

Energy Efficiency of Automobiles – A Pragmatic View

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IEEE Space

Wide Bandgap Materials

Power ICs

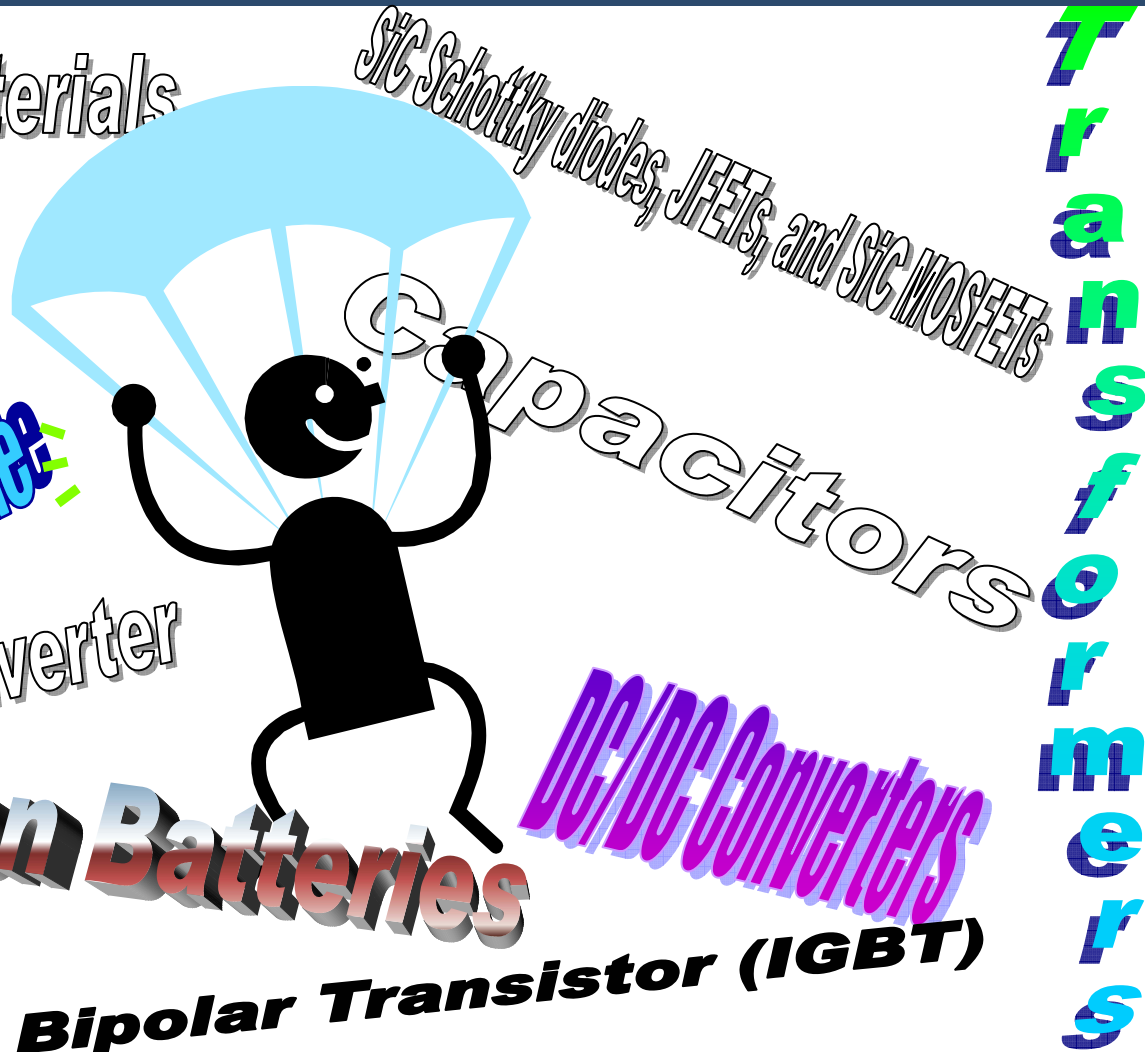
Integrated Power Modules

Voltage Source Inverter

Diode

Li-Ion Batteries

Insulated Gate Bipolar Transistor (IGBT)



Outline

- Energy efficiency space
- Fuel economy and energy efficiency
- Where does the energy go
- Fuel economy ideal function
- Pragmatic energy efficiency improvement model
- Summary

Energy Efficiency Space



What is “Efficiency” ?

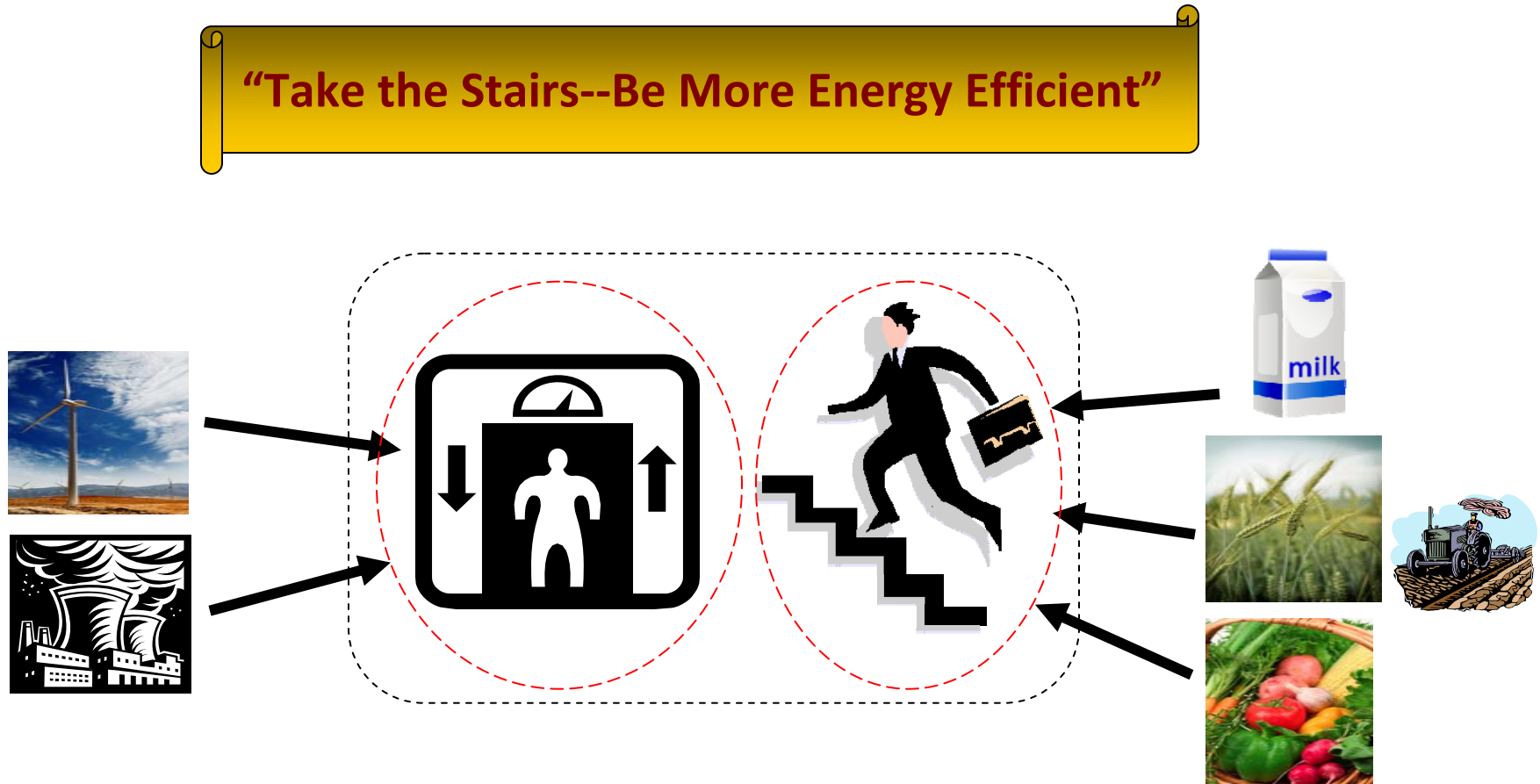
The dictionary defines efficiency as:

- The ratio of the effective or useful output to the total input in any system

- The ratio of the energy delivered by a dynamic system to the energy supplied for its operation

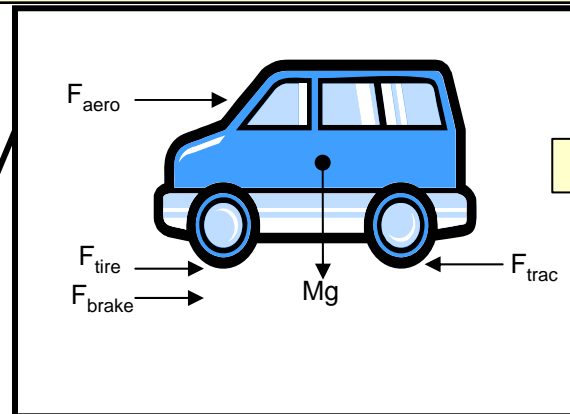
What is “Energy Efficiency”

“Take the Stairs--Be More Energy Efficient”

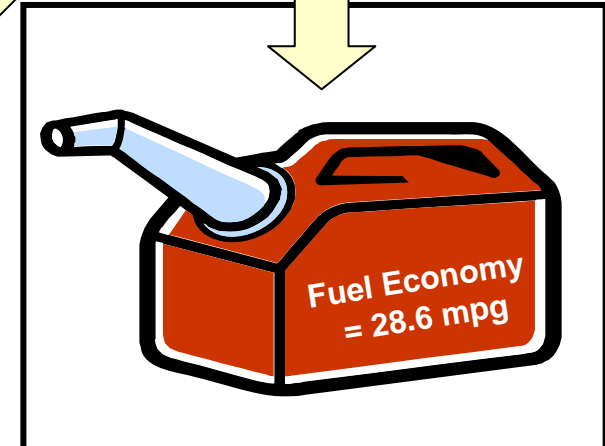
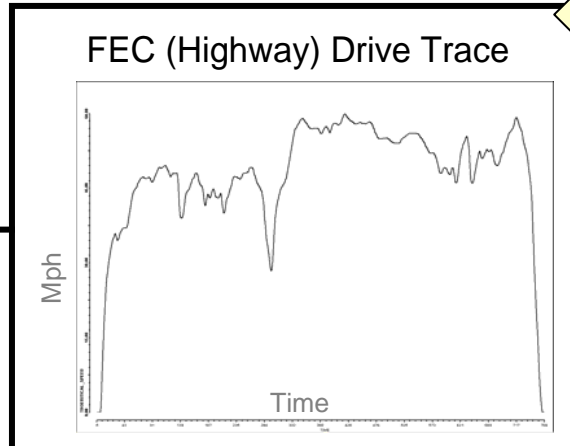


The Physics: Converting Fuel Energy to Work

Fuel Economy generally refers to how much distance a specific vehicle can be moved from A to B with a given volume of fuel. Fuel Efficiency generally refers to how well the energy of the fuel is converted into useful work.



Laws of Physics
 Force = Mass x Acceleration
 Torque = Inertia x Angular Accel
 Conservation of Energy
 1st Law of Thermodynamics
 Lower Heating Value of Fuel
 Work = Force x Distance
 ...and so on



Key Fuel Economy Metrics

Fuel Economy Labels

- Regulatory requirement, but also used competitively (can be advertised)
- Administered by EPA with Manufacturer self-certification

Consumer Reports

- Competitive testing by highly influential Independent 3rd party
- Cannot be advertised
- Chrysler strategic objective is to be top quartile in each segment

Corporate Average Fuel Economy (CAFE)

- Fleet mpg average, administered by NHTSA

European Union Fuel Consumption

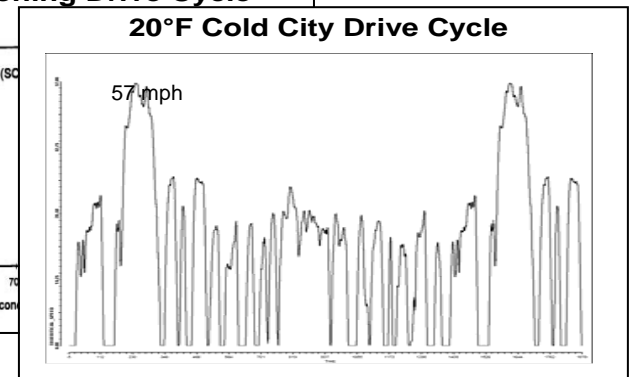
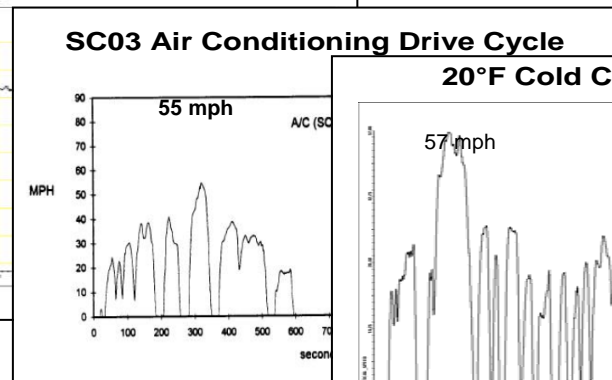
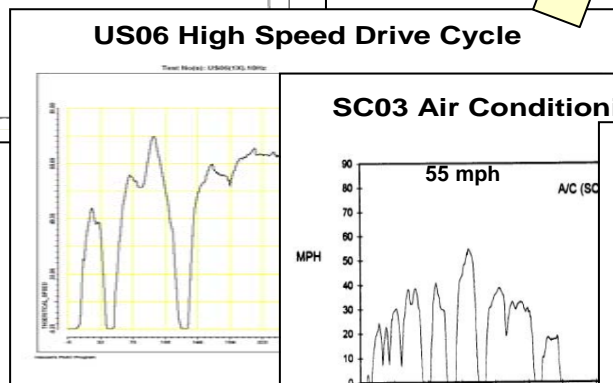
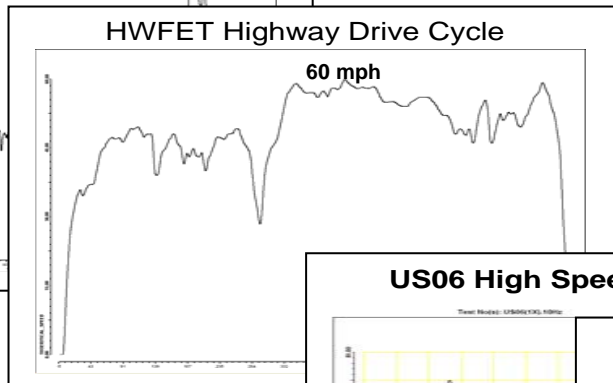
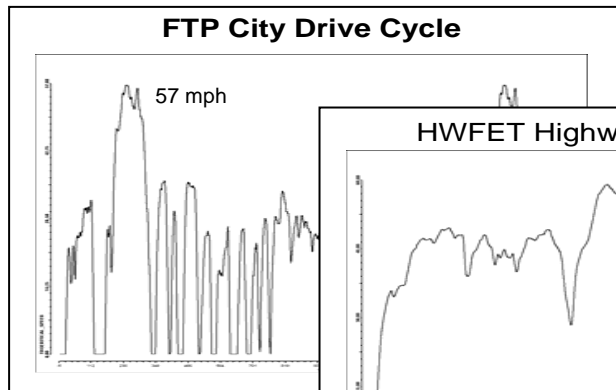
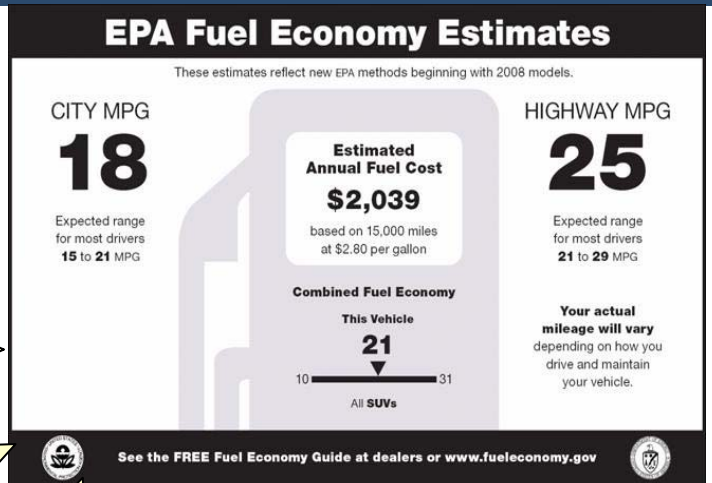
- Expressed as Liters/100 Km on unique New European Driving Cycle (NEDC)
 - Homologation testing conducted by Manufacturer with an EU approved witness
 - Widely reported (German *Auto Motor und Sport* is similar to Consumer Reports) and can be advertised

CO₂ Emissions (Greenhouse gas “pollutant”)

- Inversely proportional to mpg fuel economy (directly proportional to fuel consumption) for a given fuel. Expressed as gm/mi or gm/km
- Voluntary fleet average agreement exists between Manufacturers Association (ACEA) and the European Union

Key Metrics & Cycles – Fuel Economy Labels

EPA City and Highway label values are calculated as weighted combinations of 5 key tests. They are posted on the new vehicle's window label along with a competitive segment position. The city, highway and cold city cycles feature light engine loads and mostly low vehicle speeds.

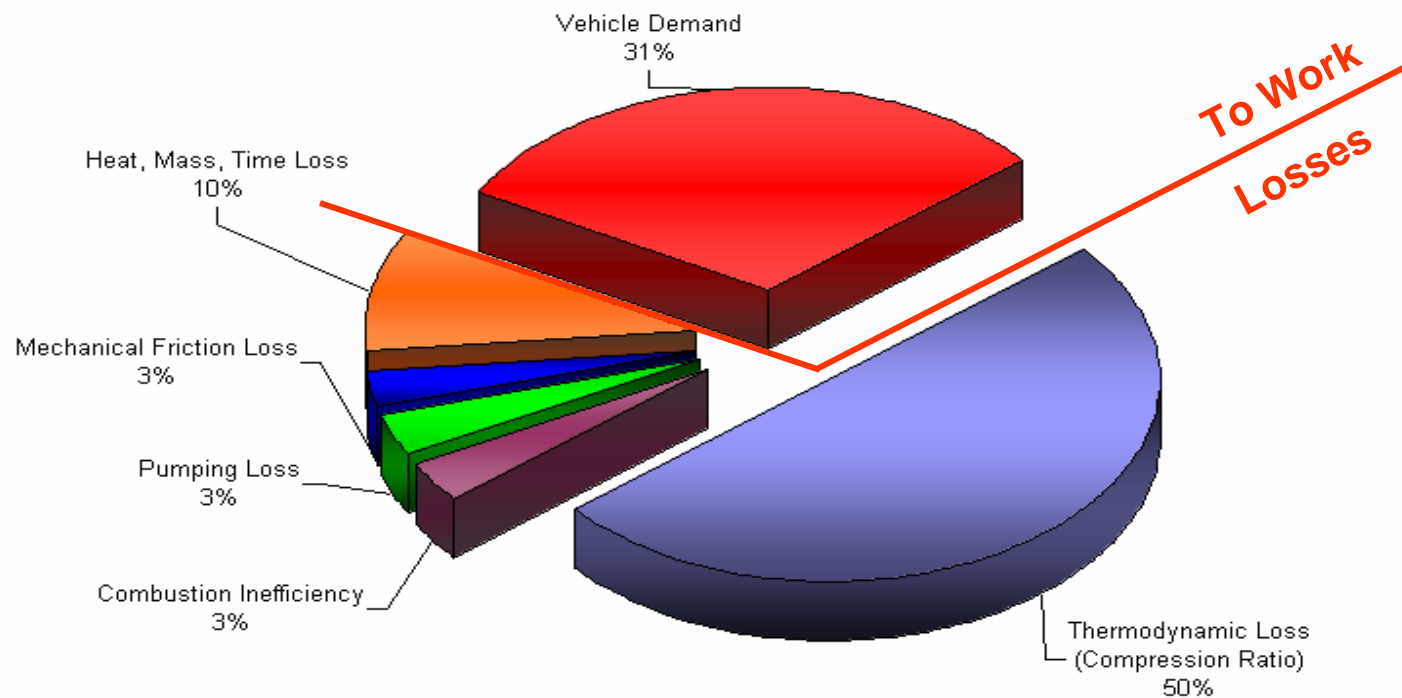


The FTP City and HWFET Highway are also combined into an EPA unadjusted value for use in CAFE

Energy Supply from Internal Combustion Engine

Only about 1/3 of the fuel energy is converted by the internal combustion gasoline engine into vehicle work. Advanced gasoline engine technologies (and diesels as well) are aimed at improving the efficiencies and reducing the losses associated with the other 2/3 of the energy available.

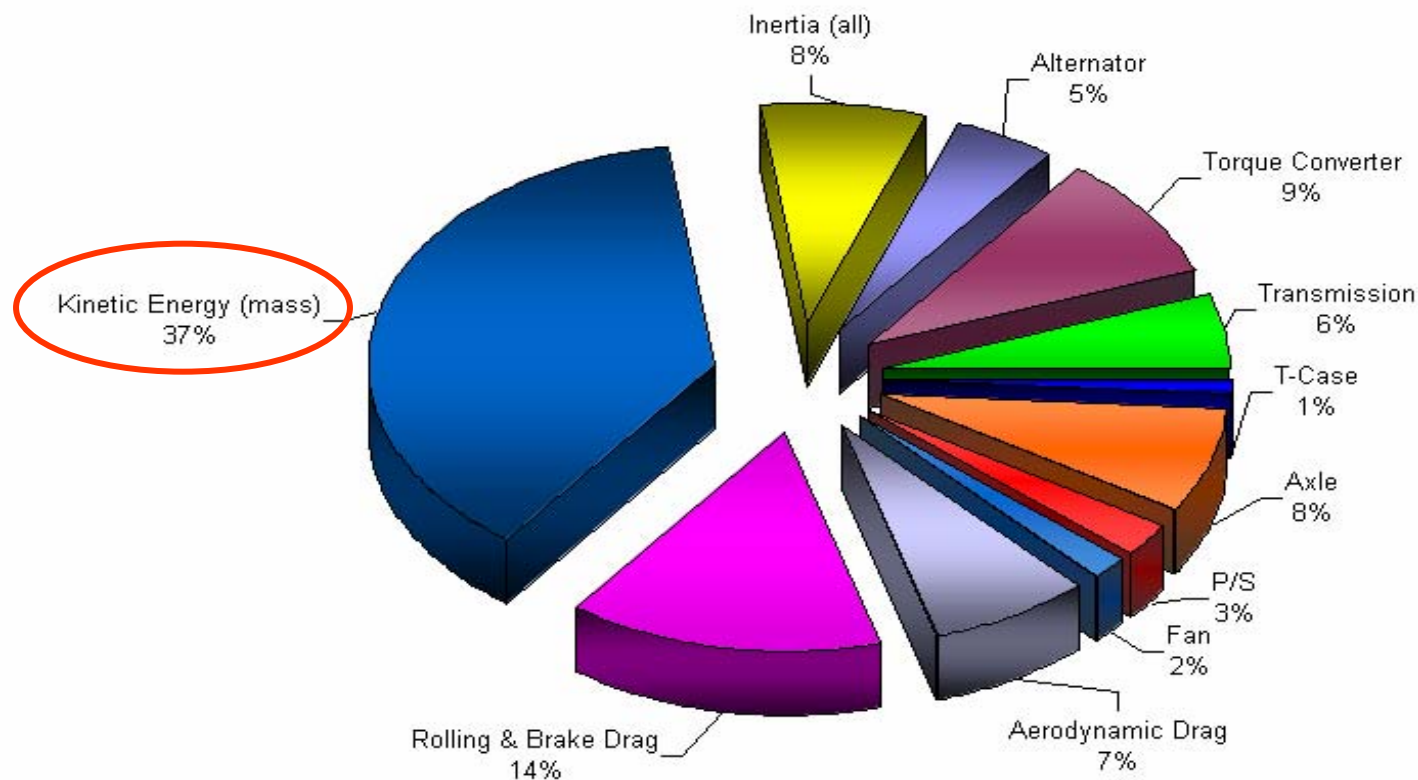
Analysis of Energy Supply (Engine) - Consumer Reports City Cycle



Where the Vehicle Energy is Spent in City Driving

Most of the fuel energy on a city type cycle is consumed by (repeatedly) accelerating the mass (weight) of the vehicle, but other vehicle demands & losses take energy also.

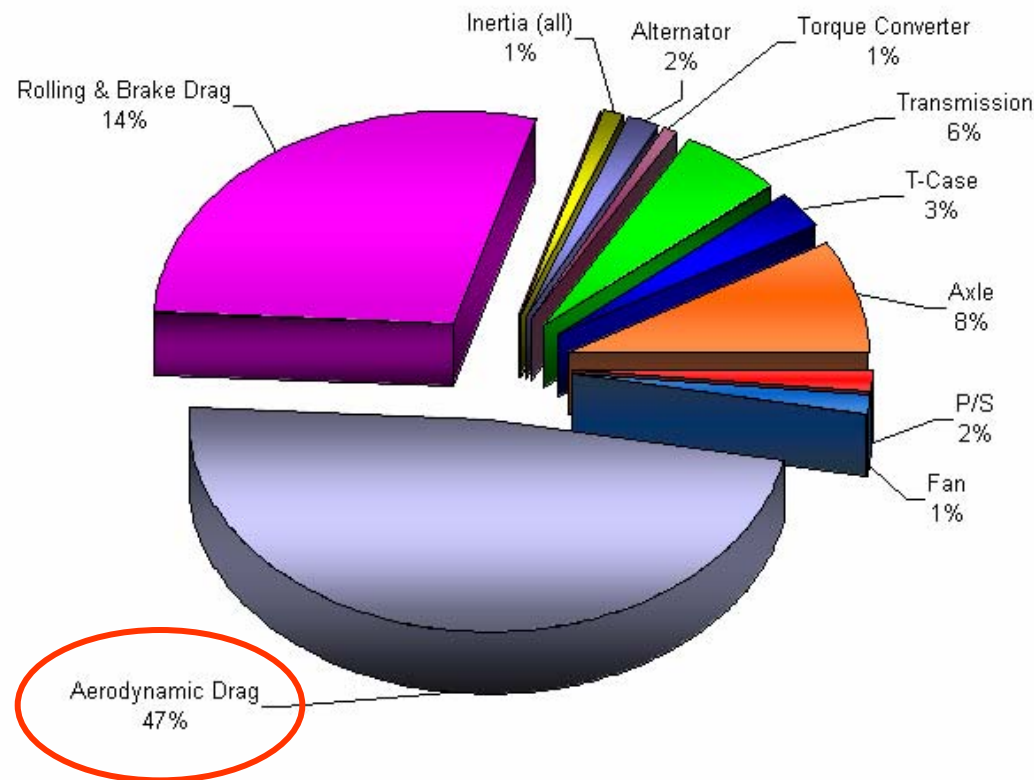
Analysis of Energy Demand (Vehicle) - Consumer Reports City Cycle



Where the Vehicle Energy is Spent in Highway Driving

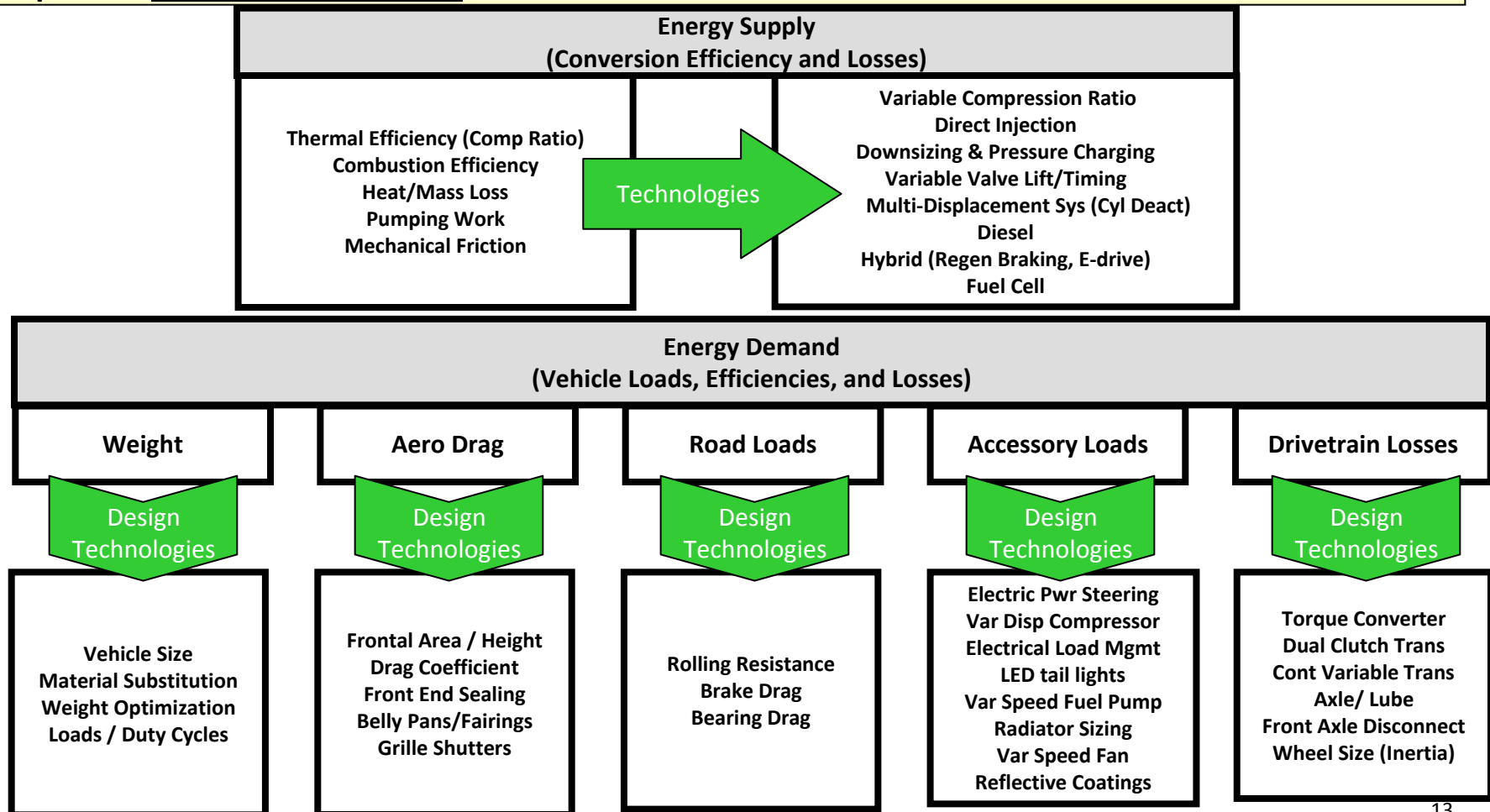
Most of the fuel energy on a highway type cycle is consumed overcoming the aerodynamic drag of the vehicle, but other demands & losses take energy as well.

Analysis of Energy Demand (Vehicle) - Consumer Reports Highway Cycle

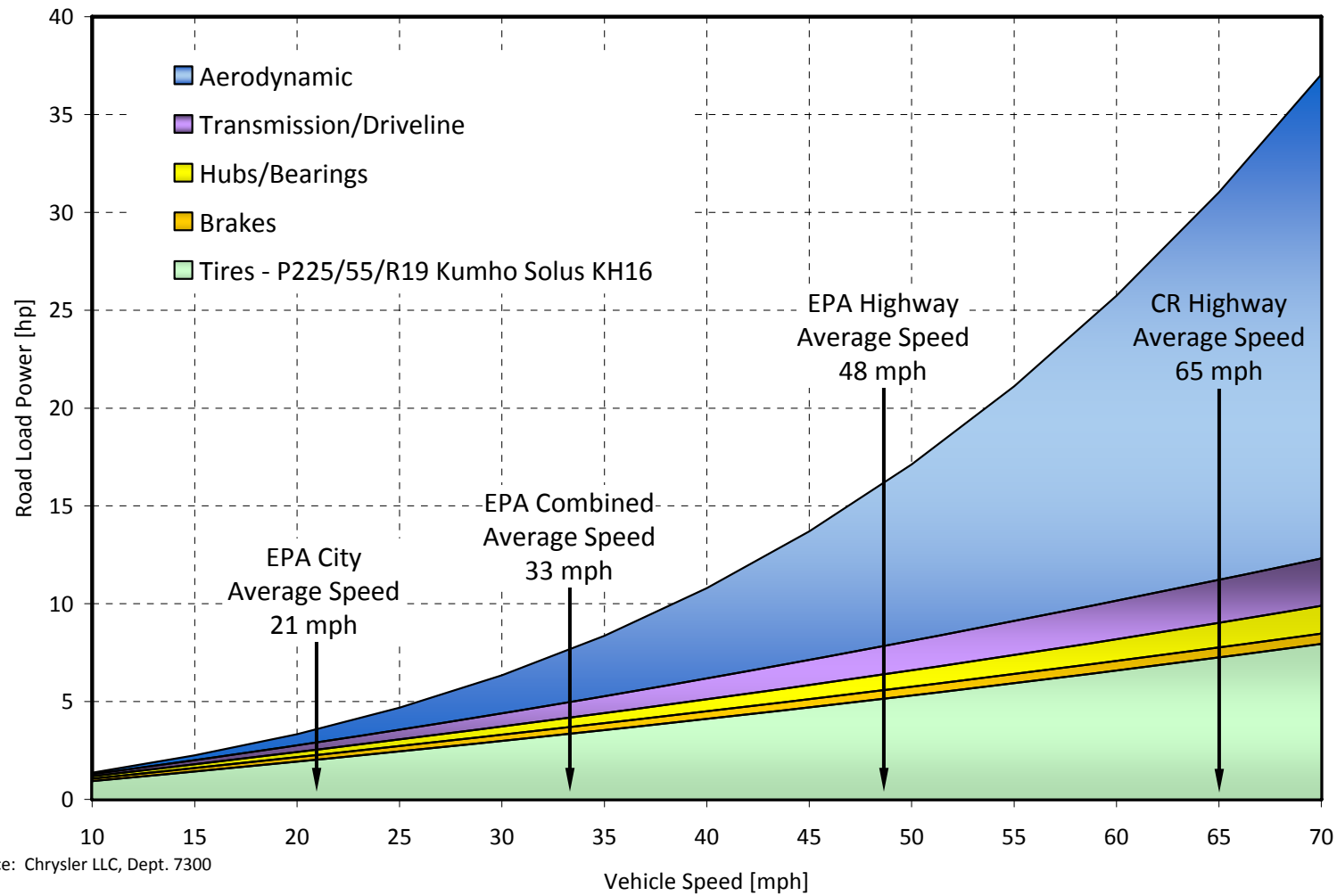


Energy Supply and Vehicle Demand

The Physics: Fuel Economy is a function of the *total vehicle system*, comprising both energy supply in the propulsion system and energy demand of and from the vehicle. Improving it thus requires a *total vehicle solution*.

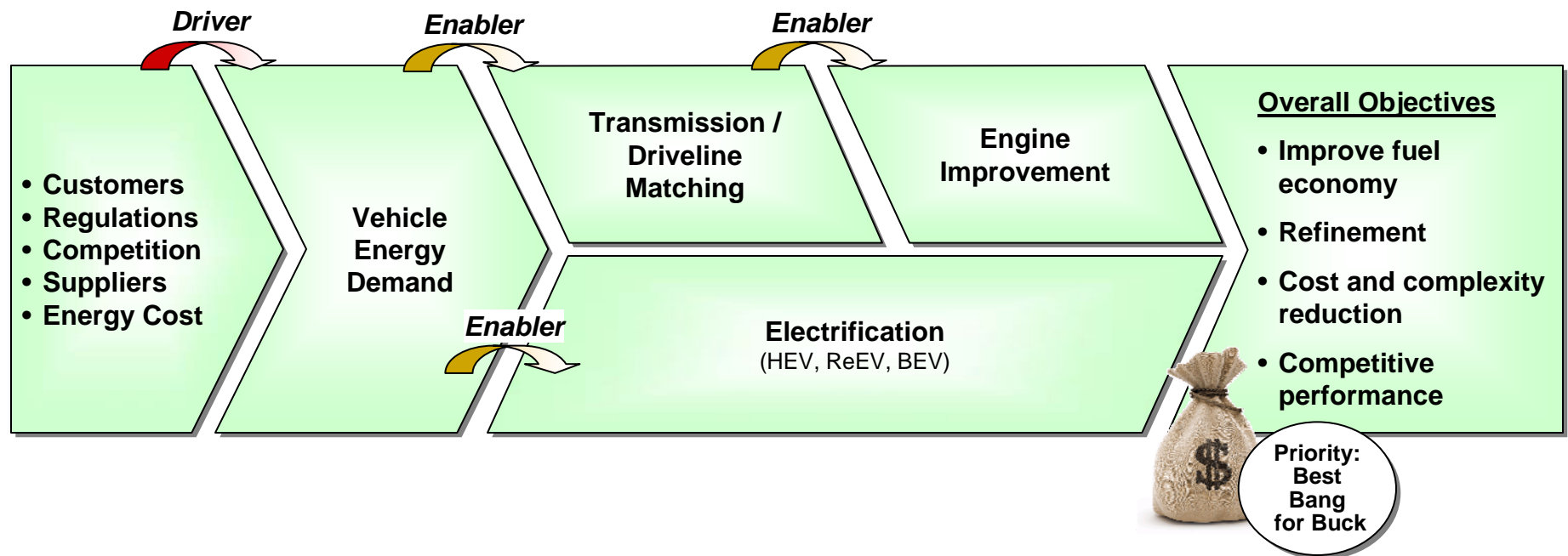


Road Load - Subsystem Contributors



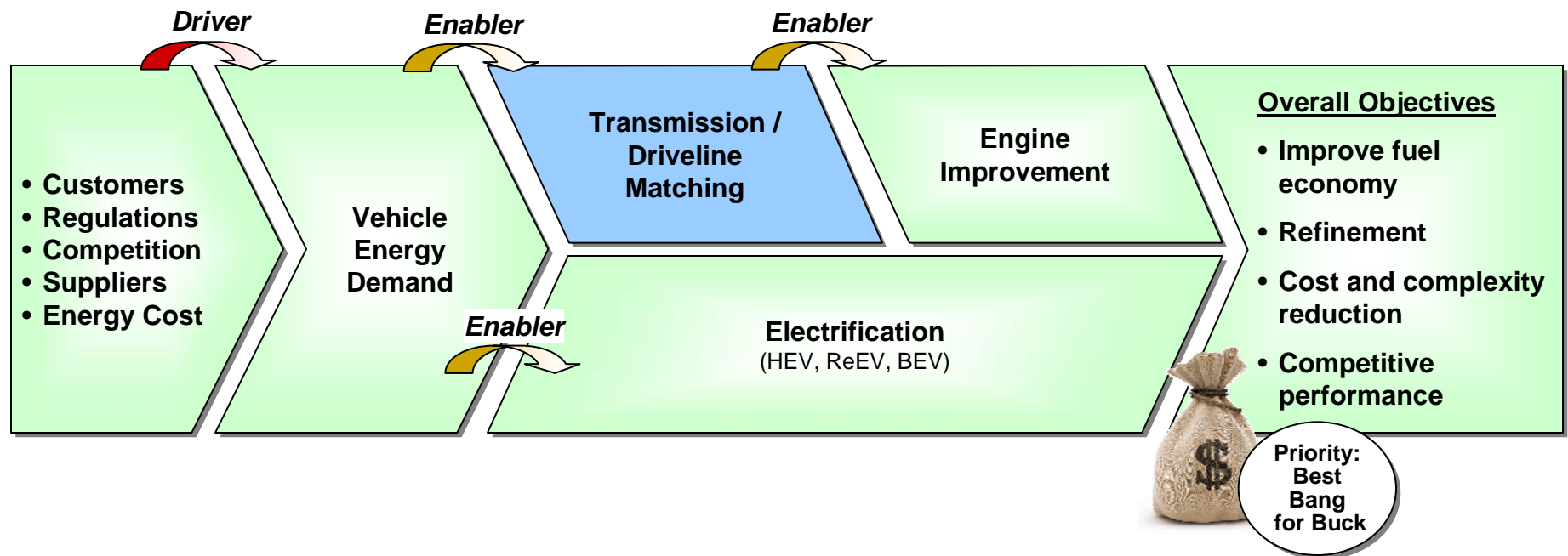
Data Source: Chrysler LLC, Dept. 7300

Pragmatic Efficiency Improvement Model



- Gains in propulsion efficiency are best built upon reduced vehicle energy demand, as it maximizes the impact of transmission matching and allows engine size and technology to be optimized.

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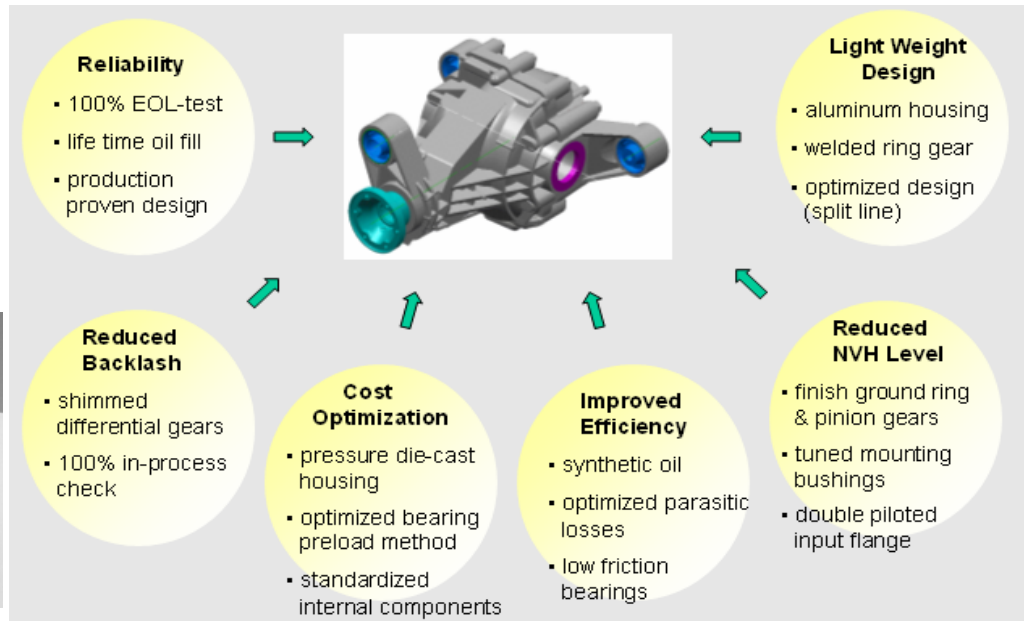
Transmission and Driveline – Efficient and Light Weight Axle Technology

Technology

Fuel Efficient Rear and Front Drive Units
for Pass Car & SUV
Open diff, LSD, eLSD



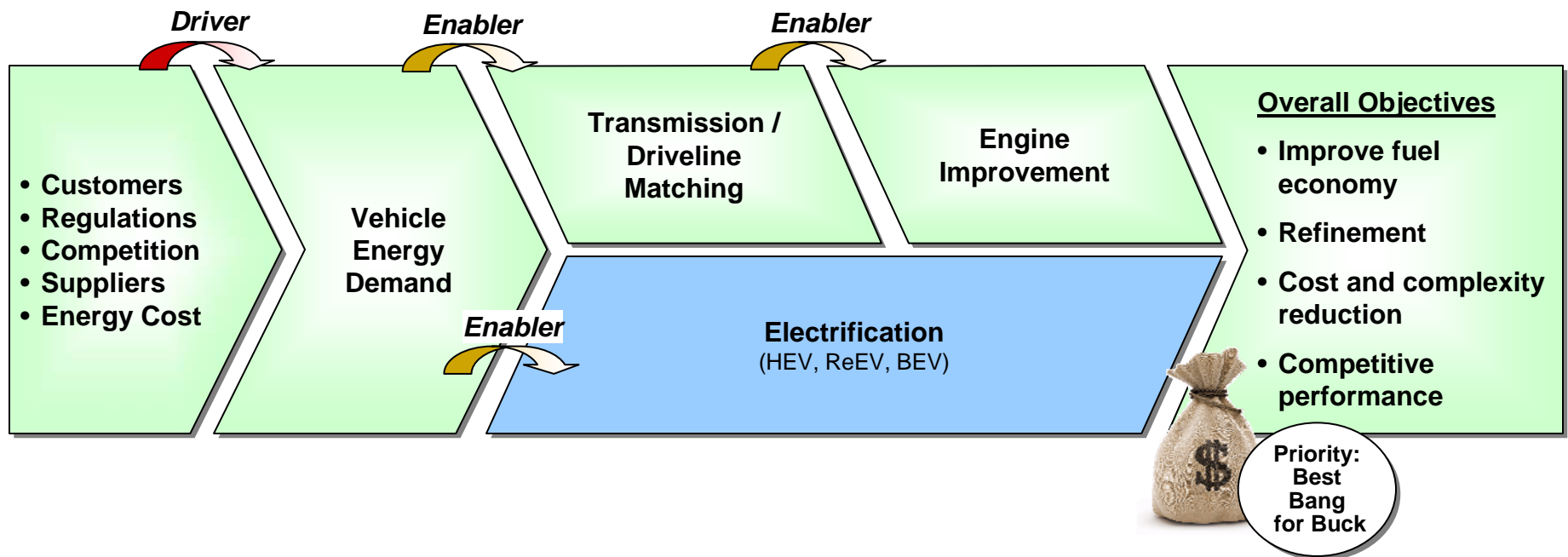
Benefits



Products



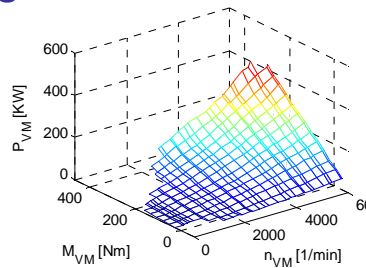
Pragmatic Efficiency Improvement Model



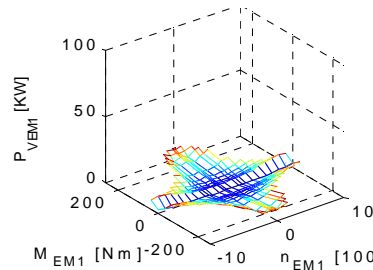
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Electrified System Optimization

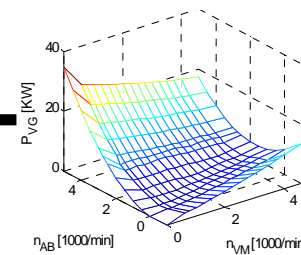
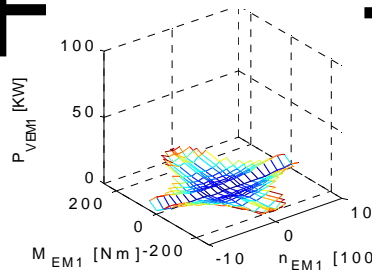
Combustion Engine Losses



Electrical Losses EMA

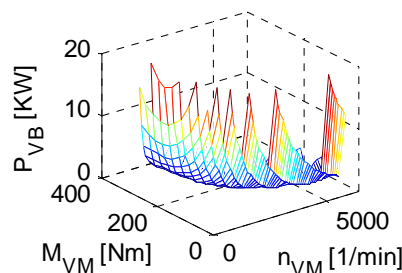


Electrical Losses EMB

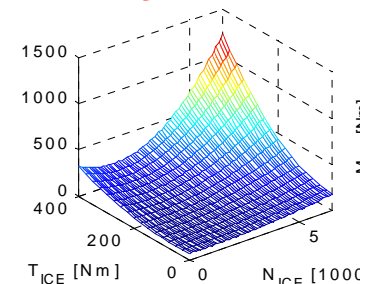


Transmission Pump Losses

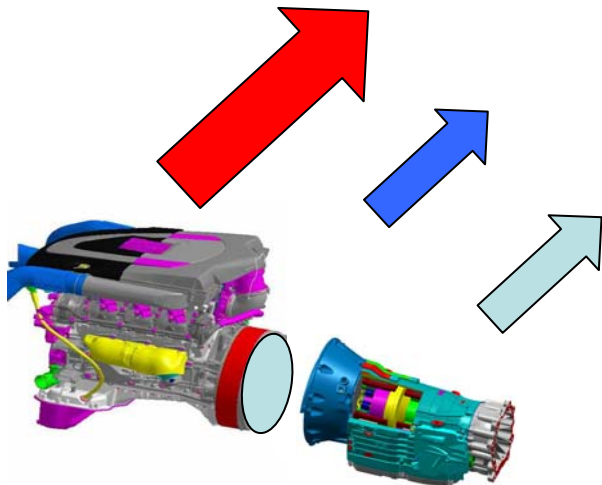
Battery Losses



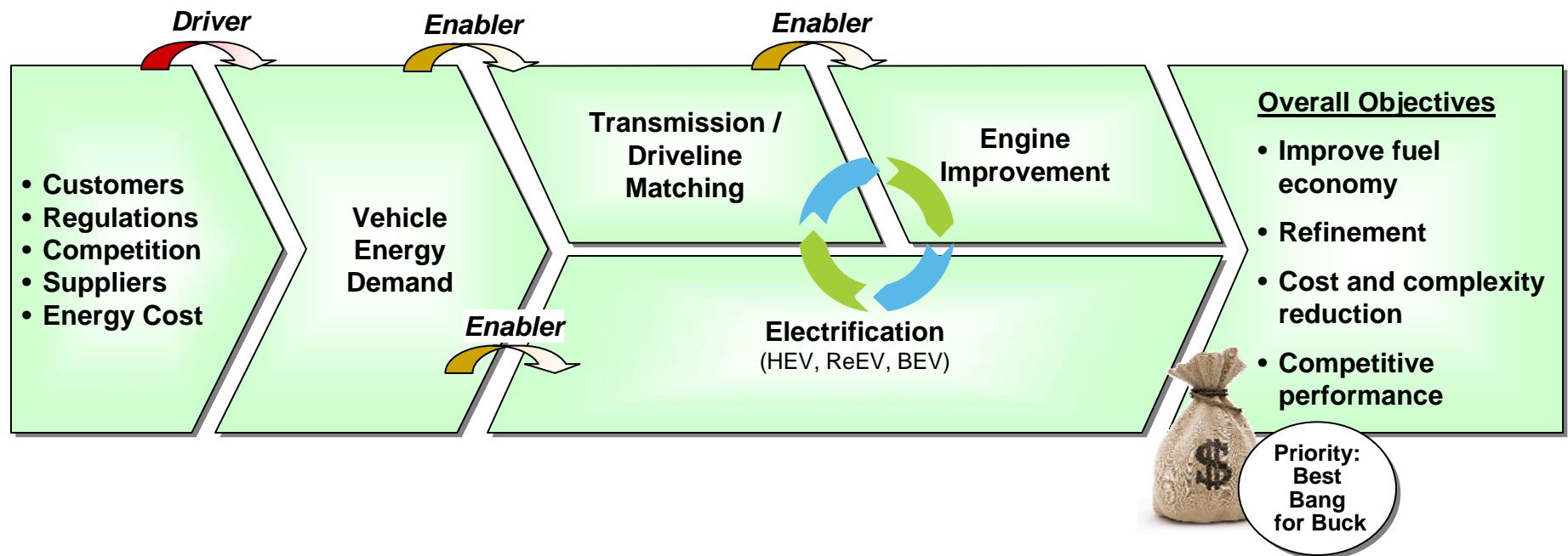
Overall Powertrain System Loss



The optimal solution is found in the minimal point of the sum of all losses



Pragmatic Model



- **Gains in propulsion efficiency are best built upon reduced vehicle energy demand, as it maximizes the impact of transmission matching and allows engine size and technology to be optimized.**

Summary

- Automobile energy efficiency can be viewed as the relationship between Vehicle Demand Energy and Propulsion Efficiency over a given drive cycle
- Increasing energy efficiency should be a total vehicle exercise requiring detailed improvements in both Vehicle Demand Energy and Propulsion Efficiency
- Reductions in Vehicle Demand Energy typically provide better "Bang for the Buck" and are synergistic with electrification scenarios
- Electrified powertrains require closer cooperation between the traditional mechanical and electrical disciplines to maximize energy efficiency

Thank You