Energy Usage, Alternatives, and Transportation in the U.S. and What it Means to Michigan

prepared by

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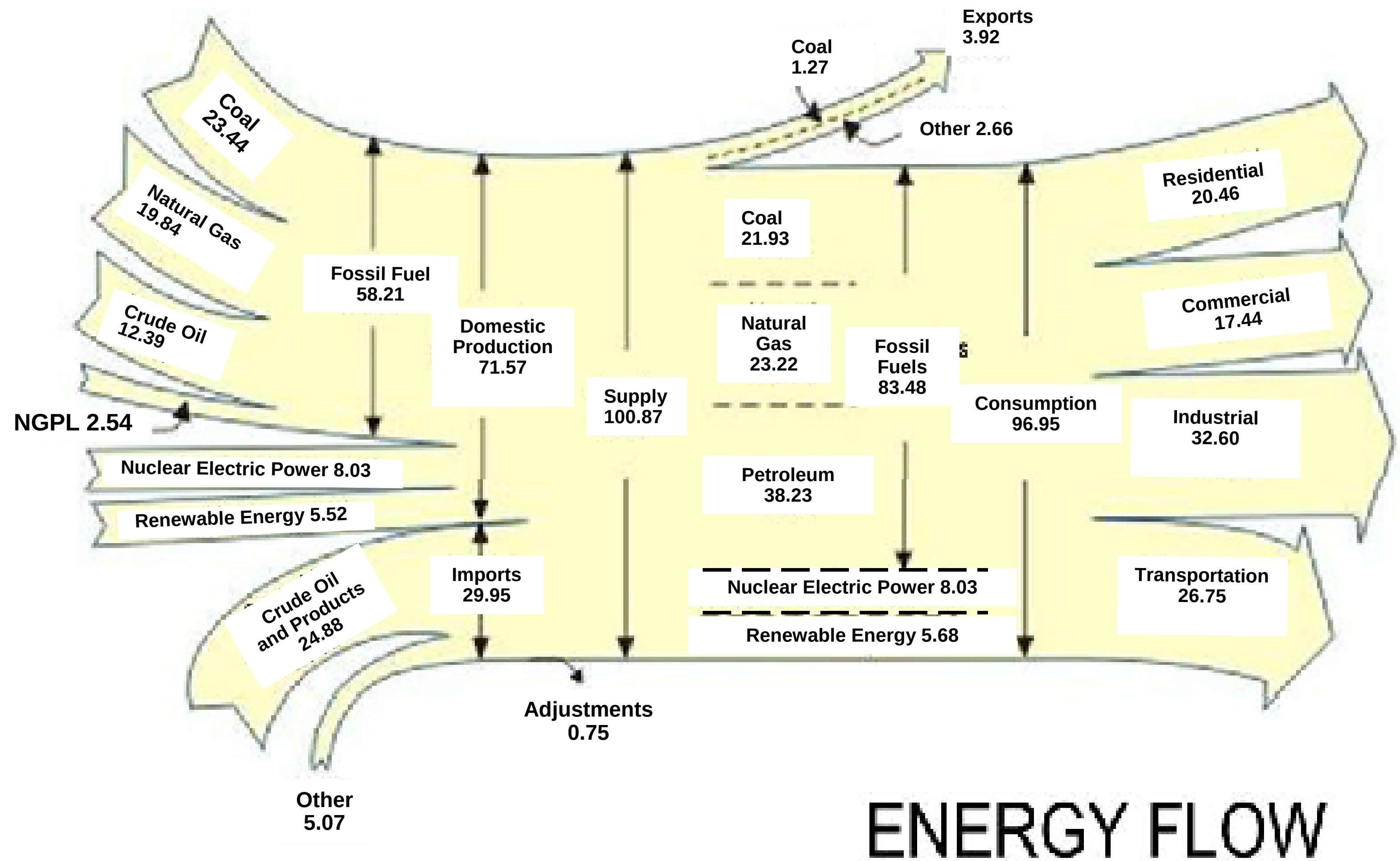
US Energy Flow Diagram

For the year of 2002, U.S. Department of Energy Website



RENEWABLE ENERGY IN TRILLION BTUs

Hydroelectric Power (2376, 42%); Wood (2170, 38%); Waste (551, 10%)

Alcohol Fuels (147, 3%); Geothermal (315, 6%); Solar (64, 1%); Wind (59, 1%)

US Energy Flow Diagram

For the year of 2004, U.S. Department of Energy Website (Units Quad BTUs)

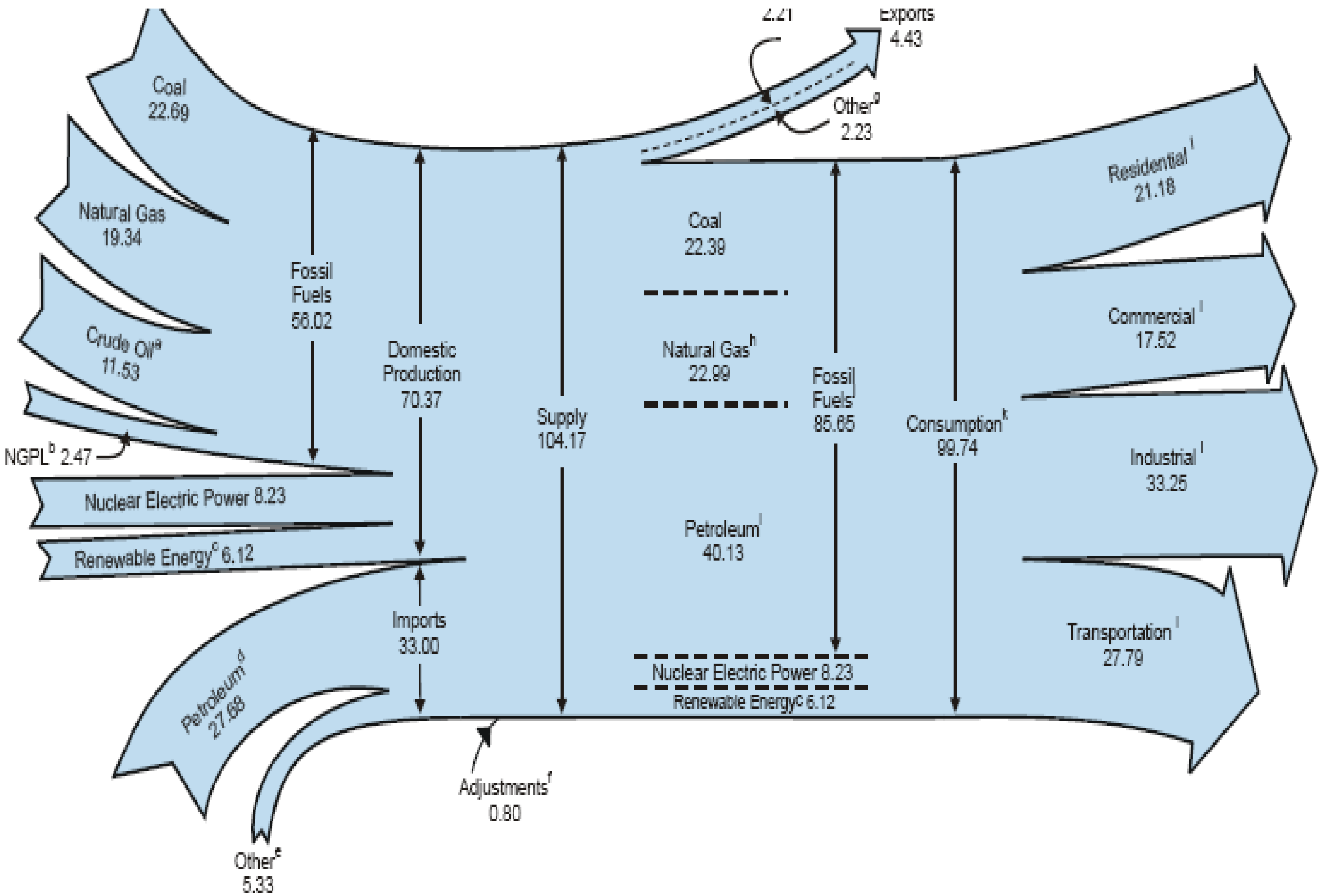
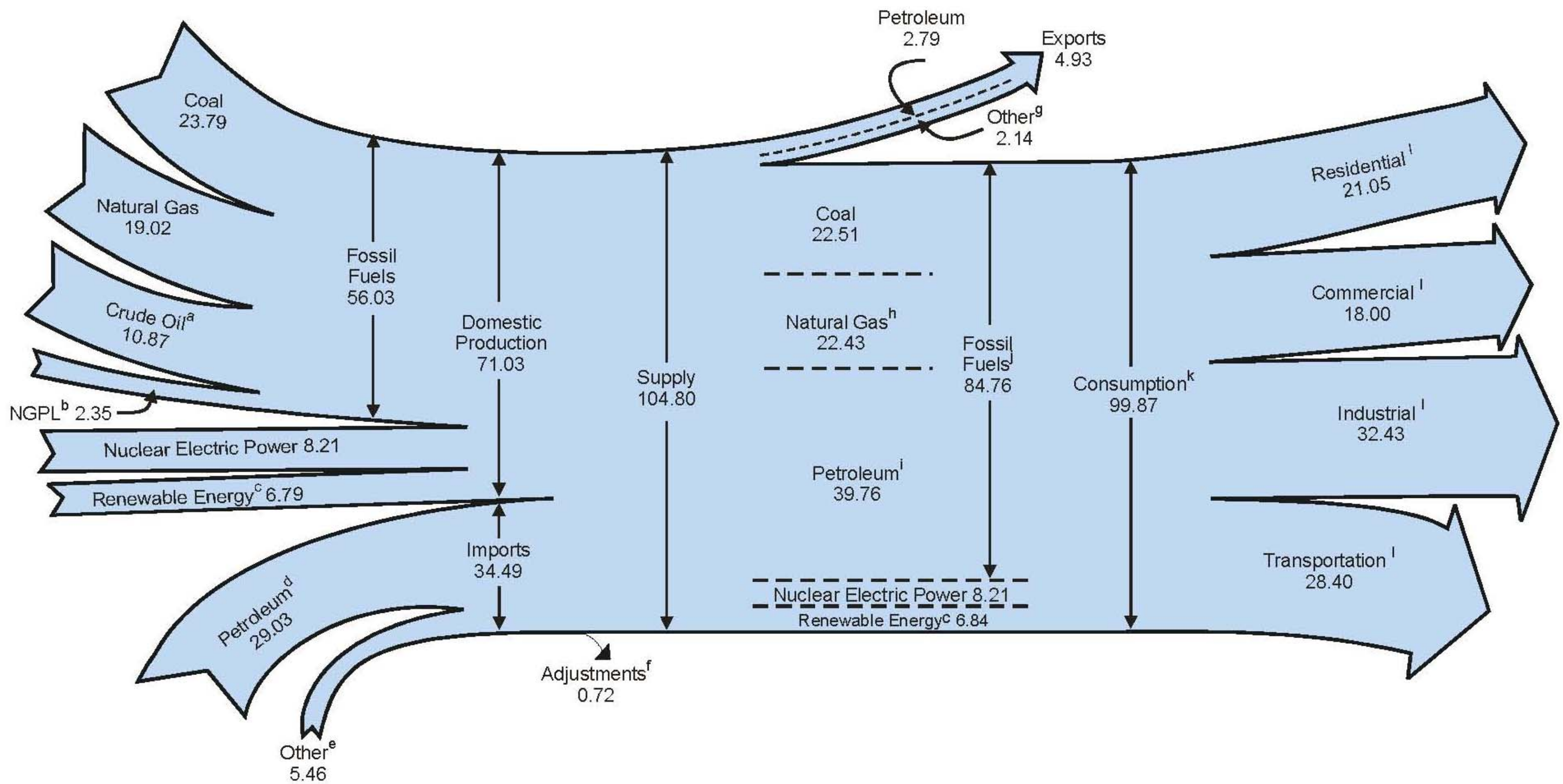


Diagram 1. Energy Flow, 2006
(Quadrillion Btu)



[a] Includes lease condensate.

[b] Natural gas plant liquids.

[c] Conventional hydroelectric power, biomass, geothermal, solar/PV, and wind.

[d] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.

[e] Natural gas, coal, coal coke, fuel ethanol, and electricity.

[f] Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.

[g] Coal, natural gas, coal coke, and electricity.

[h] Natural gas only; excludes supplemental gaseous fuels.

[i] Petroleum products, including natural gas plant liquids, and crude oil burned as fuel.

[j] Includes 0.06 quadrillion Btu of coal coke net imports.

[k] Includes 0.06 quadrillion Btu of electricity net imports.

[l] Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.

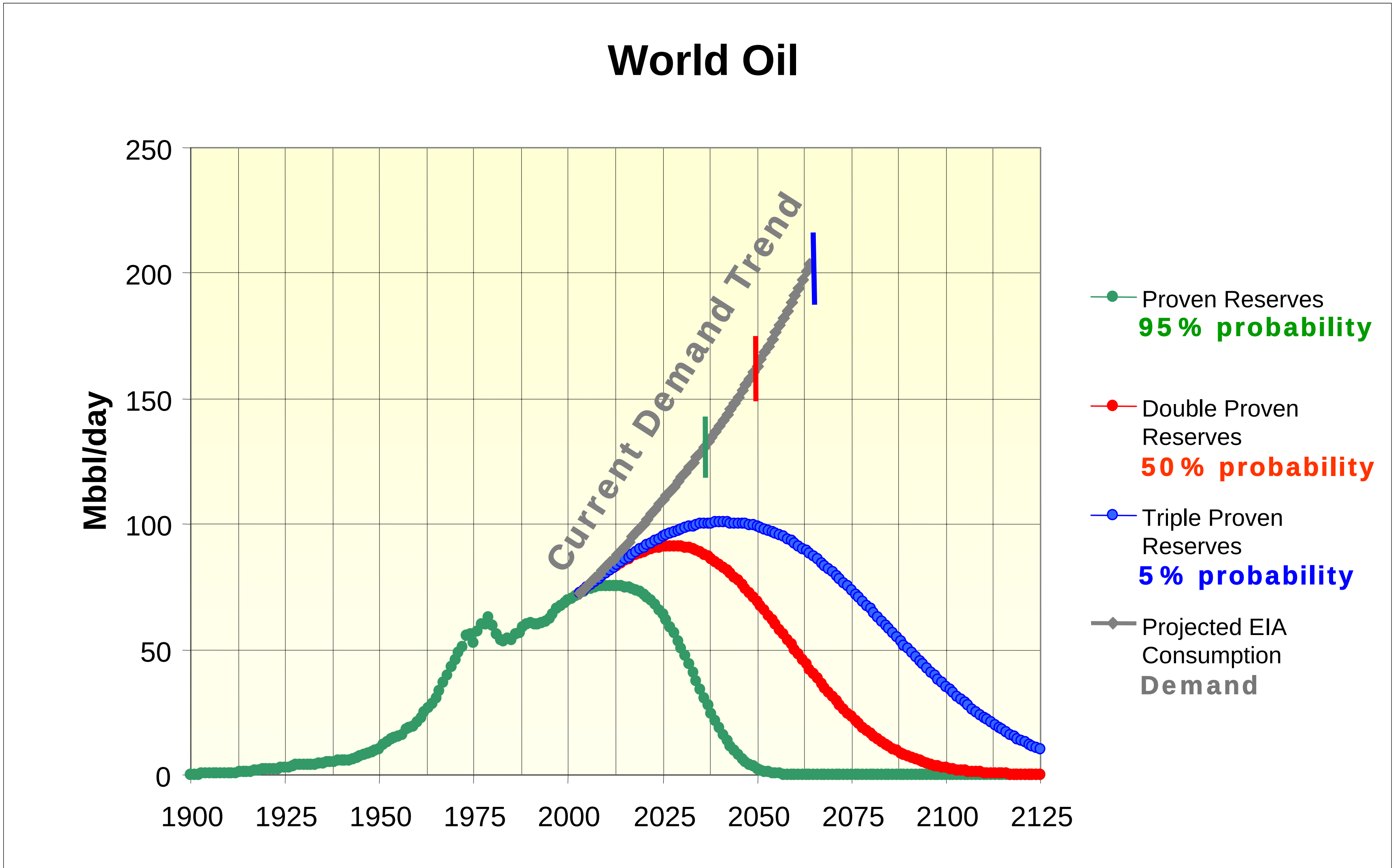
Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.

What Brings us Here? The World Oil Supply!

- Hubbert's Peak – M. King Hubbert (1903-1989)
  - Geologist who grew up in San Saba, Texas
  - Trained BS, MS, PhD University of Chicago
  - Worked at Columbia Univ, WW II Production Board, Shell Research Lab in Houston, after retirement taught at Stanford and Berkeley and worked for the US Geological Survey
  - **In 1956 predicted, through a combination of knowledge, analysis and insight predicted world oil production would peak in 70s**
  - Recent estimates indicate peak may have been in 2005 but recent major price fluctuations show the near equality of supply and demand…per capita production peaked in the late 1970s
  - As demand exceeds supply lifestyles will change …. Unless oil is replaced with something else …. **Is this day is upon us?**

The Urgent Call for Action!



Colored bars on the projected consumption curve indicate the years when proven reserves, double and triple proven reserves are depleted at the current consumption growth rate. **Source: C. Gray, EPA**

Some Powertrain and Fuel Options for the Next Quarter Century

- **Coal**
- **Tar Sands – Heavy Oil**
- **Oil Shale**
- **Nuclear**
- Ethanol and Biofuels from Crops, Cellulose or other
- **Hydrogen from Hydrocarbons or other**
- **Advanced IC Engines/Hybrids (Gasoline and Diesel)**
- Natural Gas Fuels
- Electric Power from Grid

Coal

- Pros
  - Cheapest source of energy
  - Six thousand active coal mines currently in the US
  - **Worldwide production viable for a few hundred years at current rate**
  - US and former Soviet Union have the world's largest coal reserves
  - Fisher-Tropsch reaction uses an iron rich catalyst to convert gases to high grade gasoline and diesel fuel …including gases produced from coal … **likely part of the future**
- Cons
  - Smog, acid rain (sulfur), mercury pollution and carbon dioxide
  - Hazardous to mine underground and unsightly in open pits
  - **Environmental problems** that have plagued us for decades will not be solved in a few years

Tar Sands (Heavy Oil Sands)

- Pitch, bitumen, tar and asphalt go back to the dawn of civilization
- Tar sands discovered in 30 countries around the world but two stand out
  - Eastern Alberta Canada and North of the Orinoco River in Venezuela
  - **These two have more oil than all of the world's conventional wells**
- In-situ (20% recovery) and surface mining are both options
- Production of oil from tar sands requires heat for extraction and hydrogen for upgrading the oil …both processes major users of natural gas
- Significant water usage and it's dispersal after use for oil recovery are important issues for both mining types
- Infrastructure issues are significant with cost and the variability in natural gas prices which can make a venture not economical

Oil Shale

- About 30 Countries and eight states in the US produce oil from shale
- Oil shale is an immature source rock for petroleum which has never been hot enough to be “cooked” into oil
- **Green River Area where Utah, Wyoming and Colorado come together contains 60% of the world’s oil share … more oil than all the oilfields in the Mideast**
- Commercial viability involves going from a lower H-C ratio to a higher one …thus need hydrogen and water
- Surplus natural gas (for H2 and heating) have been driven up due to the use of natural gas for making electricity
- The Green River flows into the Colorado then to San Diego, Las Vegas and water flow apportioned through a treaty with Mexico

Nuclear Energy

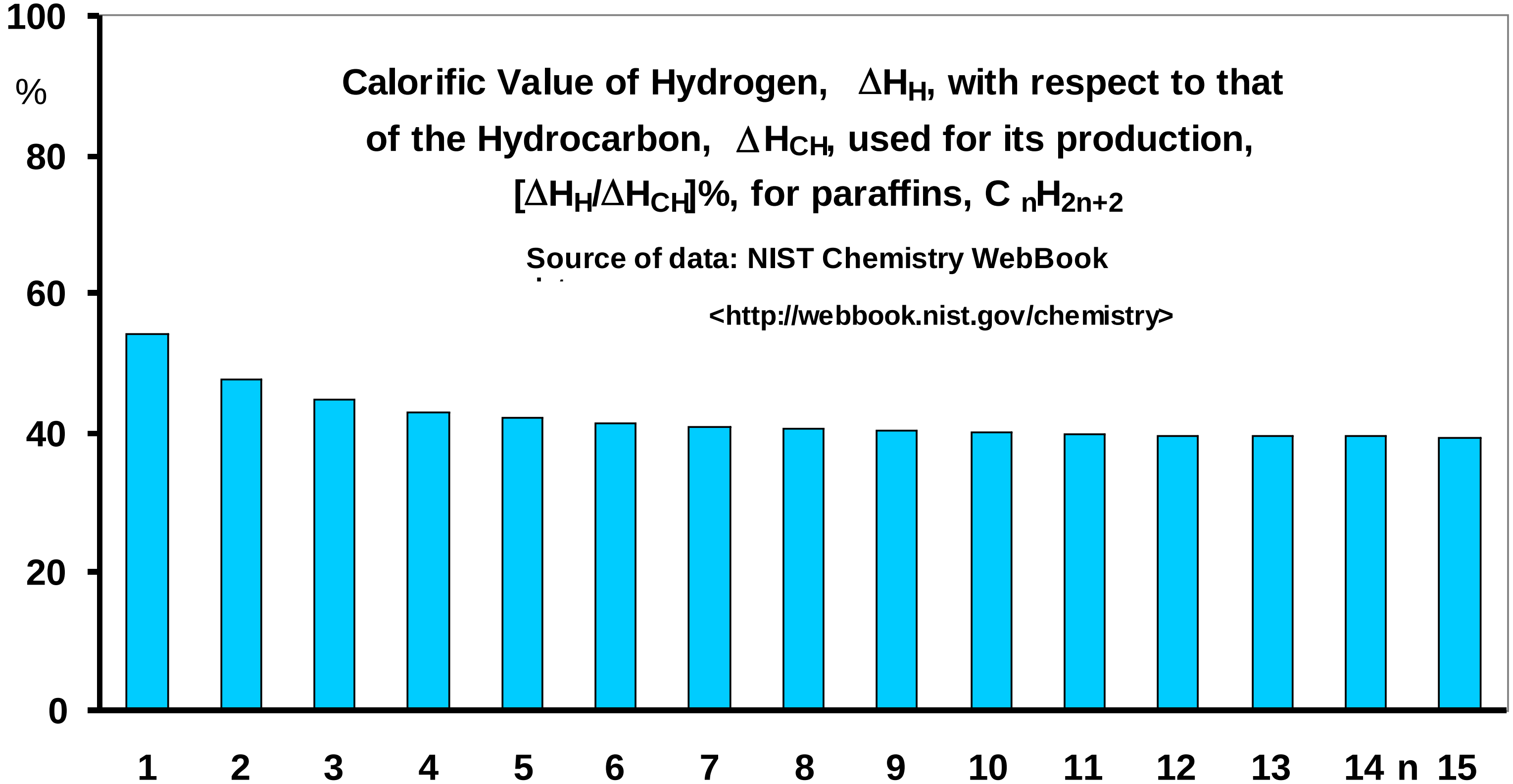
- 442 nuclear power reactors in operation in 31 countries around the world (~23% of the world's electricity), 32 more under construction
- Current power reactors are Generation II and III, 103 plants produce 20% of the electricity in the US
- Generation III+ and particularly Generation IV have significant advantages in safety and life cycle cost advantages over other energy sources
- DOE estimates that Gen IV plants could produce hydrogen equivalent to 1.4 M bbls/year of gasoline …**about 3389 new nuclear plants would be required to meet the 13 M bbls of oil per day used in transportation in the US**
- DOE's Advanced Fuel Cycle Initiative and the Global Nuclear Energy Partnership has the goal of utilization of a higher fraction of energy in uranium, extending world's resource from 100 to 1000 years
- Electricity: mean cost estimates (Univ. of Chicago 2004)normalilized to coal: coal=1, natural gas=1.1, nuclear power=1.1 not counting costs of carbon sequestration for coal and natural gas

Fossil Fuels Availability and Costs?

- **Availability:** estimates are that there as much as tens of of centuries worth of natural gas, coal, tar sands and oil shale
- **Cost:** Possibility of Global Warming caused by green house gases (CO_2 and other natural and man made products)

    CO_2 levels will increase because of anthropogenic activity to levels that have not been seen on earth for the last 650,000 years

    CO_2 levels have been correlated with temperature swings …but not necessarily the cause of them



Calorific Value of Hydrogen, ΔH_H, with respect to that of the Hydrocarbon, ΔH_{CH}, used for its production, $[\Delta H_H/\Delta H_{CH}]$%, for paraffins, C_nH_{2n+2}
Source of data: NIST Chemistry WebBook
<http://webbook.nist.gov/chemistry>
%
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
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11
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14
n
15

Challenges for “H_2 Economy” and Fuel Cells

- **<u>Unavailability of hydrogen!</u> The use of liquid and gaseous hydrocarbon fuels to make hydrogen for transportation has not been shown to be economically sensible at any price and there is no known viable H2 production method.**

- **There is no support infrastructure in place to deliver hydrogen**
  - Storage, supply and facility location - *are not understood*.
  - Safety, emergency and building design - *are unknown*.
  - Service community - *non existent.*
  - Insurance, costs of supply etc. - *are not mature*.
  - Customer base - *is unknown.*

- **Costs of fuel cell systems are an unknown or uncompetitive**
  - Air-Gen $6,495-1kW, $14,950-2kW, AD Little est. $225/kw @500k/yr *as compared to $25 to $30 per kw for an IC engine).*
  - Durability, recycle ability and serviceability are unknown.

- **NAS report from Feb 2004**
  - Estimates at least 25 to 30 years before fuel cells for transportation are practical for consumer acceptance.

Historical and Recent HEV Developments

Historic:

- 1902 Lohner-Porsche 1st hybrid, 1905 H. Piper files US patent for a petrol hybrid vehicle..

GMR: General Motors Research Labs.

- 1966 GM Stirlec vehicle.
- 1970 GM Commuter vehicle.

1990's:

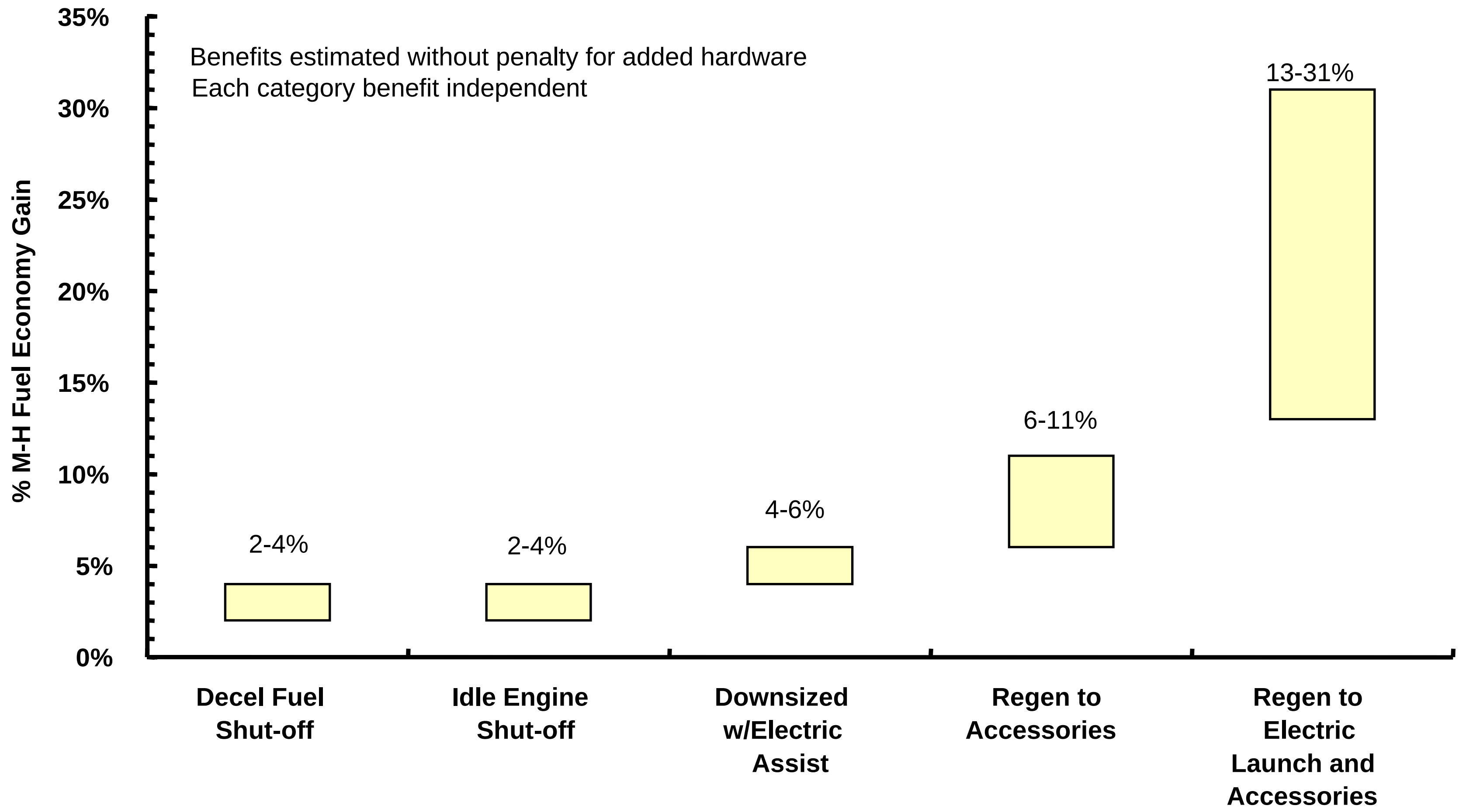
- 1991 GM HX3.
- 1993 GM Freedom.
- 1993 to 1998 DOE – GM, Ford Chrysler HPSP Program.

Recent examples:

- 1998 Honda Insight.
- 1997 Toyota Prius. 1997 Japanese market & 1999 NA Market
- 2004 Ford Escape – *<u>Toyota gen II Lic.</u>*
- 2005 Lexus SUV hybrid.
- 2006 Toyota 07 Camry Hybrid: **40**/24.8 mpg combined, 0-60 in **8.9**/9.8 s

Benefits of Hybridization

(T. Kinney, Ford Motor Company, sum of averages 41.5%)



Performance of a Modern Hybrid

2007 Honda Civic / Civic Hybrid

Combined fuel economy:	33/47MPG (+30% H)
Zero to 60 time:	8.3/7.4 seconds (+11% H)
Battery life of hybrid:	150,000 mile warranty

2008 Lexus RX350 / 400h

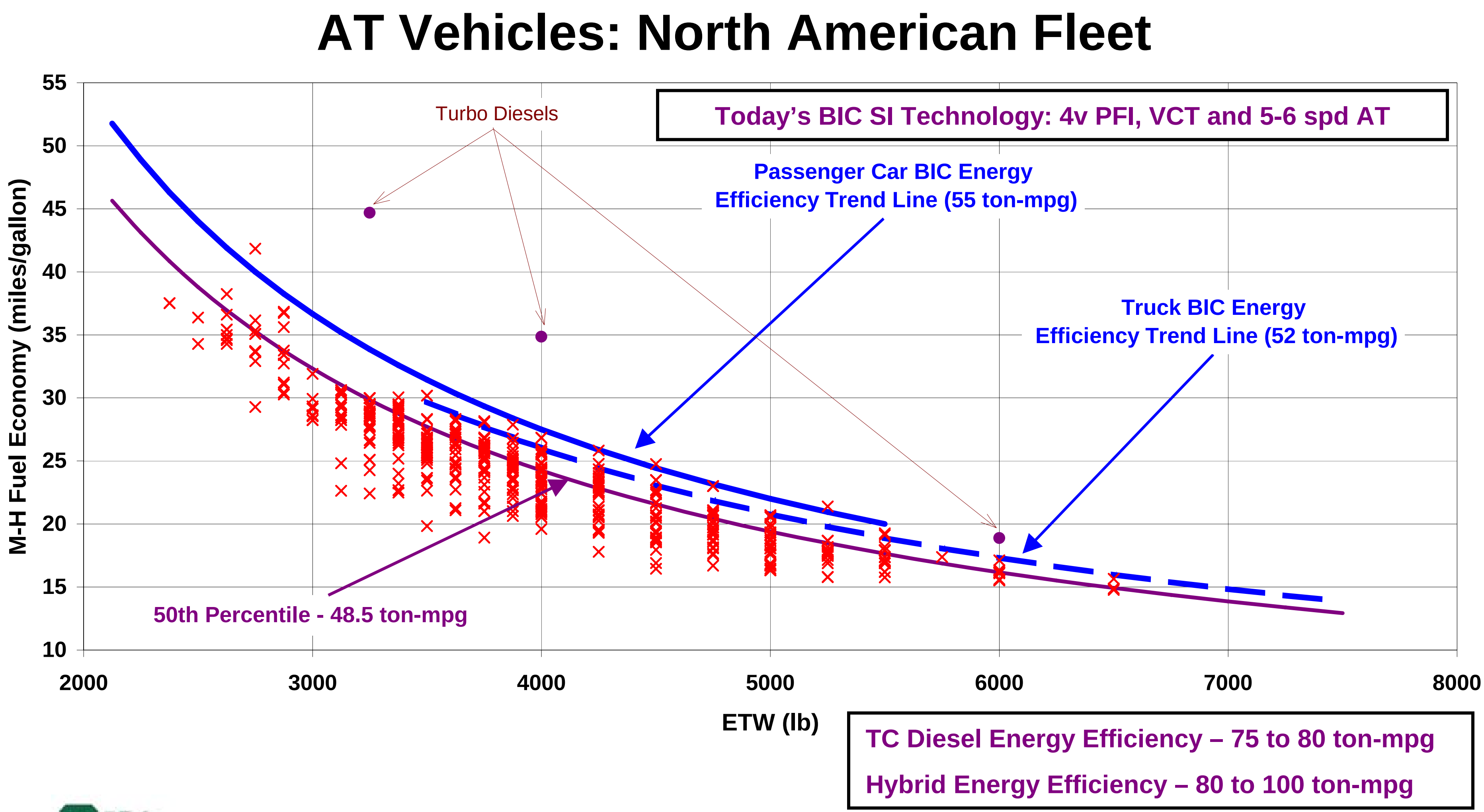
Combined fuel economy: 20.5/25.5MPG (+20% H)

2008 Ford Escape / Escape Hybrid

Combined Fuel Economy 25/32MPG (+28% H)

Unadjusted FE and Efficiency

(T. Kinney, Ford Motor Company)



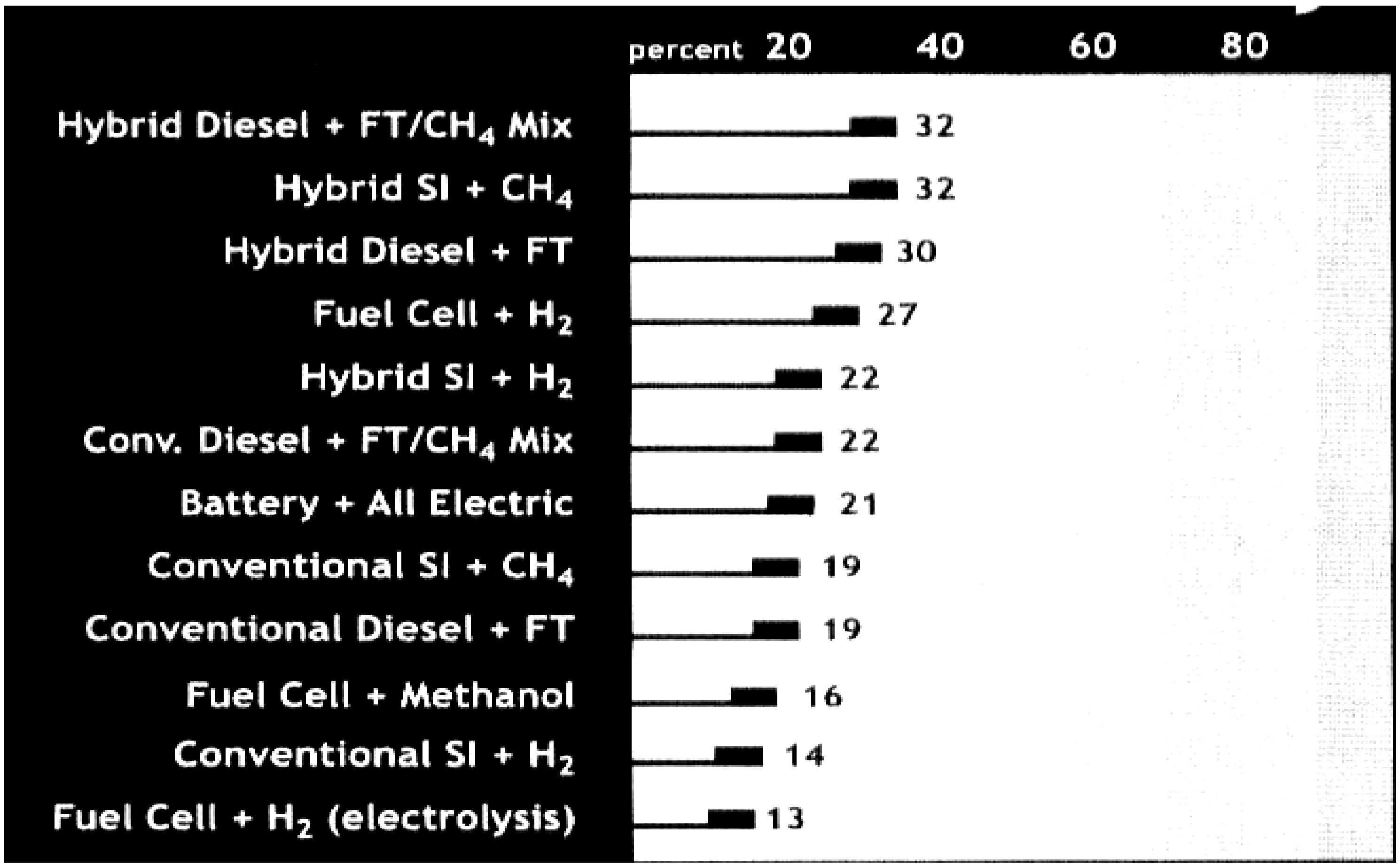
HEV Projections and Rationale

- **HEVs are a technically sound idea regardless with power plant being fuel cells or IC engines**
- **HEV design, development and production also offers the manufacturer and user the opportunity to acquire the "skill set" that would be required <u>when and if the envisioned *Hydrogen Economy* becomes a reality.</u>**
- **HEVs unquestionably address concerns of**
  - global warming, cost of fuel **($2.77)* gallon** and uncertainties of future supplies.
- **Foreign oil dependency issues and changes in customer preferences.**
  - "oil politics" coupled with balance of trade (-40B/yr @ 55% 2004)
  - unmistakable "green movement" is taking shape in the US
  - strong environmental issues on US west, east and south (Texas) coasts
- **Continued strong liquid hydrocarbon energy demand by developing countries and economies.**
  - including China and India
  - future environmental and infrastructural downside of traditional auto technologies
- **Other Important factors**
  - Risks of inaction … for the US
  - M.King Hubert Institute of Petroleum Studies has noted that <u>world wide conventional oil supplies</u> might have recently peaked - <u>late 2004.</u>
  - **<u>AAA projects a US National average - regular fuel - $3.00 to $3.20 gal by end of 2005 to early 2006</u>**.

** August 15th, 2005*

Well-to-Wheel Fuel Production Efficiency

Kreith and West, Mechanical Eng. Power, pp. 20-23, 2003



Other Opportunities: Ethanol for Transportation - from Corn for Reference

Estimated arable cropland in the US: 442 million acres (20% total land)

USDA forecast of corn yield in 2005: 148.4 bu /acre

Ethanol per bushel (dry mill): 2.6 gallons

Ethanol / year all cropland = 170×10^9 gallons

Oil required: (2005, 21.93 bbls/day , 66% transportation)

$14.47*10^6$ (barrels/day)*365(day/yr)*(42 gallons/barrel)=$221*10^9$ gal/yr

Transportation energy demands that could be met by corn to ethanol*

(66% of oil Trans, 1.5 gal ethanol=energy in 1 gal of gasoline)

((170/1.5)/221))*100 =~ 52%

* Energy production costs not evaluated

Other Ethanol Related Comments

- **Opportunity: Significant ethanol production in US possible ~ 50 B gallons per year in the US from cellulose; with projected technology improvements, 11% of arable land needed …energy equivalent to**
  - **Hydrogen production of 400 nuclear power plants (DOE est)**
  - **ANWR discovery every 5 years**
  - **Hybridization of all personal transportation in the US (30% est. improvement)**

- **Problems: Ethanol has about 66% of the energy of gasoline on a volume basis and thus *mileage, range and fuel cost* are potential issues with current spark ignition engine technology**
  - **San Paulo online paper 2/06 "…buy ethanol at 70% price of gasoline"**

- **Solution: Develop an advanced low-to-high compression ratio combustion system for ethanol fueled IC engines that results in substantial efficiency improvement …20% over today's flex-fueled engines**

FE Benefits of Advances in IC Engine Technology … All Applicable to Hybrids

Near term – 5 years (demonstrated in laboratory)

- Microelectronic control of combustion HCCI: +30% better than c. SI
- Advanced “clean” diesels: +30% better than current SI
- Directly Injected SI engines: +15%
- Turbocompounding: +5-20% depending on operating mode
- Thermoelectric recovery: +5% depending on operating mode

Longer term – 10 years*

- Microelectronic control of combustion with IVVT : +40%
- Very Advanced Combustion Control with SC (+50%) when merged with a hybrid 75 mpg possible in a midsized car

* Estimated based on lab experiments and calculations

The Big Picture - One Perspective

Fact: 66% of the oil (20+ M-Bbl/day) used in the US is for Transportation … 40% by personal vehicles

- Over the next 10 years … technology changes for sparked IC engines, implementation of diesel and hybrids have the potential of improving combined fuel economy by 30% ….or saving 2.4 M bbls./ day …about 12% of the daily US consumption … (only personal vehicles considered in savings calculation)
- Equivalent to an ANWR discovery every 5 years

  (est. 5B bbls in ANWR)
- If made from corn, this is equivalent to using 32% of arable land in the US to making ethanol for transportation @150 bu/acre
- Energy costs for making HC fuel from crude and ethanol from corn not considered

Strategic Challenges…

Business Challenges:

- Compliance with Tier2 and 2007/2010 emission standards
- Ever increasing cost of petroleum

Societal Challenges:

- Clean Air
- Climate Change issues
- Resource conservation
- Costs of increasing oil imports
- Higher trade deficits
- National security

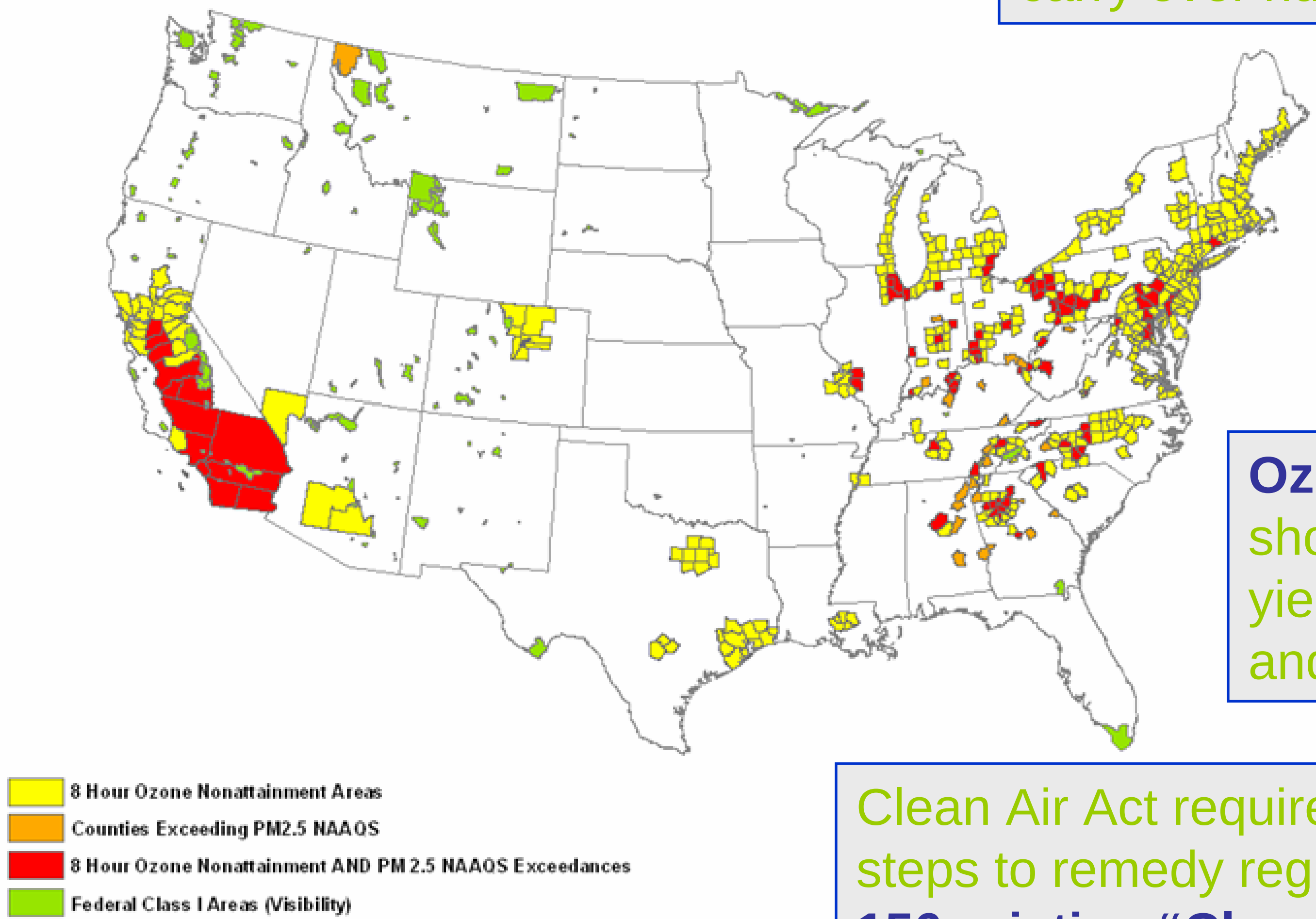
Vehicles Contribute to Unhealthy Air for Millions
source: C. Gray, USEPA

65 million people live in areas that violate the fine PM air quality standard; **159 million** people live in areas that are not in attainment for ozone

Fine particles from diesel exhaust can remain in the atmosphere for weeks, and carry over hundreds of miles

Diesel exhaust is **likely to be** **carcinogenic** to humans

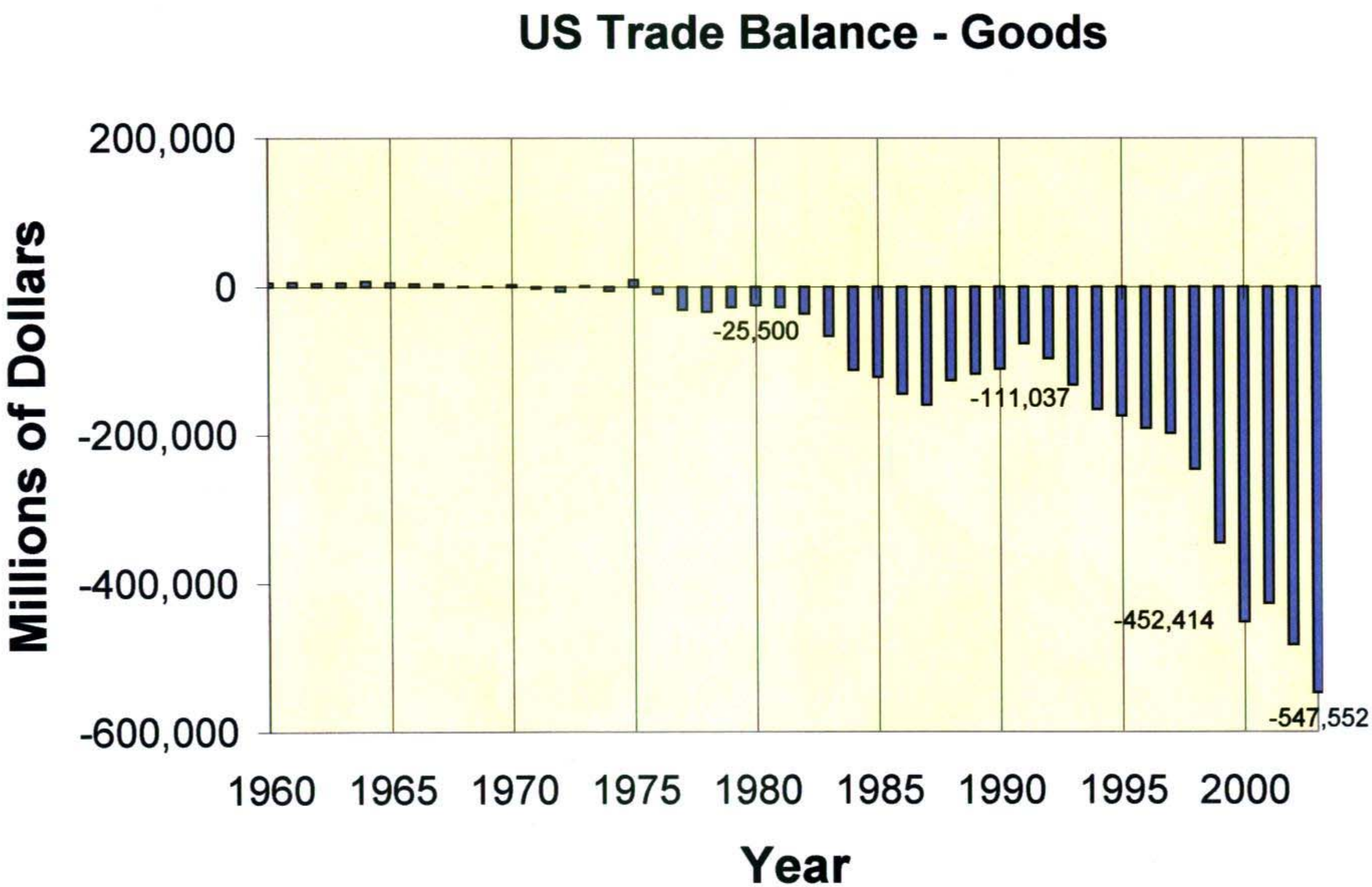
Ozone has been shown to reduce yields of vegetables and field crops



Clean Air Act requires EPA to take steps to remedy regional haze in **156 pristine “Class I” areas**

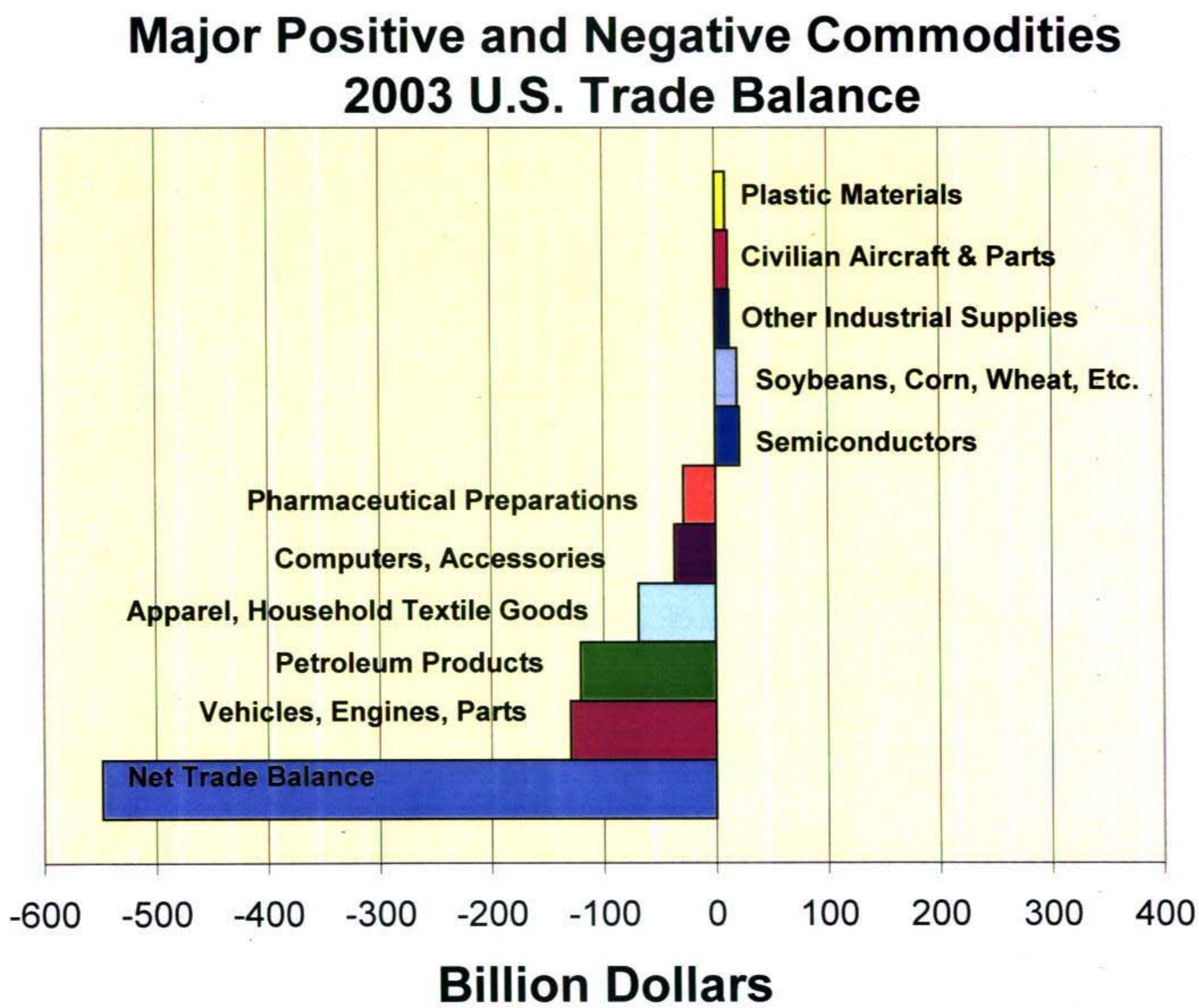
Big Picture Economics – 2003

source: C. Gray, USEPA



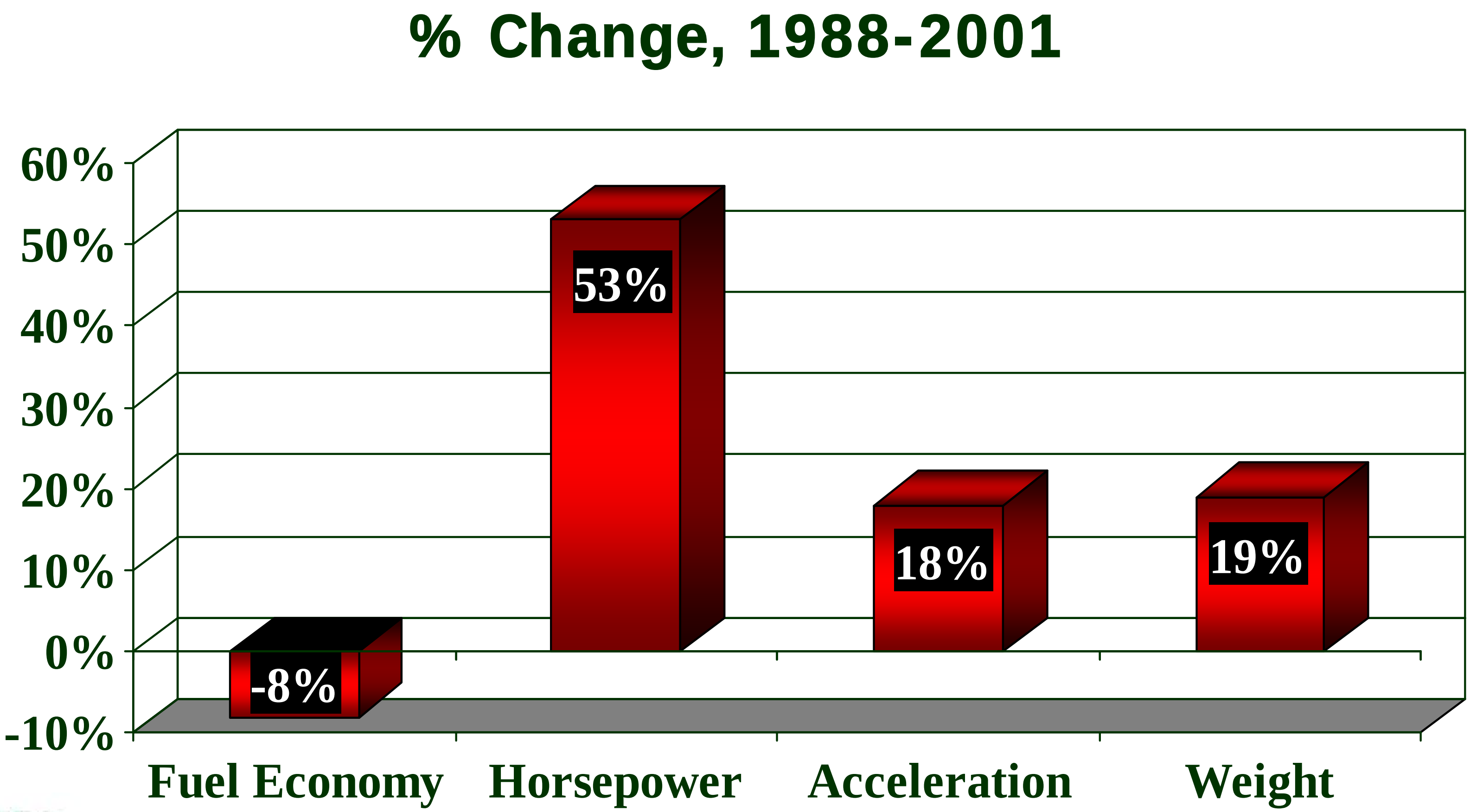
Petroleum's Share of Trade Deficit – 2003

source: C. Gray, USEPA



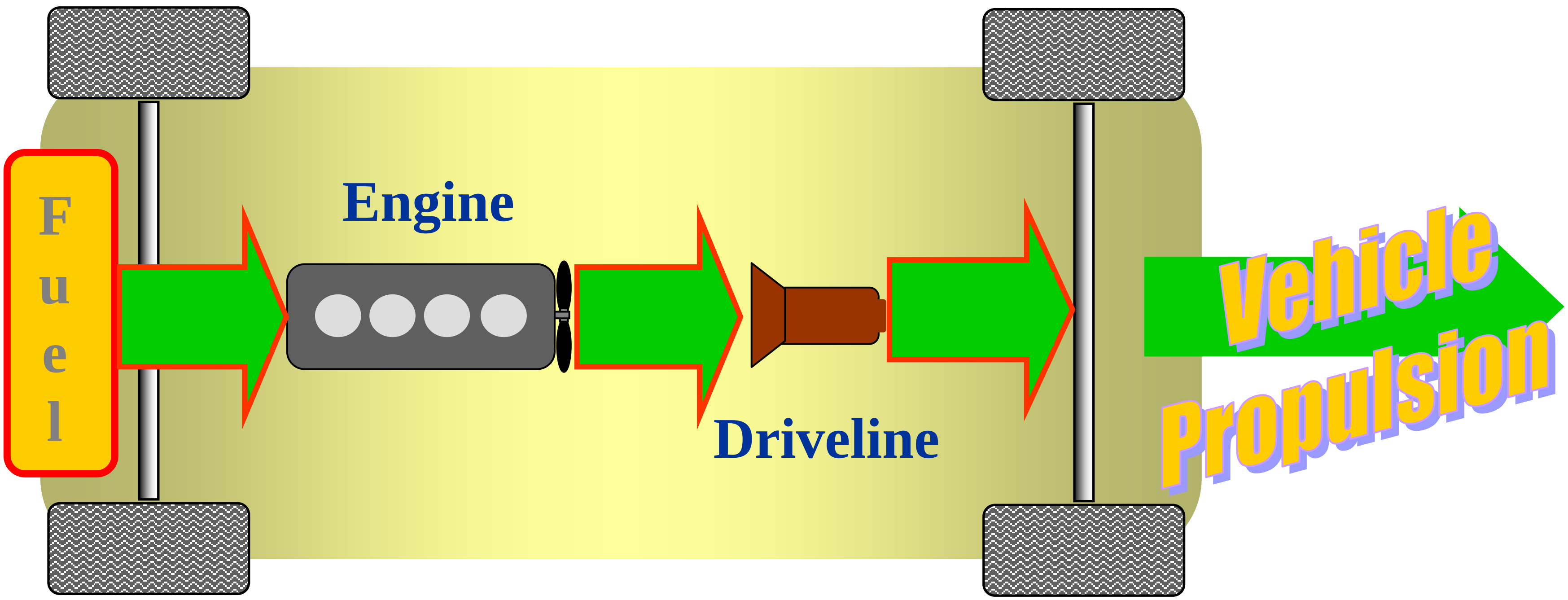
New Technology Used for Power/Size, Not FE

source: C. Gray, USEPA



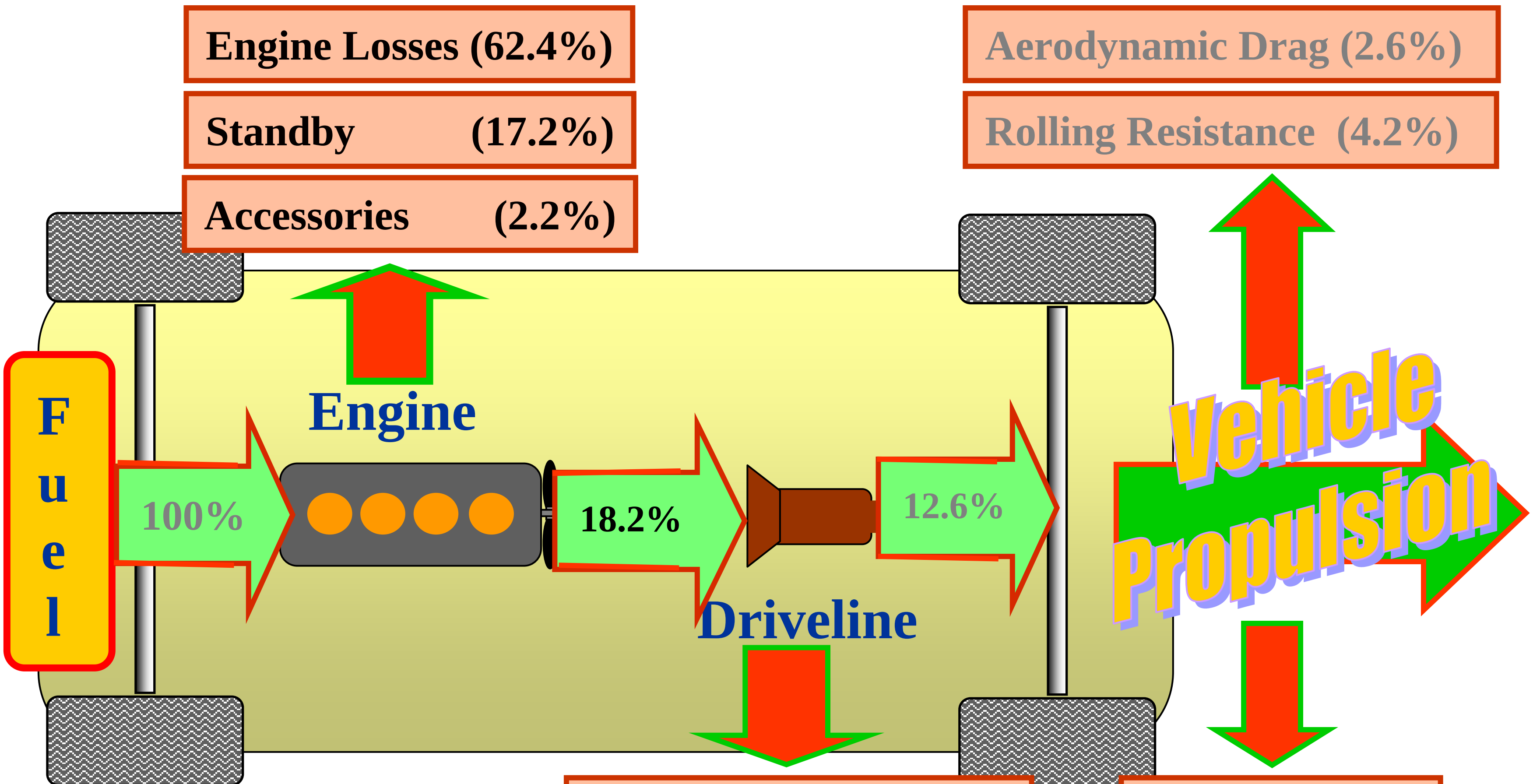
Traditional Vehicle Energy Path

source: C. Gray, USEPA



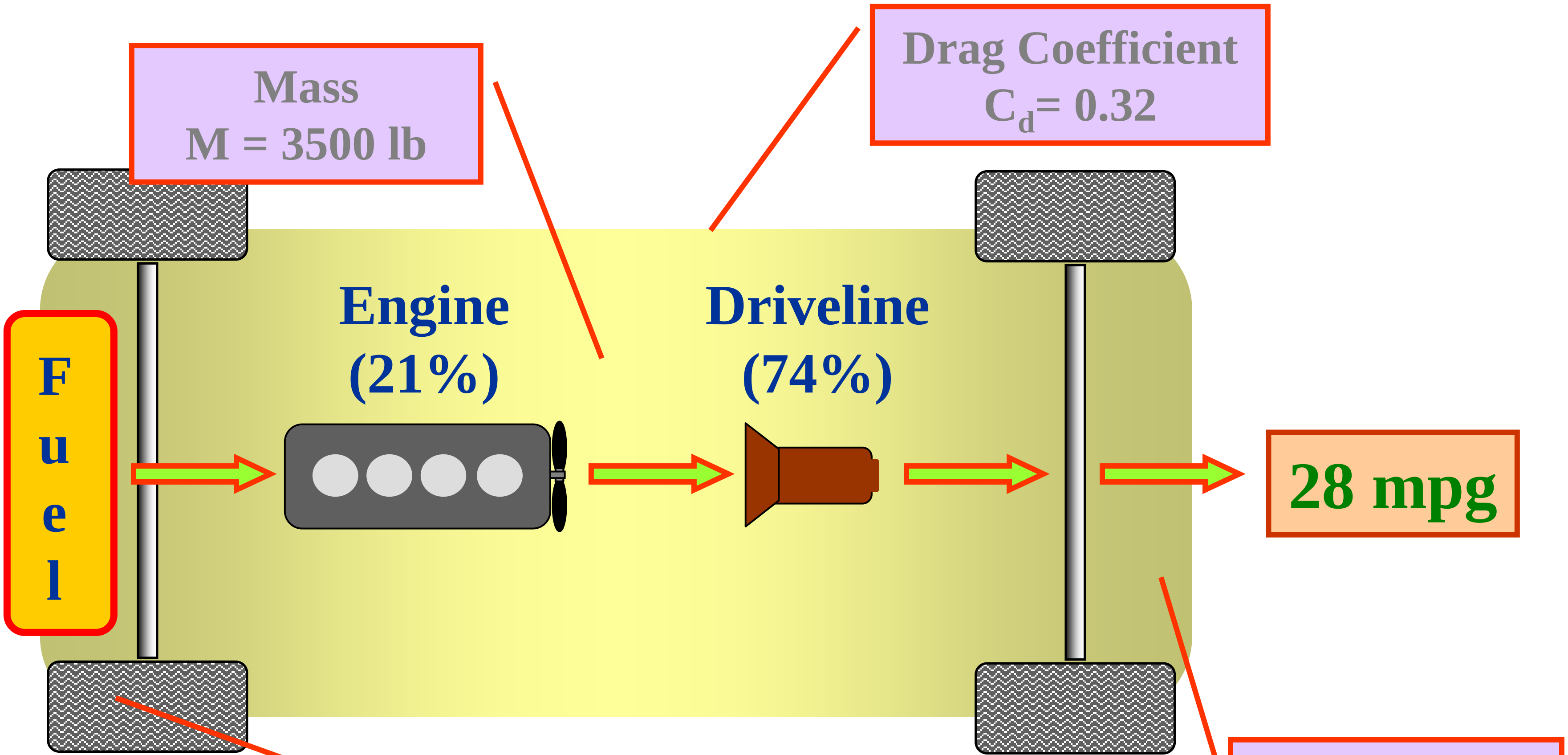
Where Does the Energy Go in Typical Urban Driving

source: C. Gray, USEPA



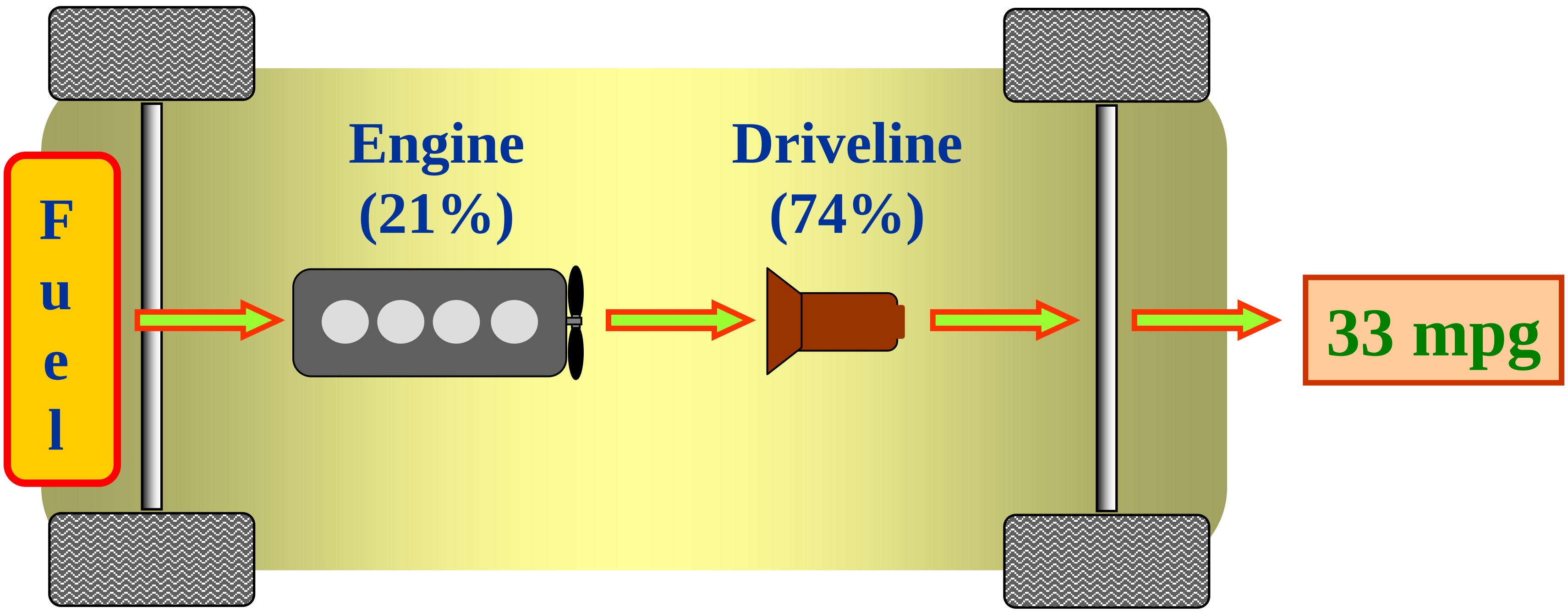
Typical Combined City/Highway Component Efficiencies

source: C. Gray, USEPA



With PNGV Aerodynamic Drag and Tire Characteristics

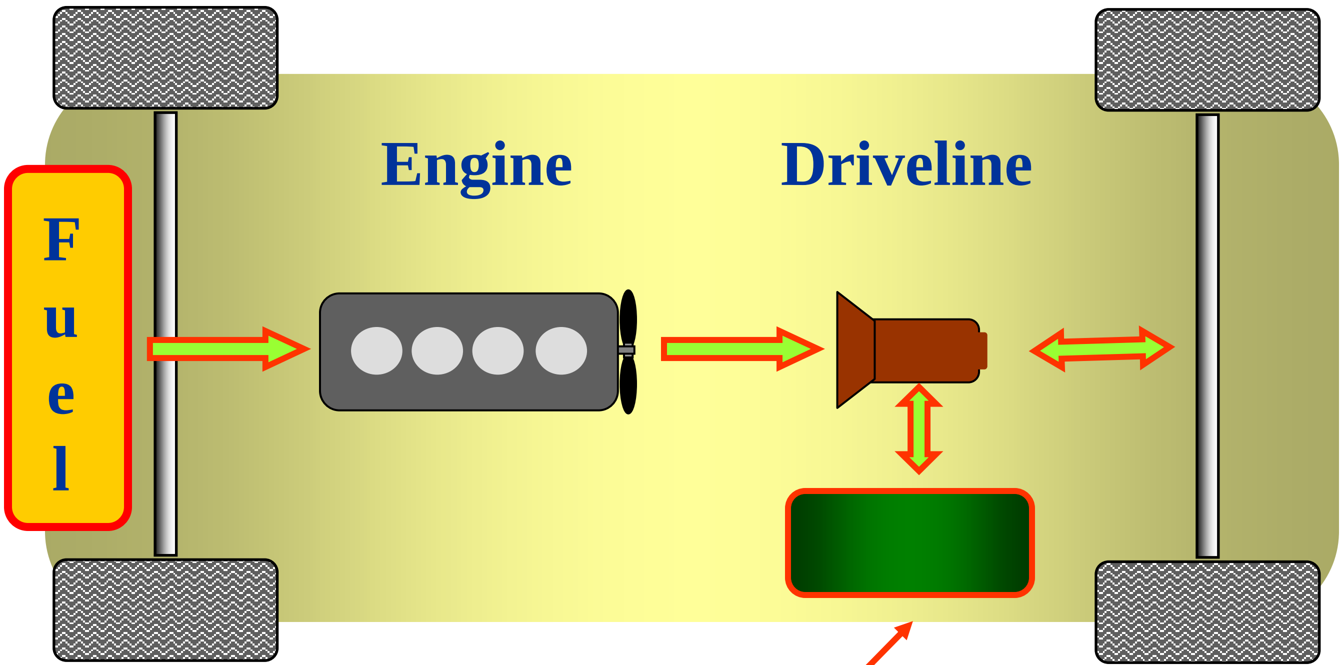
source: C. Gray, USEPA



C_d = 0.2
FA = 2.0 m^2
C_{rr} = 0.006
M = 3500 lb

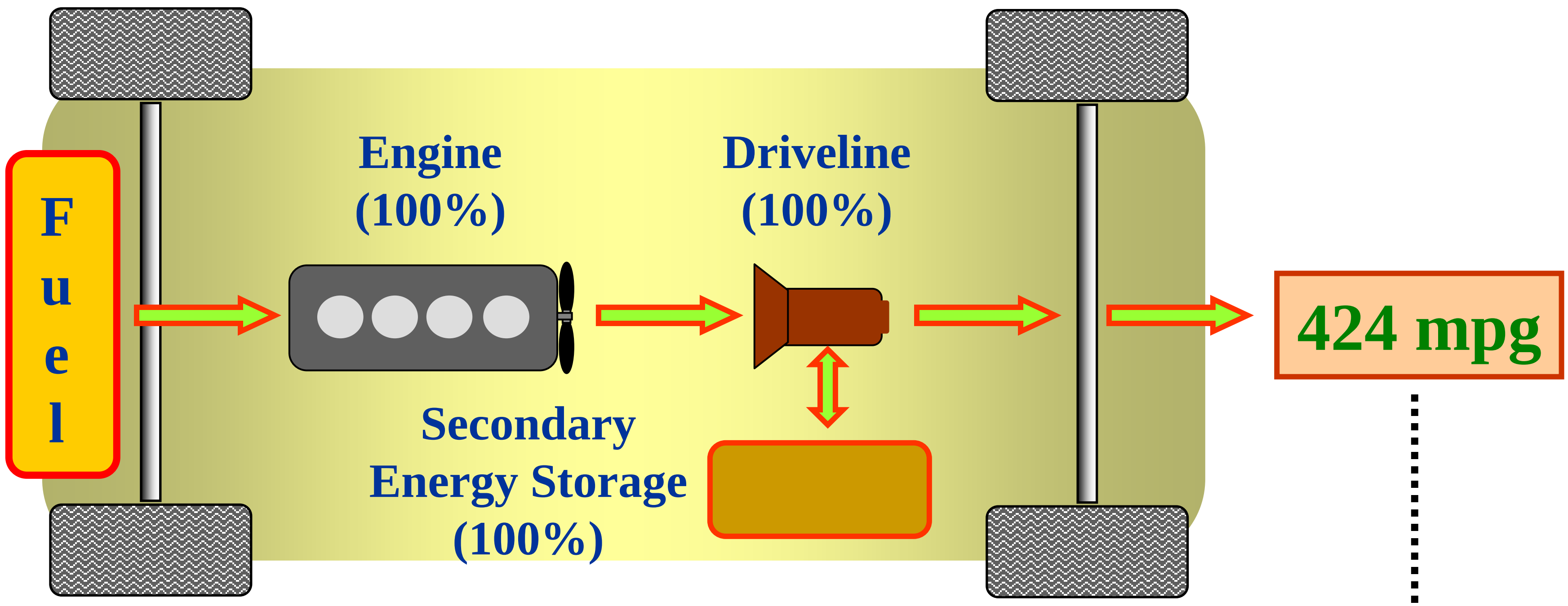
Hybrid Vehicle Energy Path

source: C. Gray, USEPA



Secondary Energy Storage
***Regenerative braking**
***Engine buffer**

“Perfect” Hybrid Vehicle Component Efficiencies: Source C. Gray, USEPA

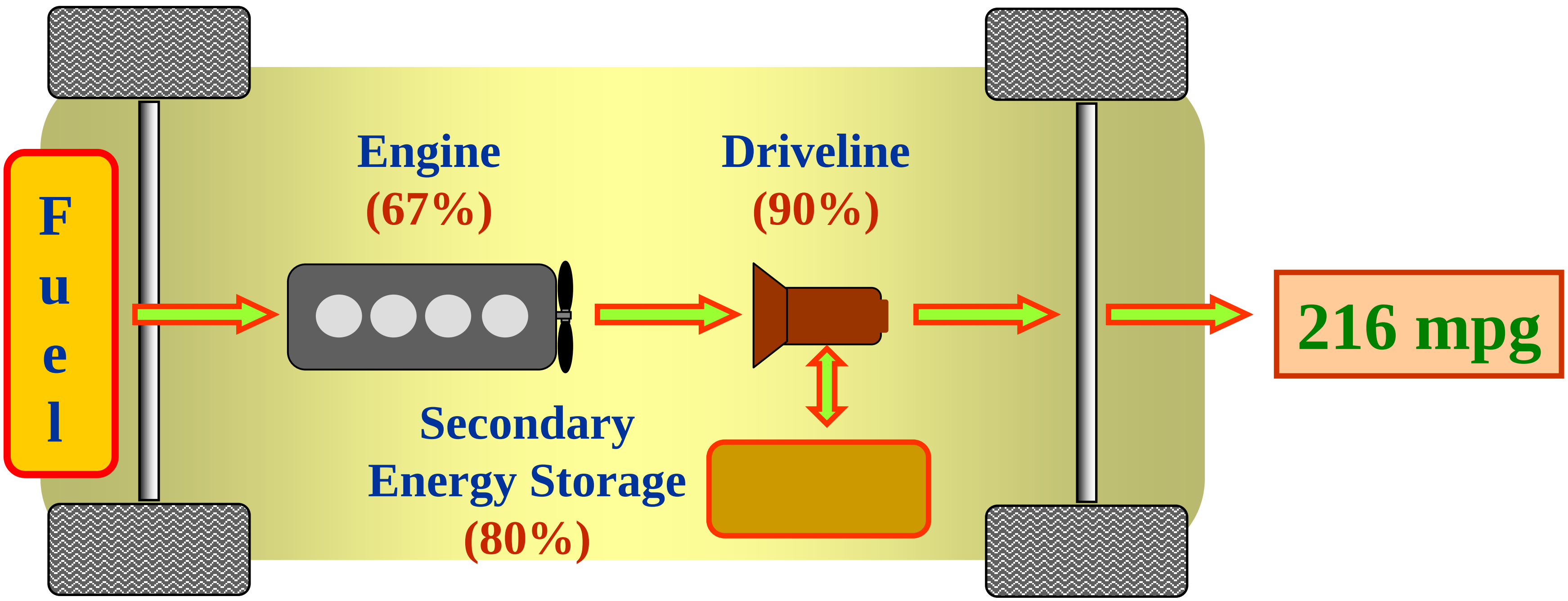


C_d = 0.2
FA = 2.0 m^2
C_{rr} =0.006
M = 3500 lb

With high efficiency (33%) engine: *140 mpg*
Without regenerative braking: *70 mpg*

Reasonable Long-Term Target

source: C. Gray, USEPA

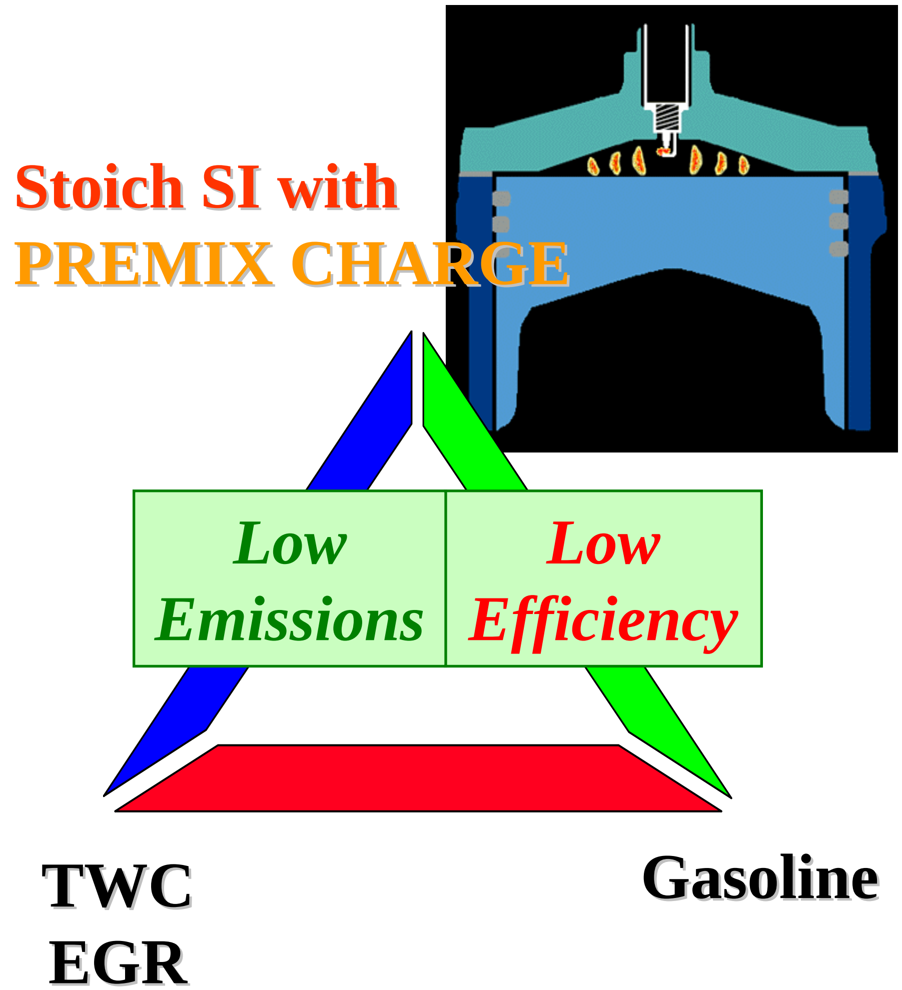


C_d = 0.2
FA = 2.0 m^2
C_{rr} = 0.006
M = 3500 lb

Conventional SI with Premixed Charge + Gasoline = Low Emissions, *but Inefficient*

source: C. Gray, USEPA

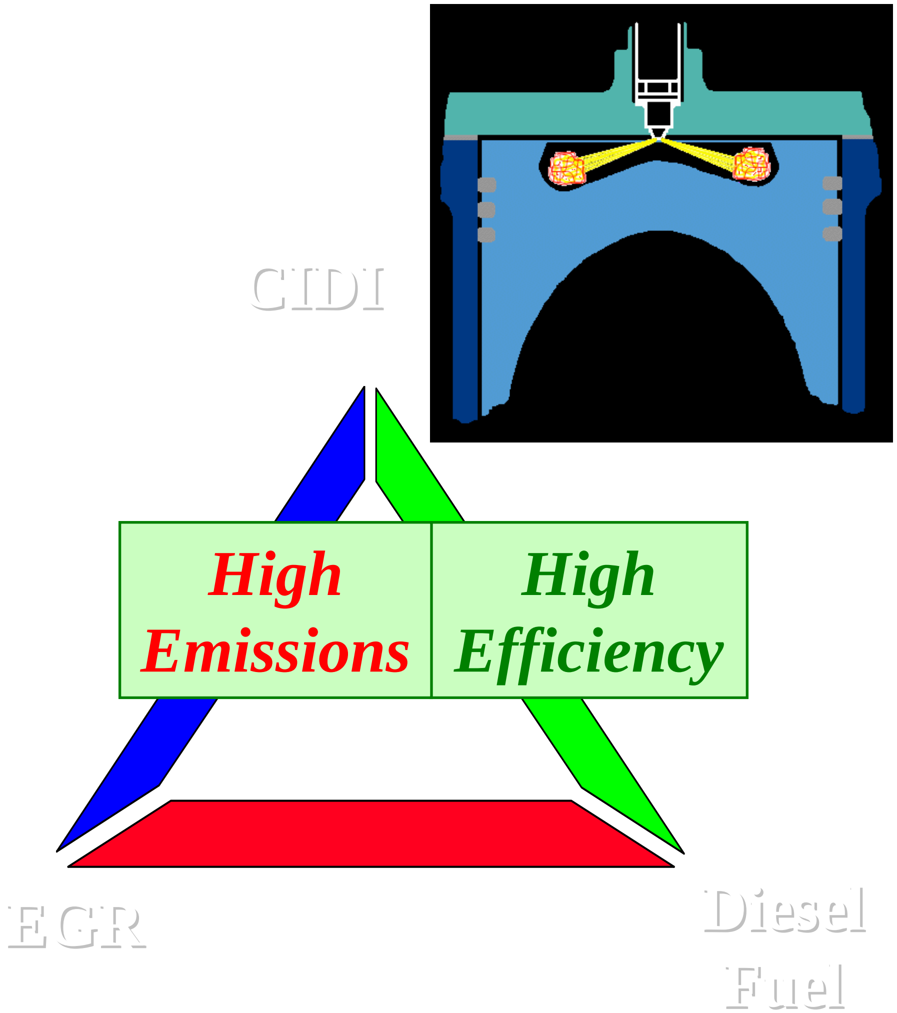
- Homogeneous charge, inherently low PM
- High peak temp = High NOx, but Stoich operation allows TWC
- *Throttling and Low compression ratios reduce efficiency*



Conventional CI Direct Injection + Diesel Fuel = Efficient, but has *High Emissions*

source: C. Gray, USEPA

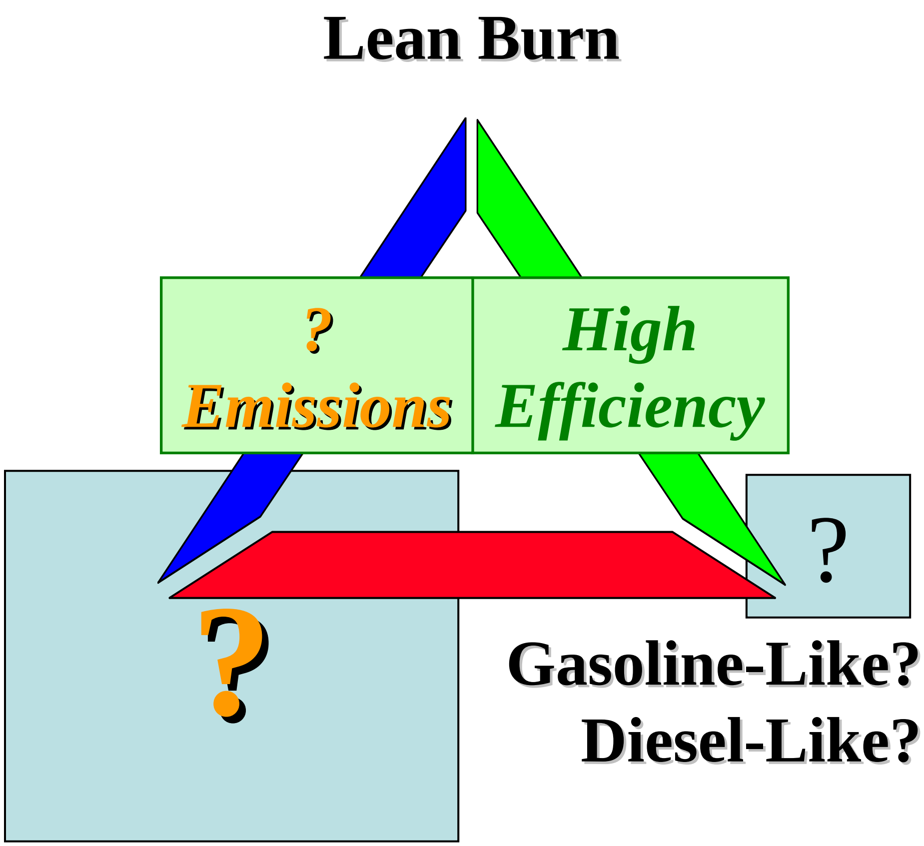
- High compression & unthrottled = high efficiency…
- *…But Stratified Charge = High PM*
- *High peak combustion temperatures = high NO_x ; lean operation prevents use of TWC*



Research Opportunity: Lean Burn on Gasoline/Diesel-Like Fuels

source: C. Gray, USEPA

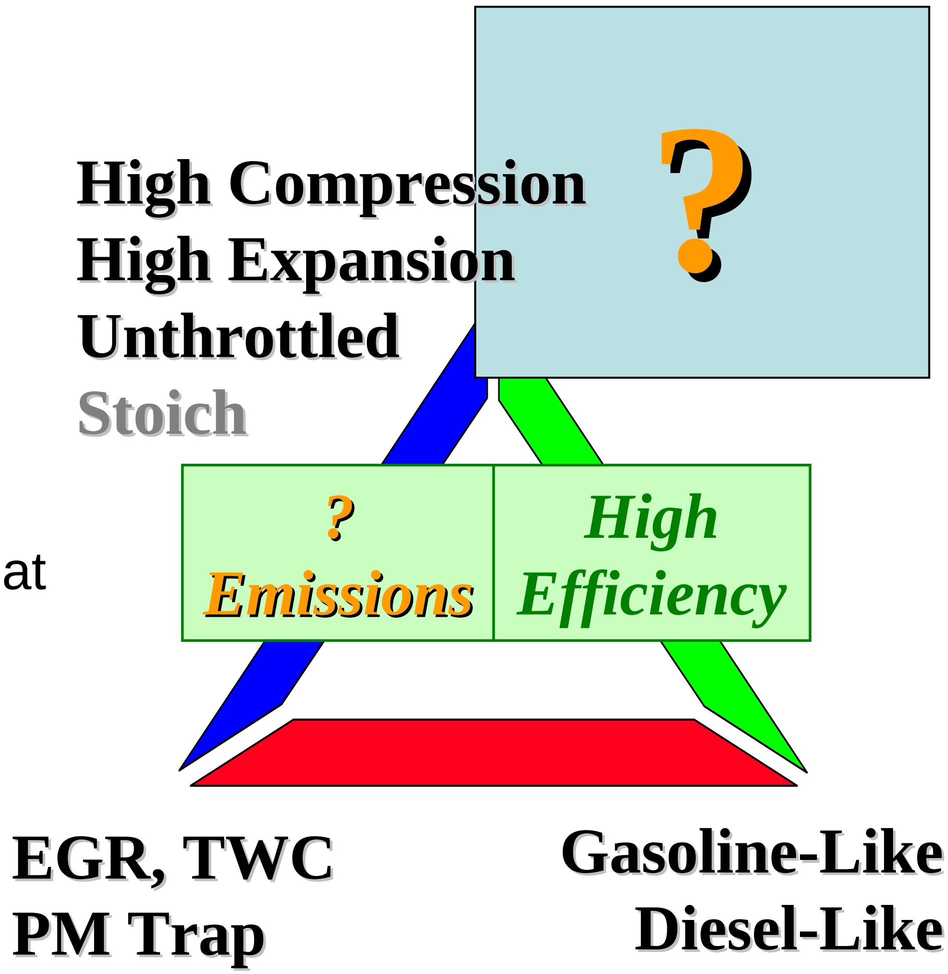
- If engine is operated with lean burn...
- Need more research on NOx Adsorbers, Plasma Cats, PM Traps
- Includes issue of achieving intermittent rich operation to purge adsorber



Research Opportunity: Gasoline/Diesel-Like Fuels at Stoich

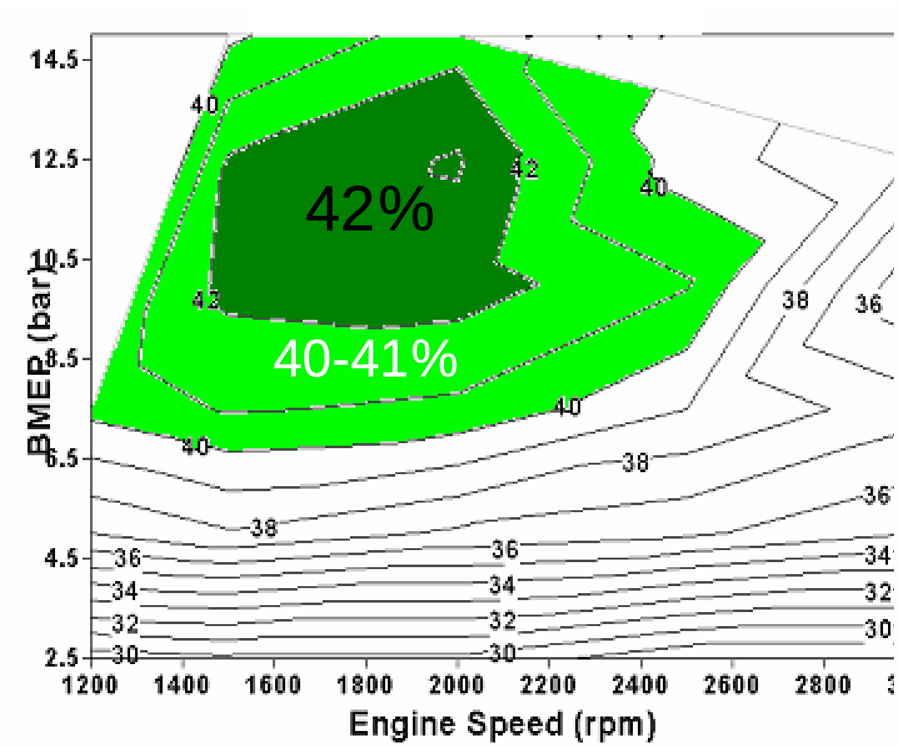
source: C. Gray, USEPA

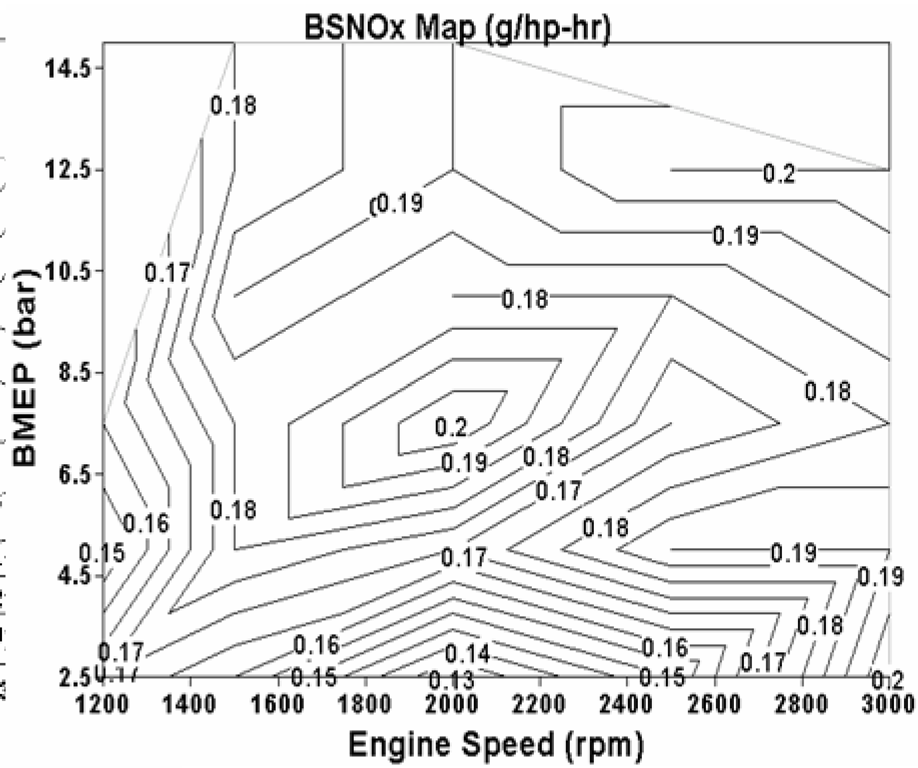
- If efficiency is obtained through high compression, high expansion + unthrottled...
- How can the engine be operated at stoich, so as to allow TWC?



EPA Clean Diesel Combustion (1.9L Multi-Cylinder Evaluation)

source: C. Gray, USEPA

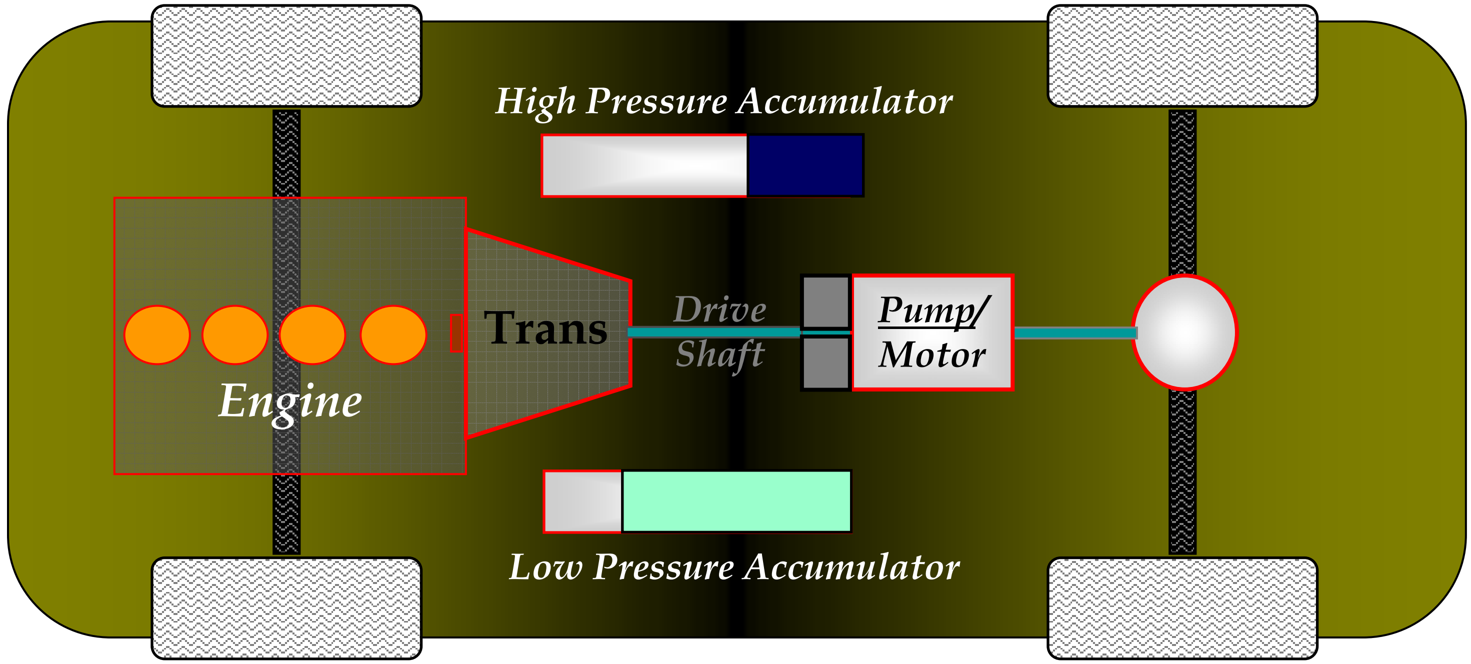




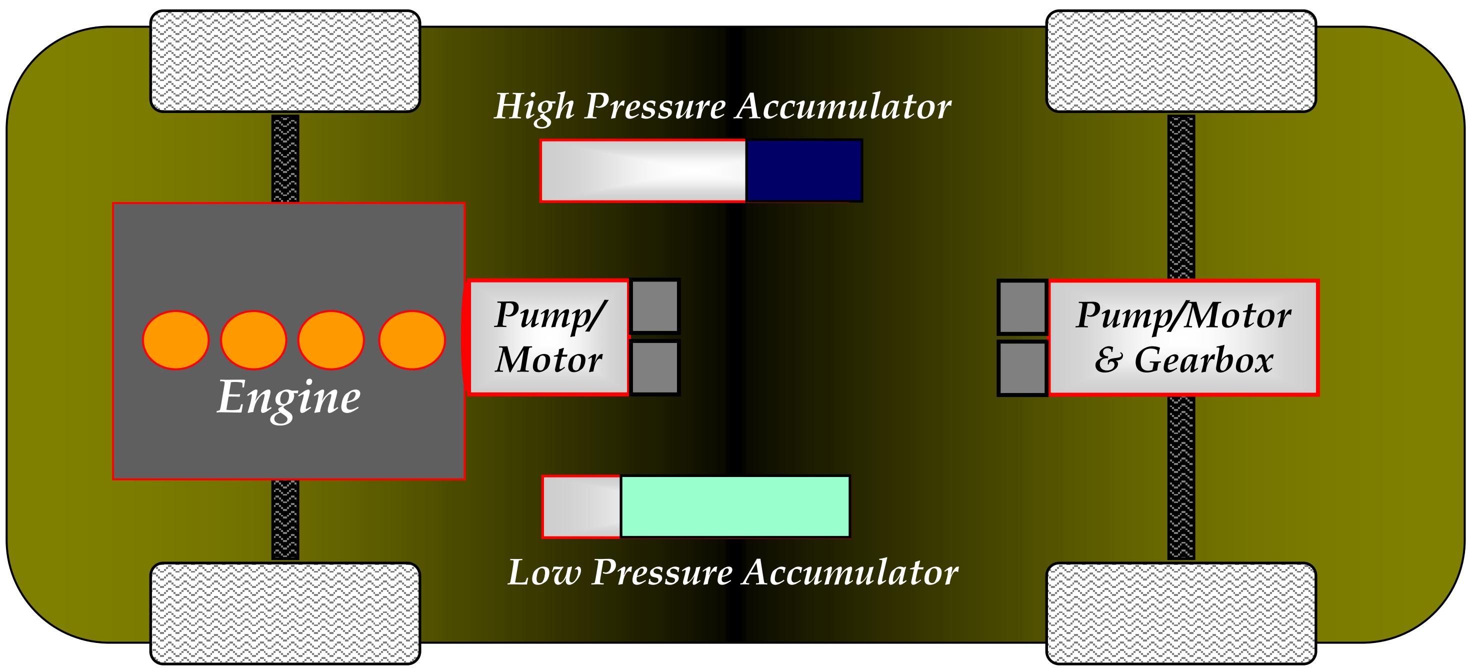
$P_{exhaust}$ = P_{input} + .1 Bar

NOx below .2 everywhere

EPA's Hydraulic Hybrid Break-Throughs source: C. Gray, USEPA



Hydraulic Hybrid (Parallel)



Hydraulic Hybrid (Series)

Historic EPA Hydraulic Hybrid Test Chassis

source: C. Gray, USEPA

Full Series Hydraulic Hybrid

80+ mpg combined city/highway mpg

~8 seconds 0-60 acceleration time

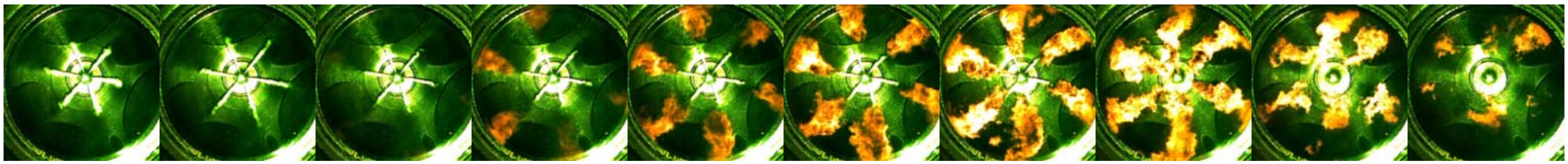
No need for expensive lightweight materials (test weight 3800 lb)

Led the way for subsequent demonstration vehicles

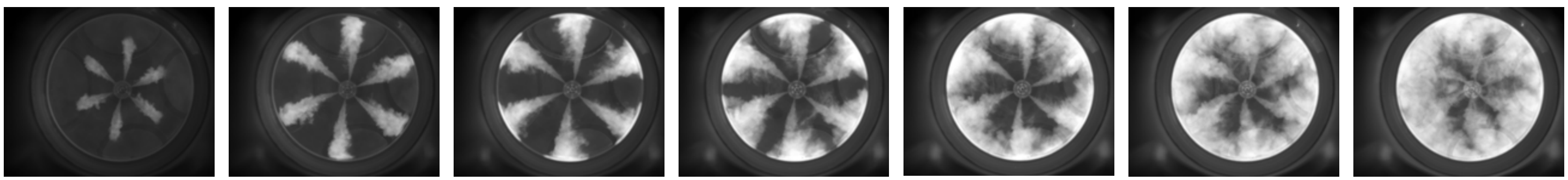
MSU's Automotive Facility:
Online Fall, 2007

Techniques for Evaluation and Control of an ICE at MSU

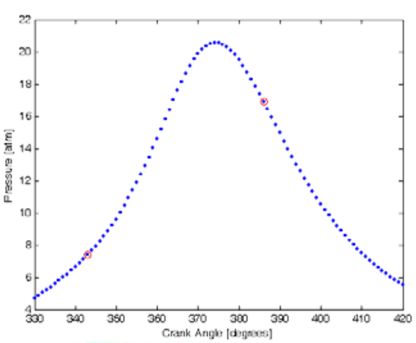
Diesel Combustion Analysis (Visual Techniques…Qualitative Analysis)



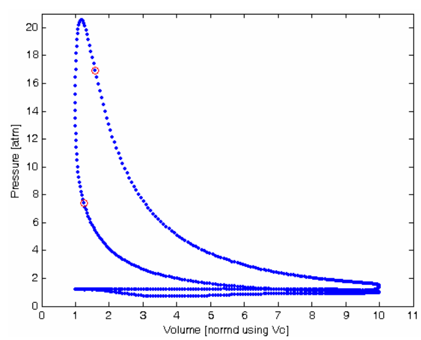
Diesel Fuel Spray Analysis (Infrared Techniques…Qualitative Mixing)



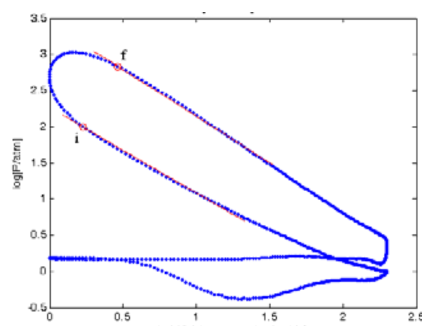
Pressure Traces are Evaluated to Study the Quantitative Conversion of Reactants to Products



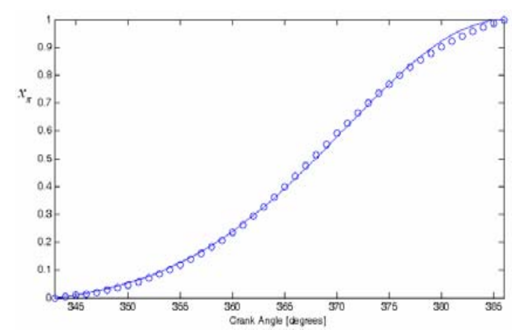
Measured pressure data



Indicator diagram in linear scales



Indicator diagram in logarithmic scales



Quantification of dynamic stage of combustion (i-f)

Technology Being Developed in MSU-Hybrid Project

- Power electronics for component and system efficiency
  - DC-DC converters
  - Z-source inverter
- Electrical machines and drives
  - IPMAC for reduced iron losses, weight, and torque pulsations
  - Operation with minimal sensors for cost and reliability
- Fault diagnosis and prognosis for components and systems
- Development of advanced prime movers
  - Numerical simulation tools for powertrain optimization
  - Advanced clean diesels including the ability to effectively use biofuels
- Vehicle integration
  - Durability, reliability and performance optimization
  - Physical and virtual development/validation

How can the University Community from the State of Michigan Contribute?

- Develop technology which promises “economical” production of 50 B gallons of ethanol per year (2.4 M bbls oil per day equiv)
  - High value biofuel “additive” which will enhance HCCI combustion and/or “clean” diesels
  - Requires molecules which provide local reaction sites during compression ignition (or during TJI)
- New engine technologies that take advantage of biofuel properties
  - Microelectronic controls
  - Advanced thermoelectrics
  - Other regeneration cycles
- Develop advanced technology critical to hybrids: Battery technology, power electronics, high efficiency machines, fault prognostics using cost effective technology

Thermoelectric Conversion of Waste Heat to Electricity in an IC Engine Powered Vehicle

Prepared by:

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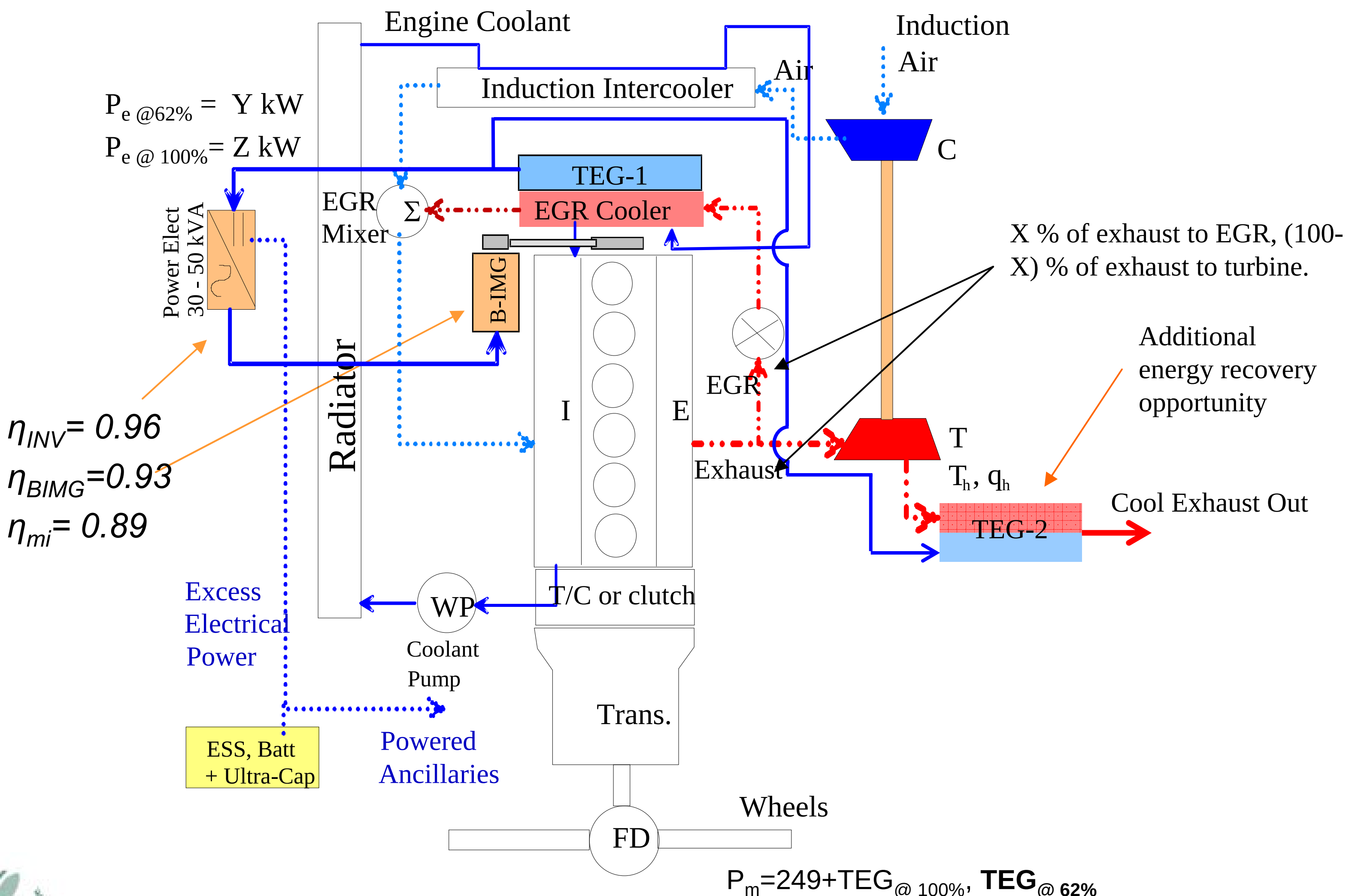
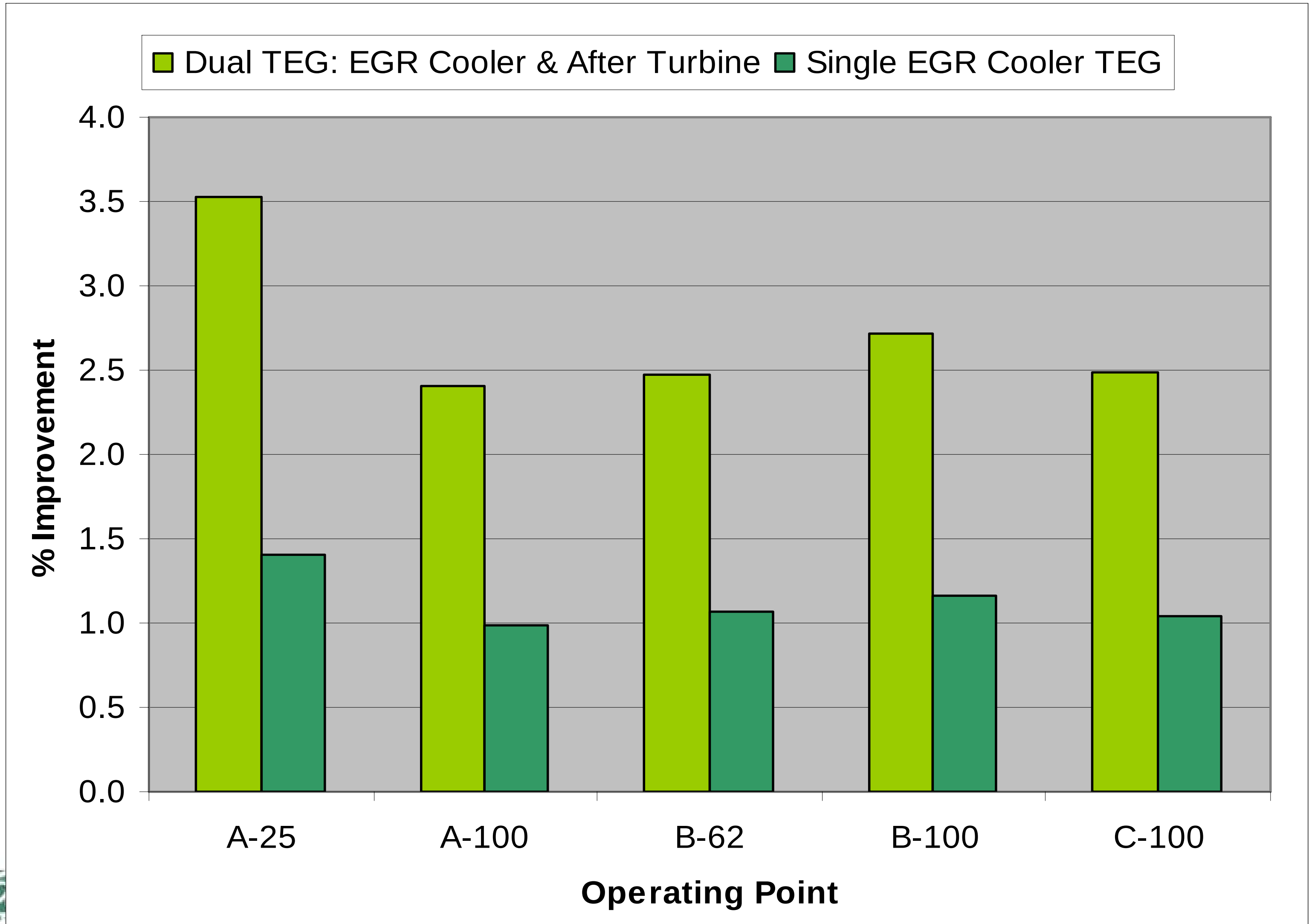
Mihal Gross, Project Monitor

Thermal Power Split Hybrid – Options

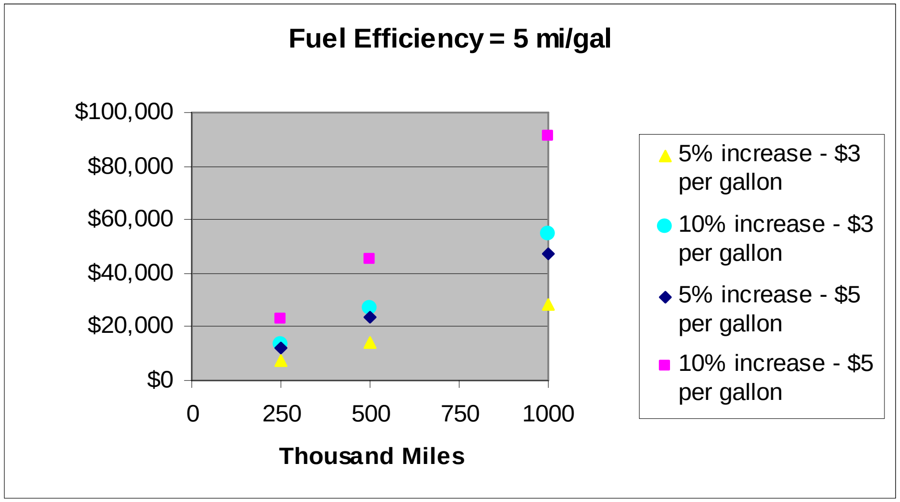
Using the electric power recovered from waste heat

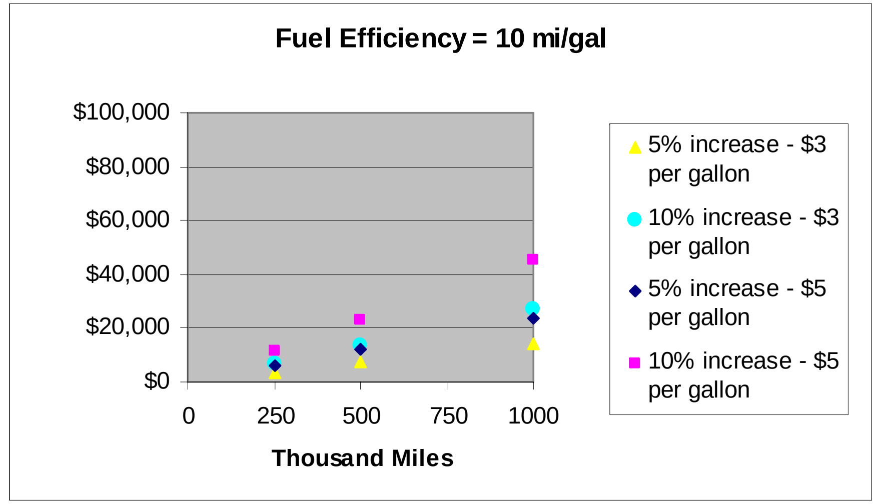


BSFC % Improvement:
Single TEG EGR Cooler and Dual TEG



Assessment of Economic Feasibility
Based on Fuel Savings





OTR Truck				
	Savings @ $3 per gallon		**Savings @ $5 per gallon**	
	5% imp. bsfc	**10% imp. bsfc**	**5% imp. bsfc**	**10% imp. bsfc**
250K miles	$7,143	$13,636	$11,905	$22,727
500K miles	$14,286	$27,273	$23,810	$45,455
1M miles	$28,571	$54,545	$47,619	$90,909

Delivery Truck				
	Savings @ $3 per gallon		**Savings @ $5 per gallon**	
	5% imp. bsfc	**10% imp. bsfc**	**5% imp. bsfc**	**10% imp. bsfc**
250K miles	$3,571	$6,818	$5,952	$11,364
500K miles	$7,143	$1,3636	$11,905	$22,727
1M miles	$14,286	$27,273	$23,810	$45,455

Summary

- For multiple decades, fossil fuels will supply the greatest fraction of our transportation energy
- Fossil fuel costs, liquid fuel power density and GHG considerations will make biofuels viable
- Next decade: Technologies such as advanced power electronics, thermoelectrics, turbo-compounding and advanced combustion systems can make 5-40% improvements in fuel economy ….. when implemented in a hybrid configuration
- Adaptation biofuels will be a occupy a small but growing market segment….and likely will require subsidies to be viable … ethanol from switchgrass and other feedstocks appears promising
- Powertrains for next 50 years: advanced IC engines which have a near 50% energy conversion efficiency implemented in hybrids

Finally - All Options Must be Considered
…the Reasonable Ones Carefully!

Thanks for your attention!

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