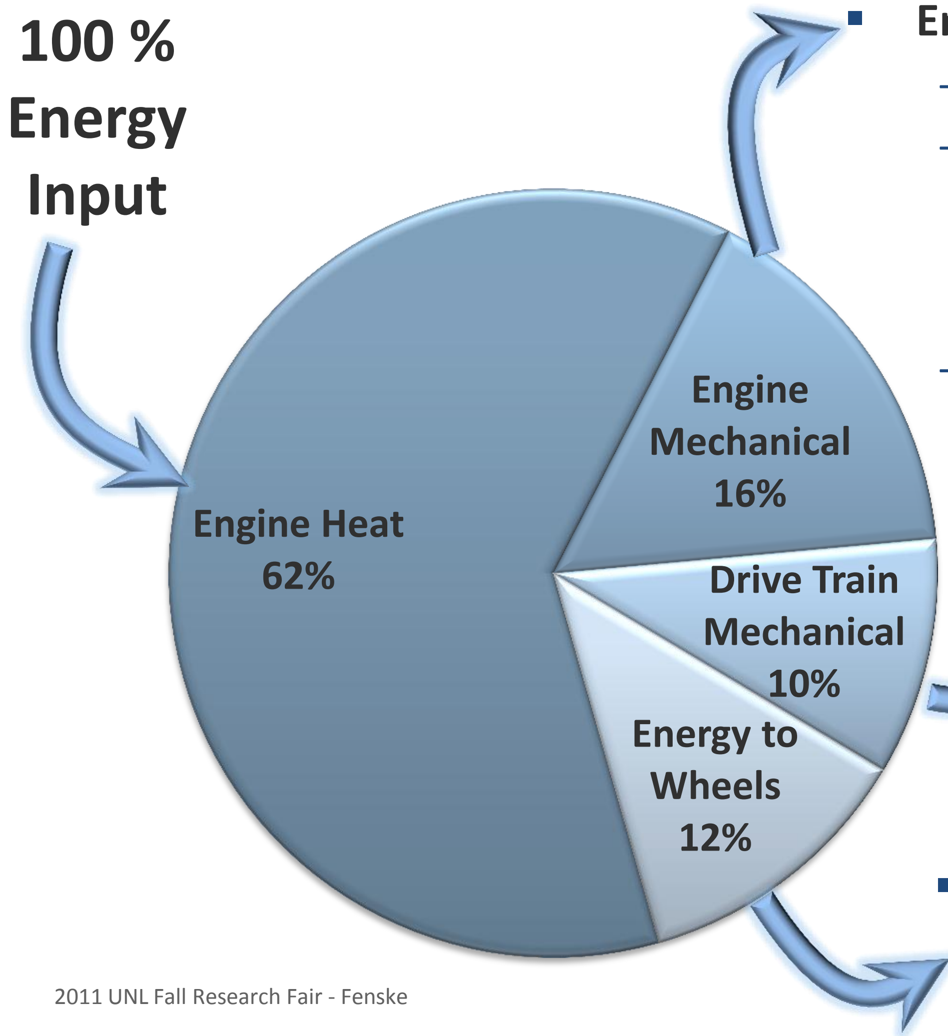


Advanced technology and use aspects of an efficiency use reduction program





How Much is Lost to Friction ? - More Energy is lost to Friction than is Delivered to the Wheels



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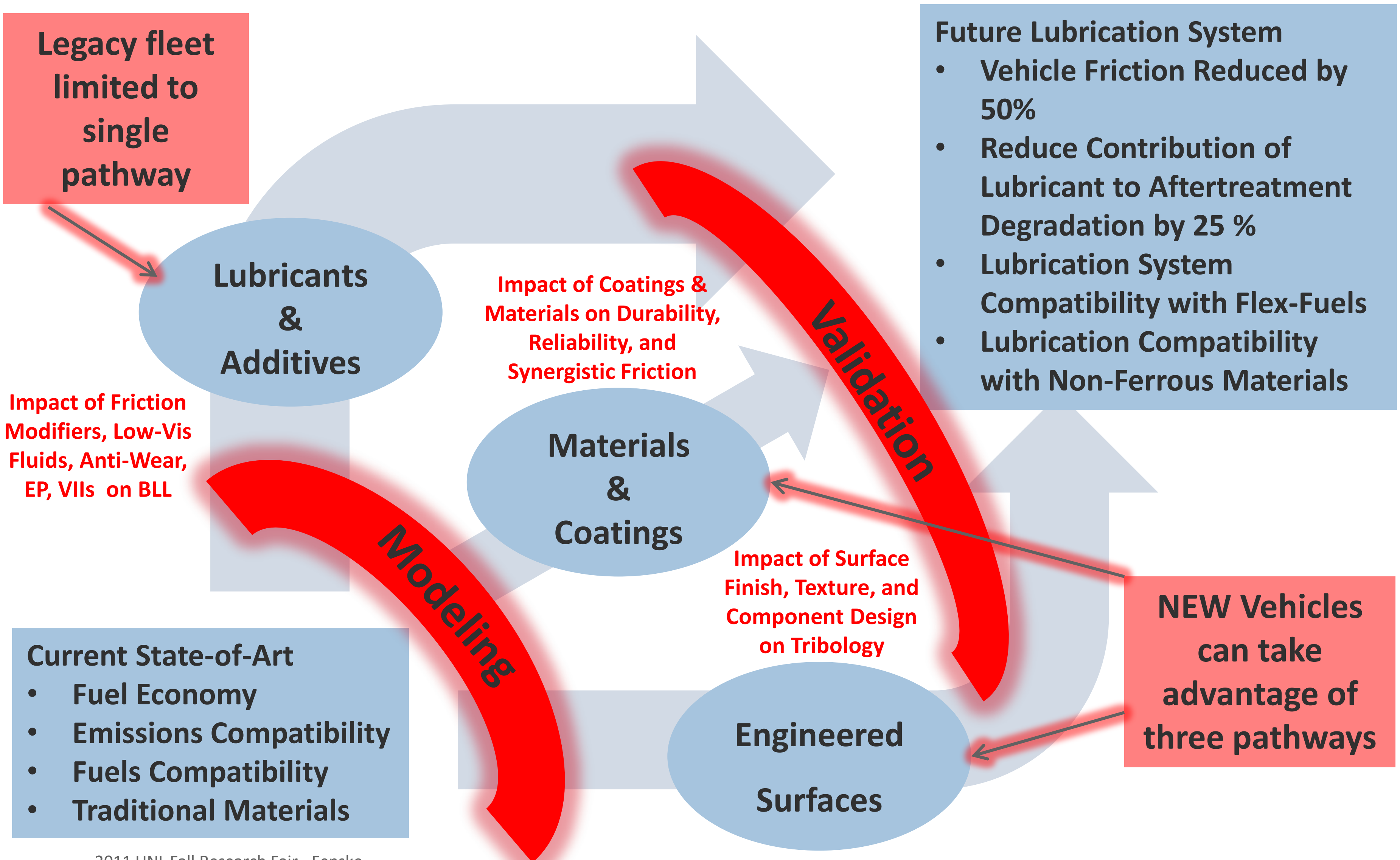
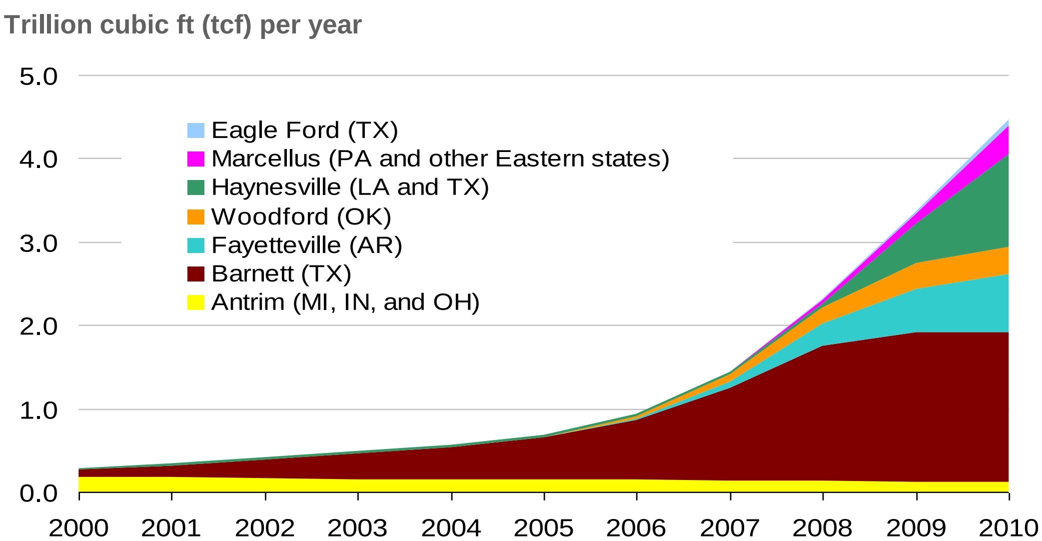
Advanced Lubrication Focuses on Identifying Pathways to Improve Fuel Efficiency in Engines, Drivelines and Vehicles



Natural Gas

- Natural gas reserves are growing at unprecedented levels
- Projections are for natural gas prices to stay low
- On the flip side, natural gas is valuable for just about everything

Shale gas production is and will continue to grow rapidly



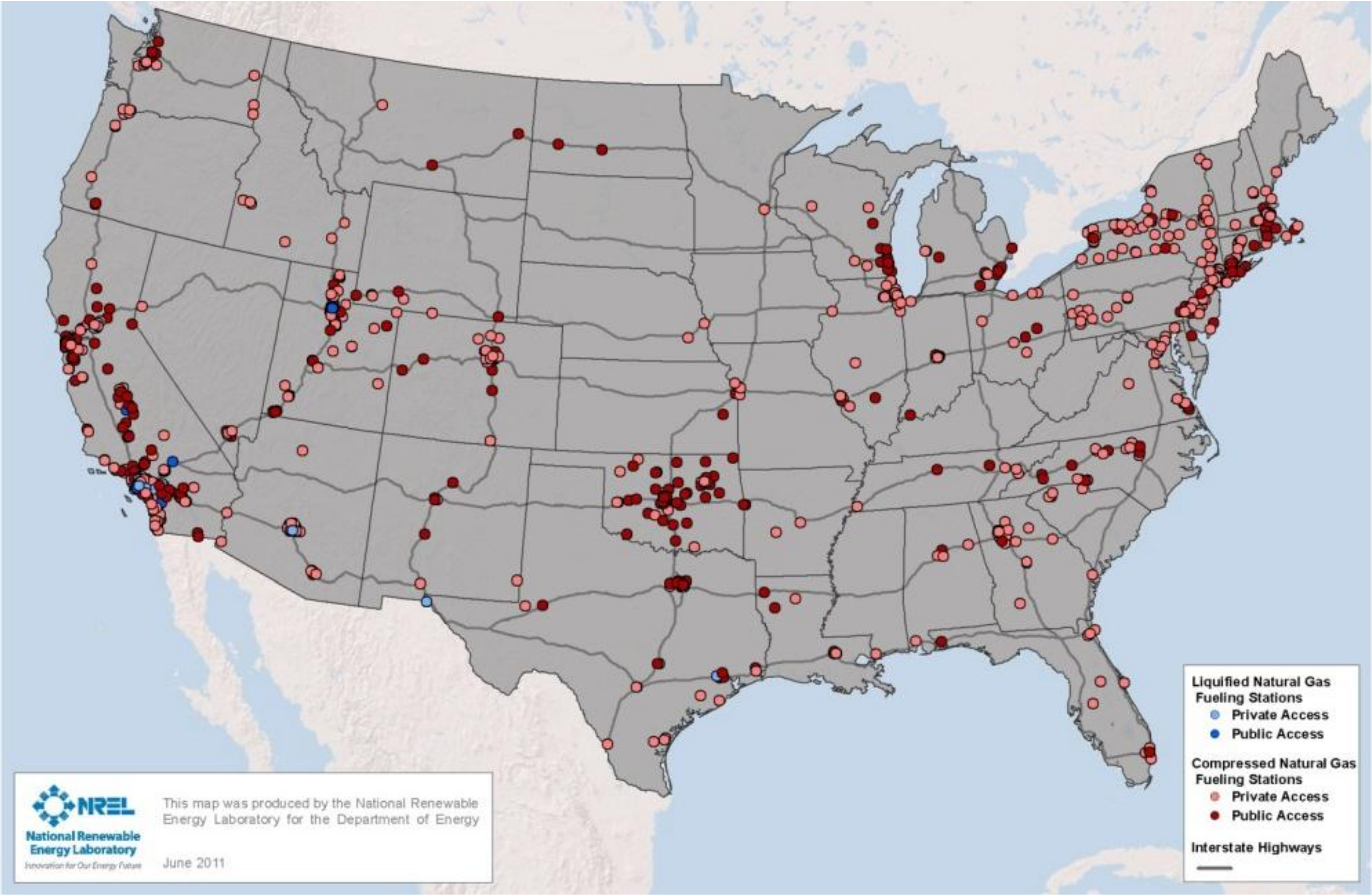
R. Newell, Dec. 16, 2010.

Photo courtesy of American Clean Skies Foundation

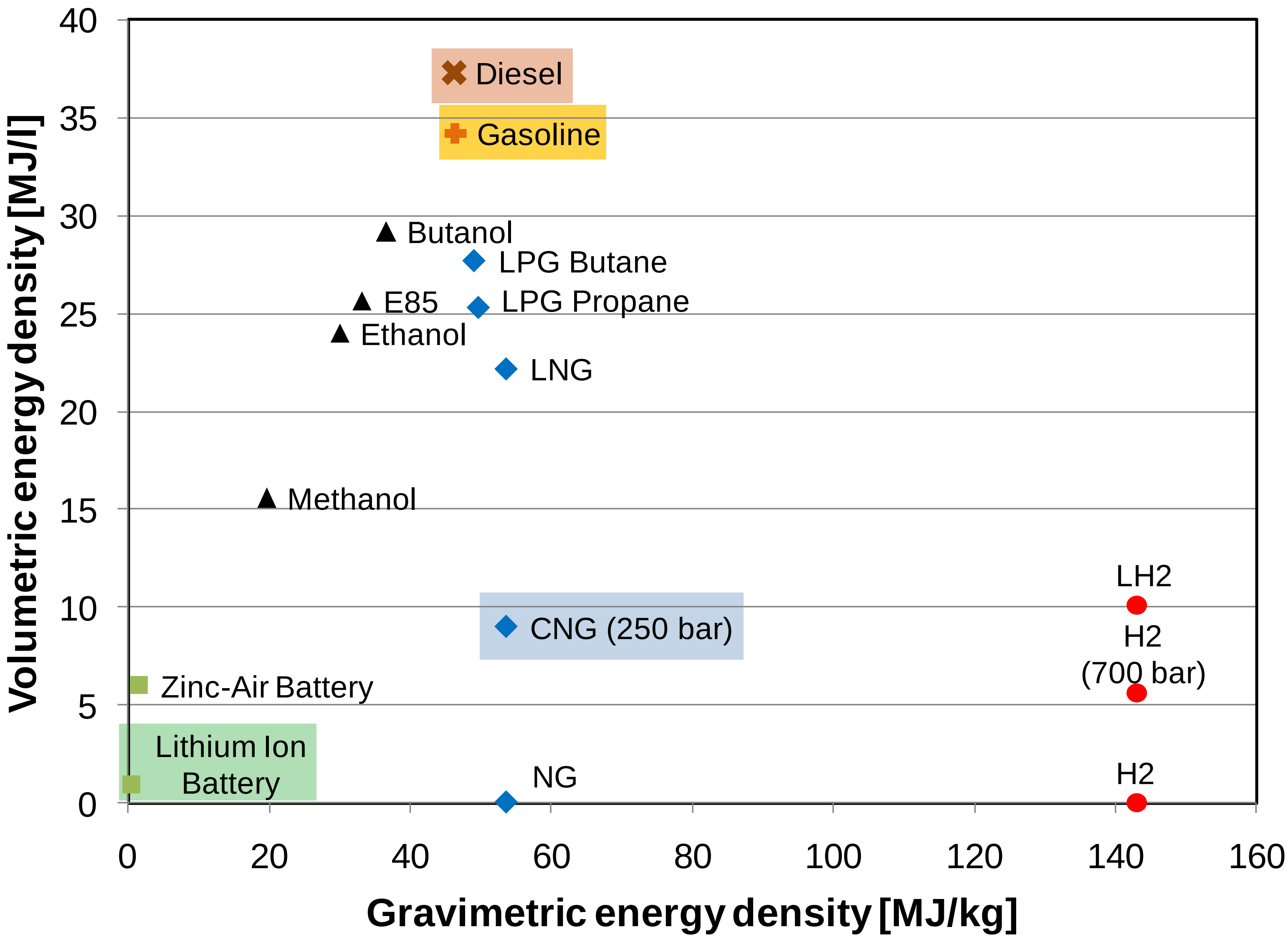
- Gas production grew 17%/year from 2000 to 2006; 48%/year from 2006 to 2010
- Total production expected to triple from 2009 to 2035.
- Of 22 shale basins in the US only 7 are now producing significant oil or NG
- New technologies have uncertain energy and environmental implications

Fueling infrastructure, particularly for LNG, is a major challenge

…but a step change may be underway



Energy carriers that compete with petroleum fuels



Consider The Following Comparison

EREV PHEV

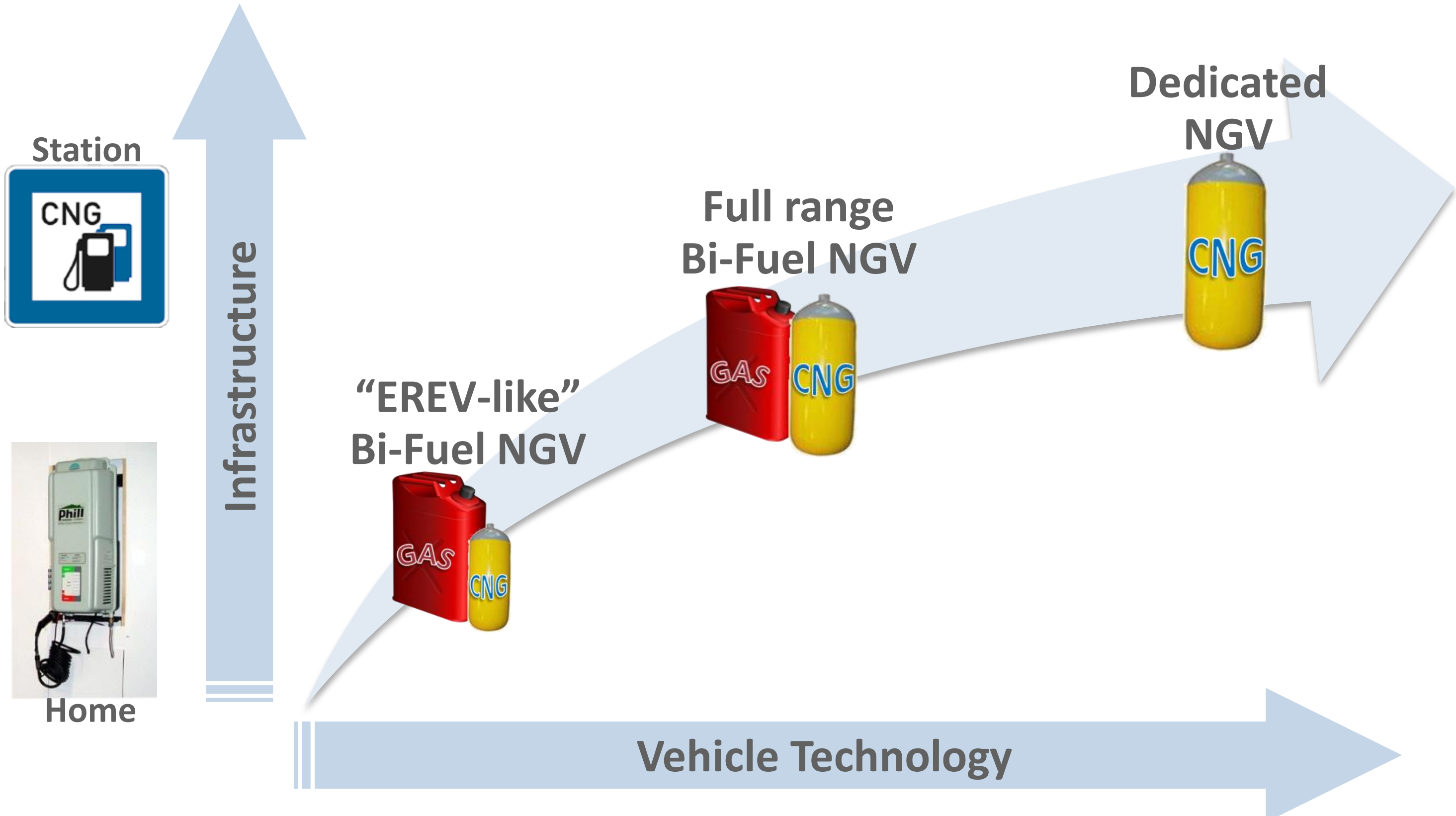
- Alternative fuel for **35 miles**
- Domestic and clean alternative fuel
- High battery costs (~$10-15k)
- 177 kg for 35 miles
- Charger costs
- High cost hybrid drive system with high-power electric motors
- Fast charging challenges
  - Battery management, infrastructure costs per vehicle

Bi Fuel CNG

- Alternative fuel for **50-100 miles**
- Domestic and clean alternative fuel
- Moderate CNG tank costs (<$1k)
- 50 kg for 100 miles (est)
- Compressor costs similar to charger costs
- No HEV needed, less sensitive to ambient temperatures
- Fast refill – CNG stations
  - Refueling infrastructure more expensive than gasoline, but much less than fast charge

AT HOME "PLUG IN" ALT FUEL CARS

Potential U.S. Natural Gas Scenario for LD Vehicles



Vehicle System (Architecture, sizing, integration)

Add-on CNG	Integrated system	Optimized platforms

Combustion System

Bi-Fuel (low tech)	Bi-Fuel (high tech)	Single fuel (high tech)

Necessary Breakthroughs and Inventions to enable natural gas vehicles

- Tanks (cheap, low tech?)
- Compressor (cheap, efficient)
- Large-scale studies (infrastructure, access to NG)
- Aftertreatment systems
- Basic combustion work (optical engine measurements)

Issues in Play

- Natural gas and oil discoveries.
  - Carbon emissions – is the atmosphere big enough to hold all that carbon?
  - Natural Gas based fuels
- Electric vehicle sales difficulties
  - Need time for the energy storage technology to develop and prices to drop
  - Infrastructure is not free, and is not ready
  - Plug-in Hybrids will dominate for the foreseeable future
- Infrastructure
  - Killer of all promising technologies – Natural Gas, Electrics, Hydrogen
- Combustion Technologies
  - Mess with the best, die like the rest
- Policy Issues
  - In America, Gasoline is too cheap and is subsidized and is essentially untaxed
  - We do not pay the true price for oil