Sustainable Energy Engineering

Mehrdad (Mark) Ehsani, Ph. D., P. E., F. IEEE, F. SAE

Robert M. Kennedy Endowed Professor,
Director, Sustainable Energy & Vehicle engineering Program,
Power Electronics & Motor Drives Laboratory,
Department of Electrical & Computer Engineering
Texas A&M University College Station, Texas 77843
Email: ehsani@ece.tamu.edu
Web address: http://www.ece.tamu.edu/People/bios/Ehsani.html

HEALTH WARNING:

THIS PRESENTATION

MAY CAUSE PERSISTING

NIGHTMARES

AND

DEPRESSION

The Biosphere

- Delicately balanced – conditions for life created by life
- Complex systems and feedback mechanisms, poorly understood
- Humanity now captures one quarter of primary productivity
- We lack management mechanisms at the planetary scale

Ecological Footprint

- Surface needed to supply the needs and absorb the wastes of an individual
- Global average 2.3 ha/person
- Italy 3.26 ha/person (lowest in western Europe), France 5.74 ha/person, Switzerland 5.26 ha/p.
- USA ~9ha/p
- Resources available 1.9 ha/person
- We overshot the earth's capacity in 1975
- Why don’t we feel this? Because we live in a developed country

http://www.globalfootprint.org/

http://www.ecologicalfootprint.org/

http://www.myfootprint.org

Human Society

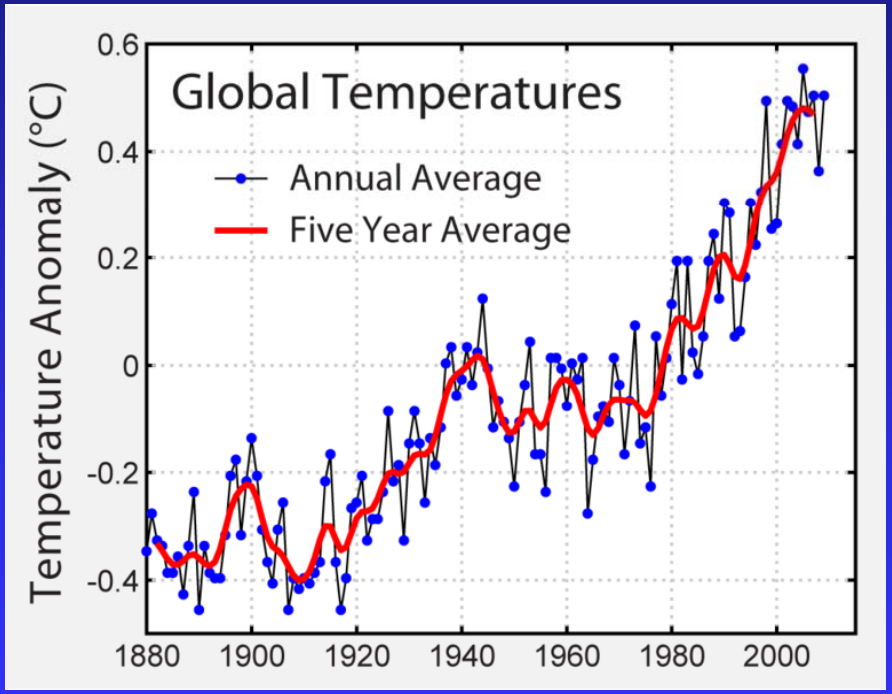
- The world population has tripled in one lifetime, and is expected by the UN to rise to 9.2 billion by 2050 before stabilizing
- By some estimates, world resources can only sustainably support 500 million people (at the US standards)
- We seem to be following a classic ecological pattern of overshoot and collapse (Malthusian growth)
- The present planetary carrying capacity depends on numbers versus standard of living; increasing one reduces the other
- Science & Engineering has to find ways to increase carrying capacity
- Greatest impact on the poor

Resources

- Many key materials are being exhausted rapidly (estimated years left: **predicted**/today's rate)
- Phosphorus (fertilizer) **142**-345
- Copper (wire, coins, pipes) **40**-60
- Zinc (galvanizing) **20**-46
- Hafnium, Indium (chips, LCDs) **5**-15
- Tantalum (cell phones, cameras) **20**-115
- Platinum (catalysts, fuel cells) **15**-360
- Silver (jewellery, catalysts) **15**-30
- Uranium (weapons, power stations) **30**-60

Global warming and the industrial activity

- Although it is clear that the earth is warming, the reason for it is still a point of controversy
- Global temperatures have been constantly rising since the industrial revolution, which suggests that this is the cause of global warming



http://en.wikipedia.org/wiki/File:Instrumental_Temperature_Record.png

Fossil Fuel Consumption and CO2 Emissions

- CO2 reduction is not a reliable motive for sustainable energy initiative because:
- Oil and other fossil fuels are fungible commodities: “If we don’t use it someone else will” and the developed world is about 5% of world population
- A vast majority of the world population is still economically developing and in need of more energy (China, India, Africa, etc.)
- This places indefinite demand on available fossil fuels

Hydrocarbon Resources on the Planet

- Estimated Total Hydrocarbon on Earth: 500 exaJouls
- Estimated Annual Human Energy Consumption: 0.5 exaJouls
- Enough Energy Resource for 1000 Years!
- "Stone age did not end because we ran out of stones"
- Transition from hunter gatherer of "wild energy" to "manufactured" or "cultivated" energy

Sustainable Energy
Must Be

- **Abundant**: no energy limits on human development and prosperity
- **Ecological**: renewable, environmentally benign
- **Economical**: reasonable capital and production cost, market driven
- **Transitional**: starting with the present infrastructure, smooth transition to future technologies
- **Global**: producible in the United States and elsewhere, eliminating international “haves and have nots”

Sustainable Energy
Must Be

- **Publicly Acceptable**: compatible with the public sense of risk, aesthetics, ethics, etc.
- **Unifying**: compatible with the sense of world economic equity and word community
- **Robust**: not prone to failures, not maintenance intensive, no single-point failures
- **Secure**: not concentrated, volatile, vulnerable to terrorism

A Vision of the Solution in the Transportation Sector

An integrated bioengineering and vehicle engineering approach is needed to truly solve the transportation fuel problem

Fundamental Vehicle Fuel Facts

- Energy Content in a Gallon:
  - Diesel fuel: 128,700 BTU
  - Biodiesel (B100): 117,093 BTU
  - Ethanol (E85): 81,844 BTU
  - Ethanol (E100): 75,670 BTU
  - Lithium-Ion Battery: 3,600-7,200 BTU (est.)
  - Nickel-Metal Hydride Battery: 1,300-1,800 BTU

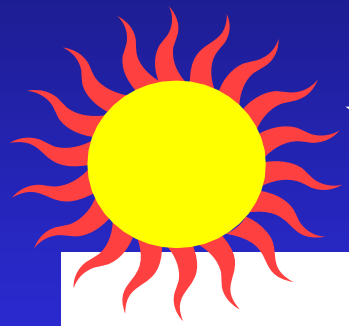
Fundamental Vehicle Fuel Facts

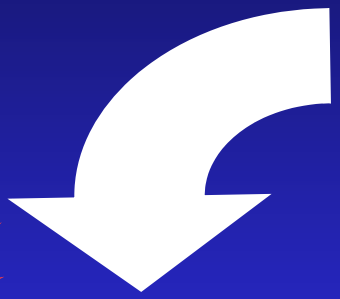
- **Hydro-carbon fuel + ICE is superior to:**
  - **chemical battery + electric motor (EM)**
  - **hydrogen + fuel cell + electric motor**
- Reasons:
  - Hydro-carbon fuel oxidant, O2, is externally available
  - Liquid hydro-carbon fuel-ICE is dense in weight & volume
  - ICE combustion produces direct mechanical power
  - No “ideal” chemical battery + EM can deliver the same range + performance as the liquid hydro-carbon fuel + ICE
  - No practical hydrogen tank + fuel cell + (battery) + EM can deliver the same range & performance as the ICE system
  - ICE power plant can be hybridized to benefit from battery advancements and EM low speed torque, for fuel efficiency

A Solution

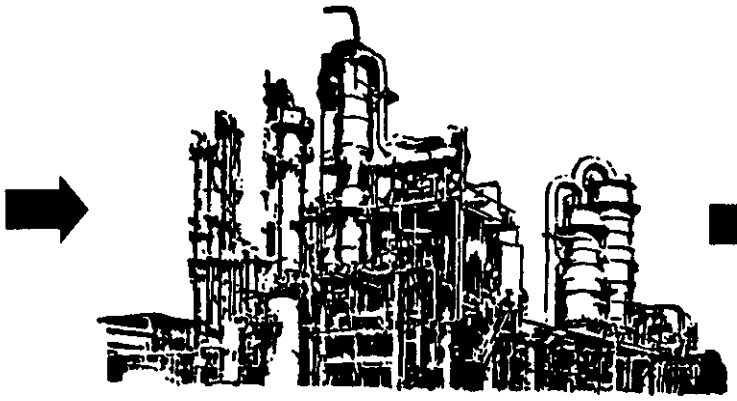
- "Biofuel-ICE-HEV" Transportation System
- The key technologies needed:
  - Biofuels
    - Address the Fossil Fuel Issue
    - Address the Global Warming Issue
  - Hybrid Electric Vehicles
    - Increase the fuel efficiency

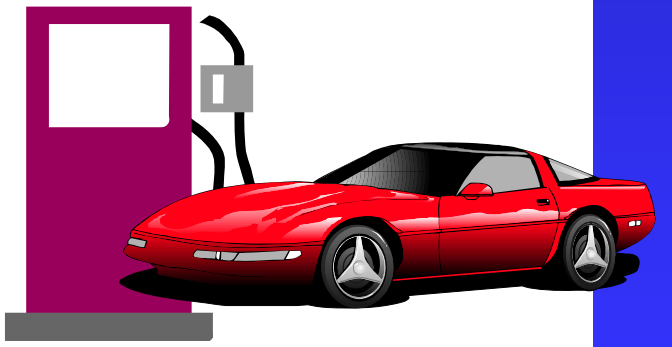
Sustainable System





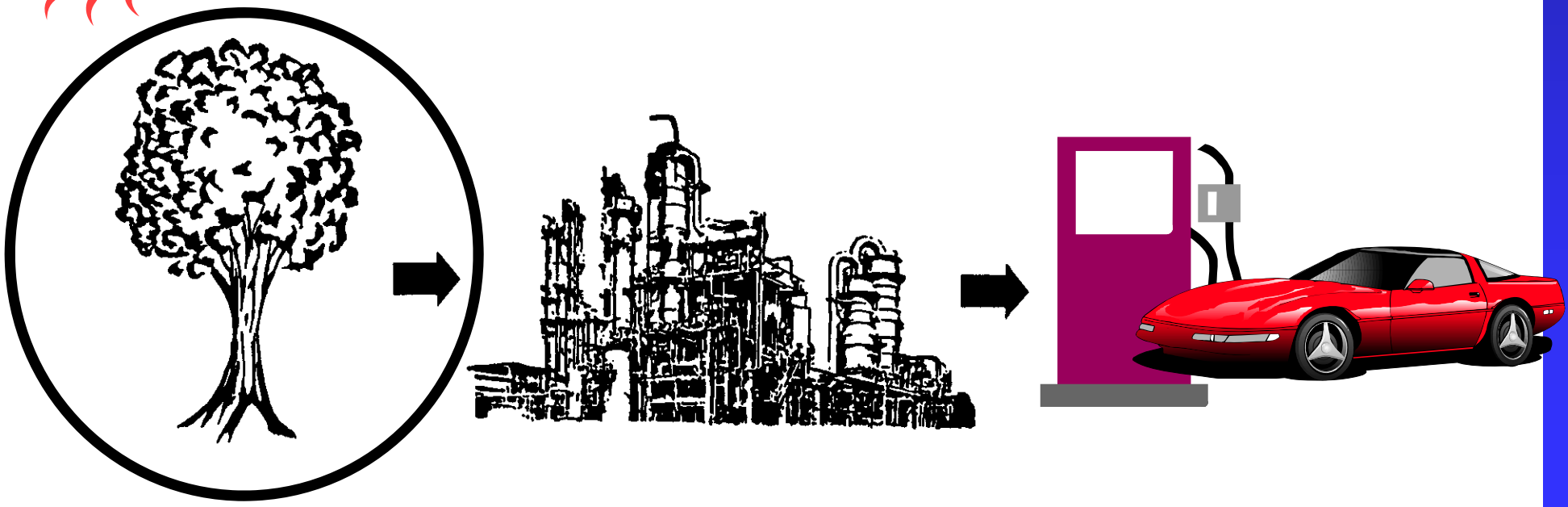
CO_2





Feedstock

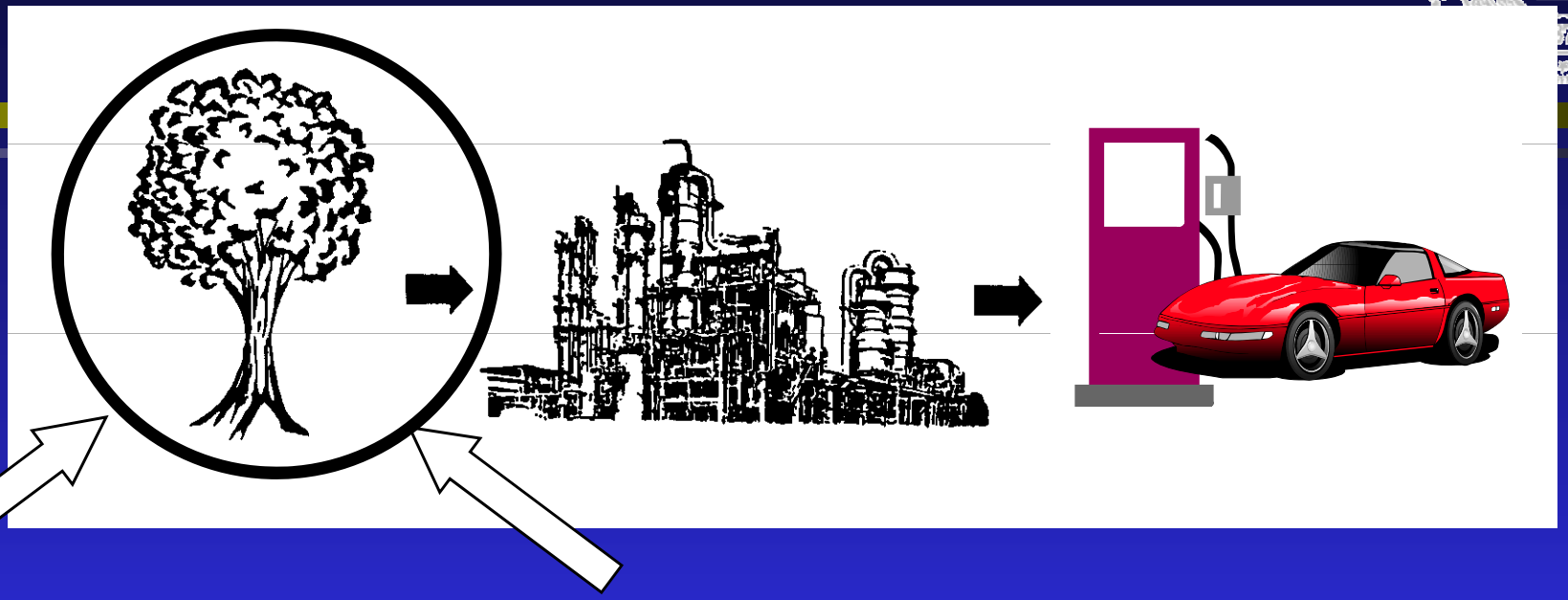
CO_2



Biofuel facts

- Supermarket and service stations competing for the same resources
- Grain required to fill a 25 gallon ethanol gas tank can feed a man for a year
- Over 60% of US Corn Used for Ethanol
- It takes 2/3rd gallons of oil to make the energy equivalent of one gallon of ethanol from corn

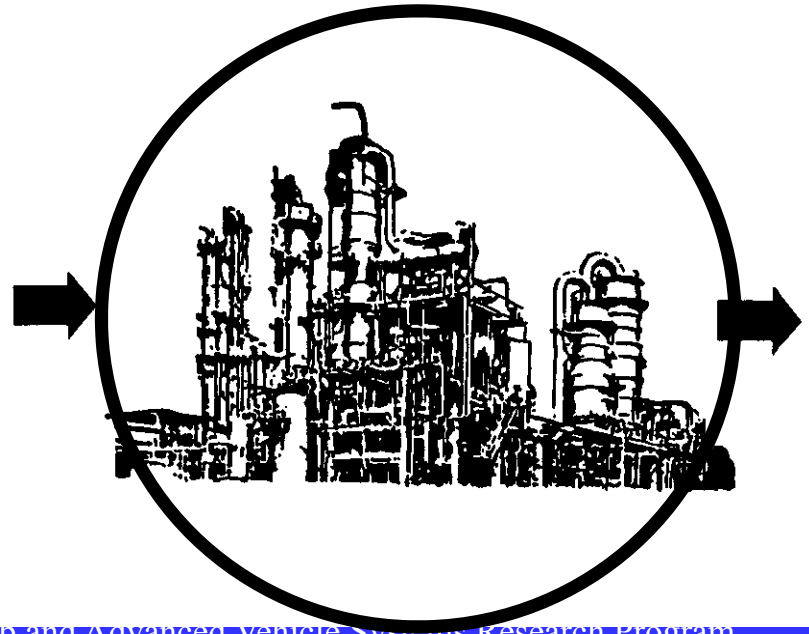
Multiple Feedstocks

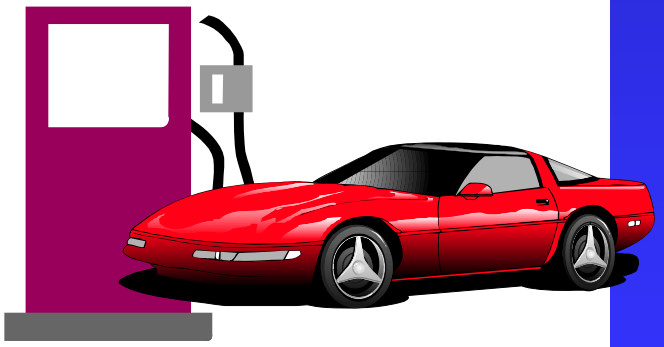


- trees
- grass
- agricultural residues
- energy crops
- municipal solid waste
- sewage sludge
- animal manure

Process

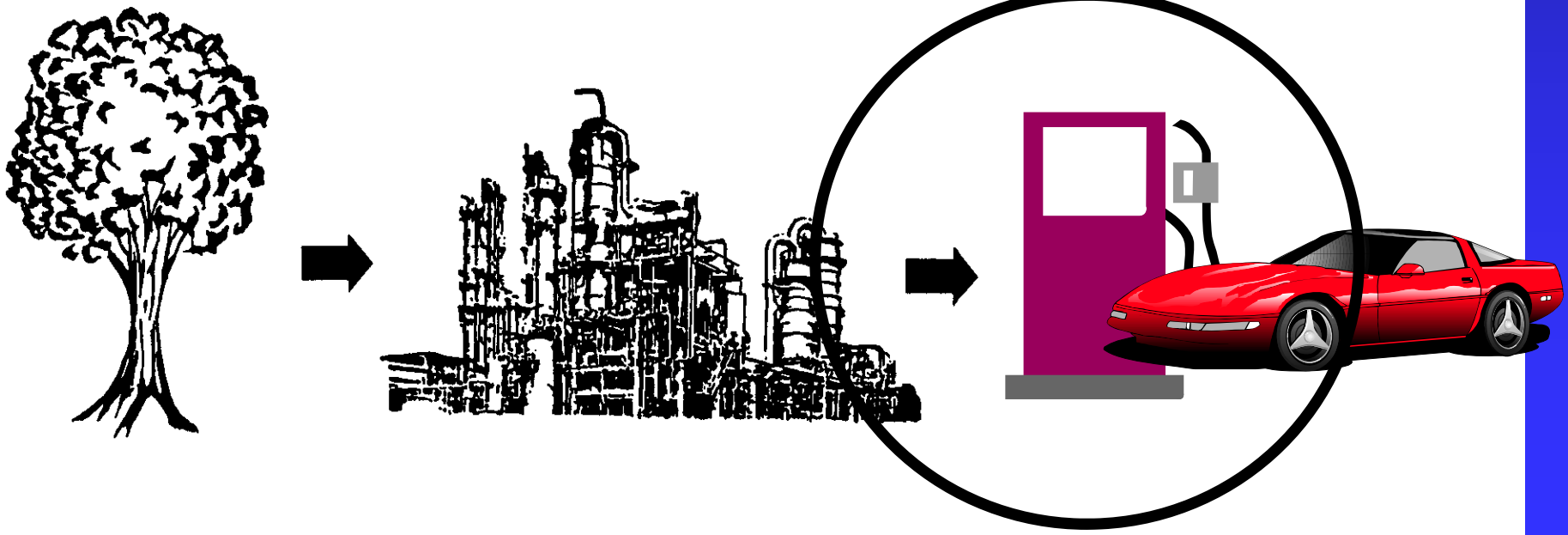
CO_2





Vehicle

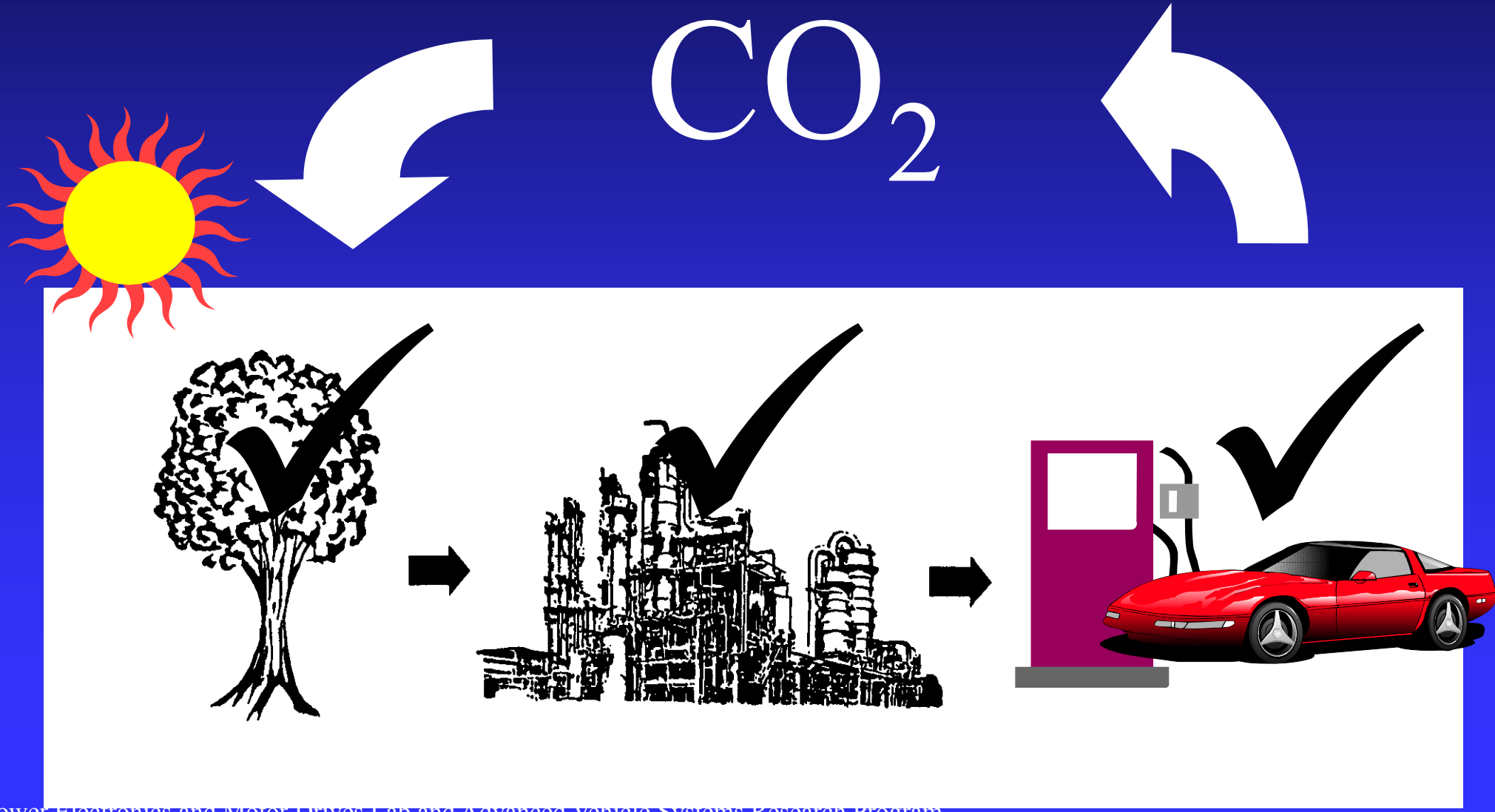
CO_2



We Can Make Hybrids Sustainable: Advanced Hybrid Electric

- Gateway to dual power plants
  (Advanced ICEs, fuel cells, etc.)
- Gateway to electronic innovations
- Gateway to vehicle design innovations
- Gateway to advanced safety systems
  (Remote control, telemetry, IVHS, etc.)
- Gateway to sustained technical and economic growth for automotive industry
- Gateway to new start up companies and industries

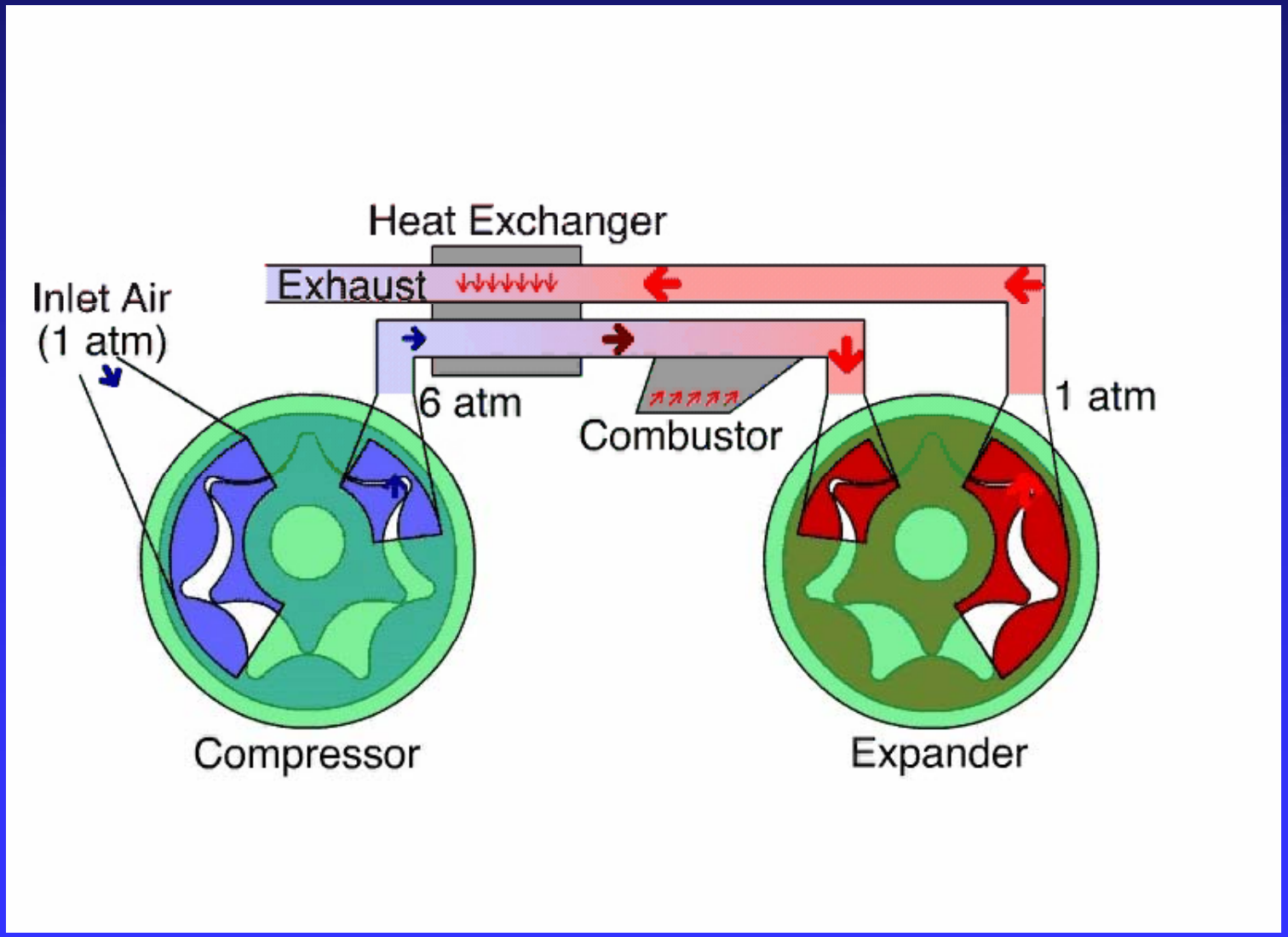
Total Solution:
A New Vehicle-Energy Industrial Complex



New Technologies

- Biofuels
- StarRotor engine
- Hybrid electric vehicle

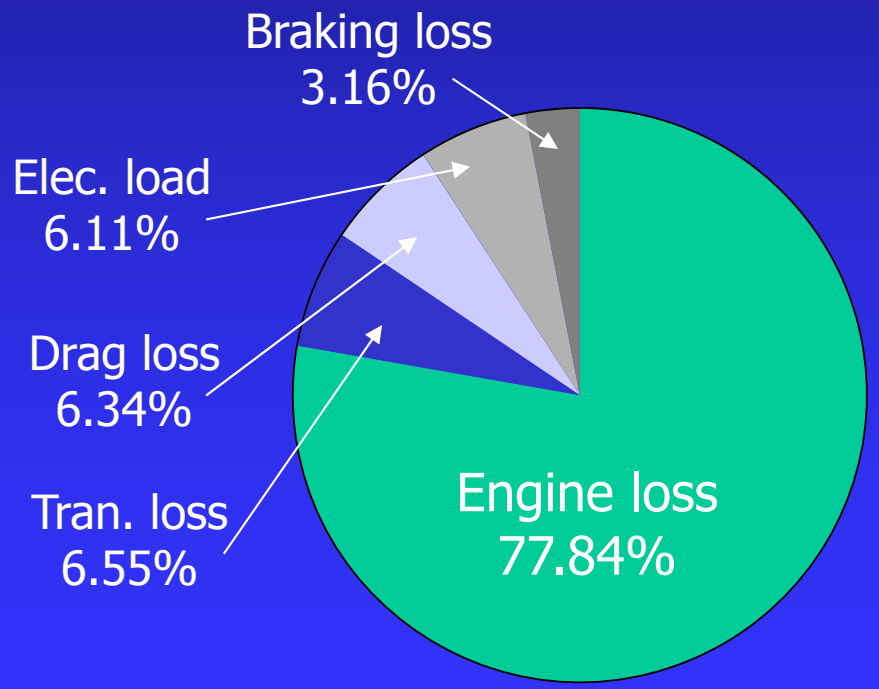
StarRotor Engine



Advantages of StarRotor Engine

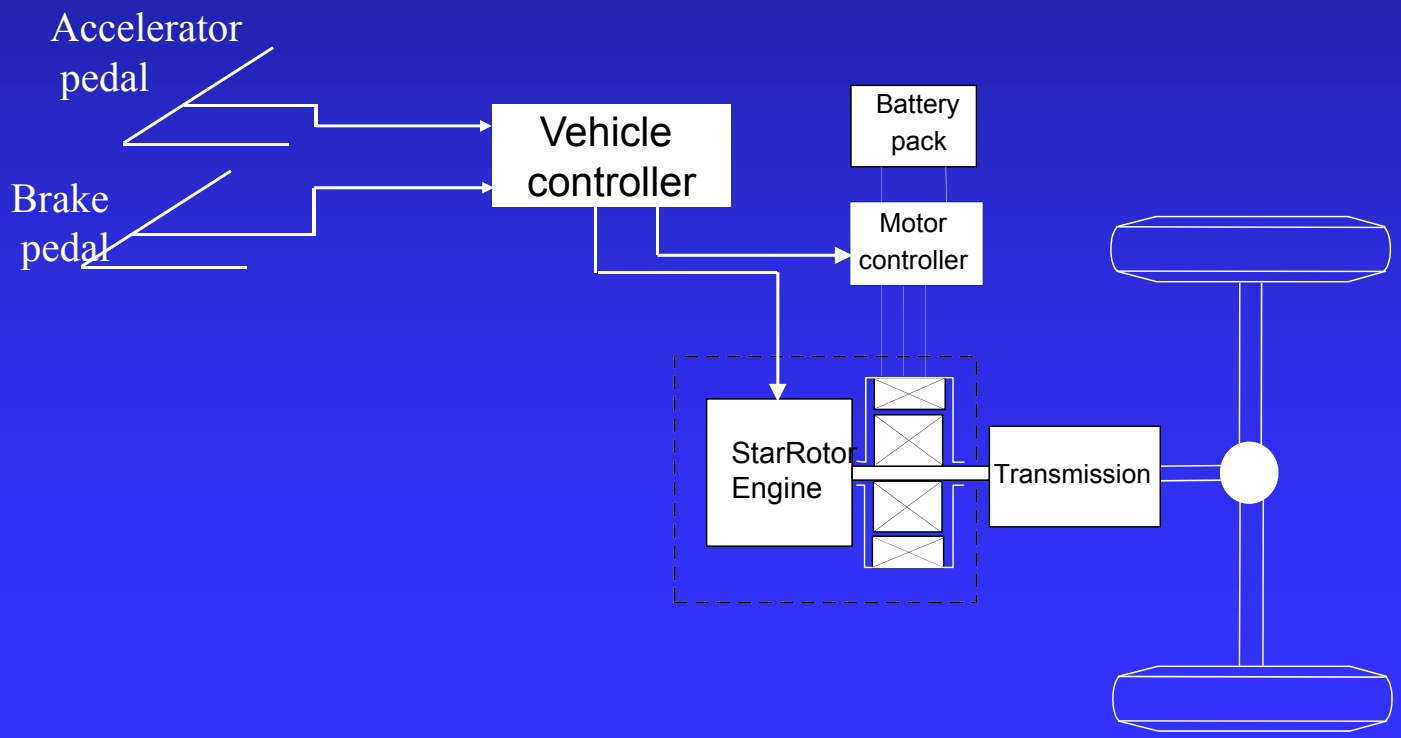
- High efficiency
- Low pollution
- Compact
- Multi-fuel
- Low cost
- Low maintenance
- Long life
- Smooth

Conventional Automobiles



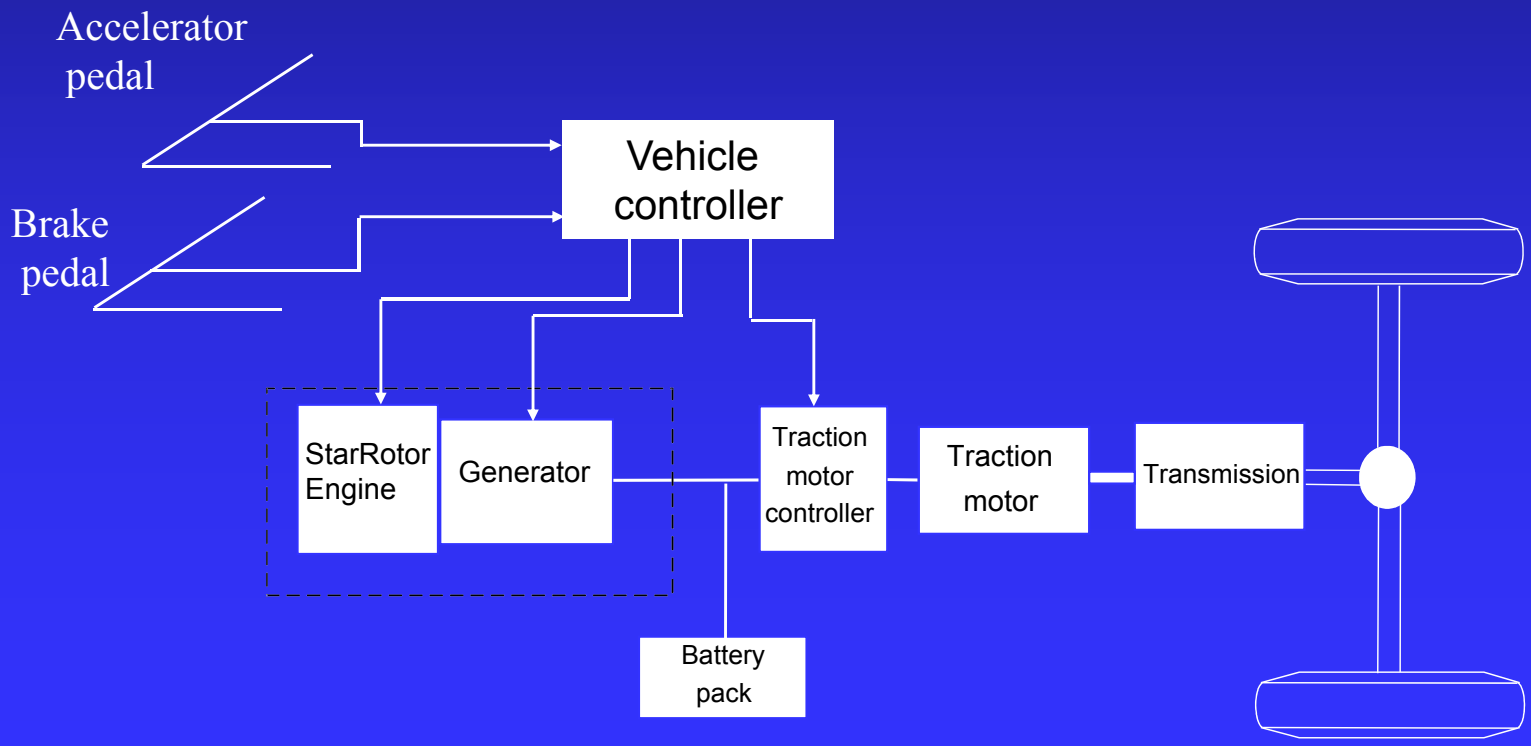
Parallel Hybrid

- Single shaft parallel hybrid drivetrain
  - Only one electric machine is needed
  - Lower losses because of the direct propulsion by the engine

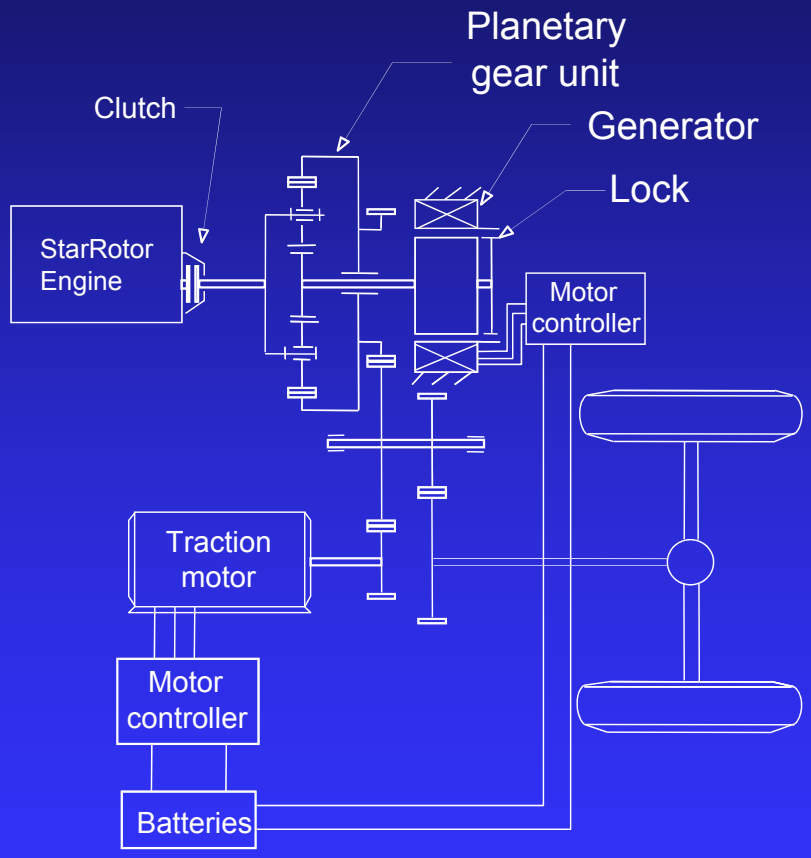


Series Hybrid

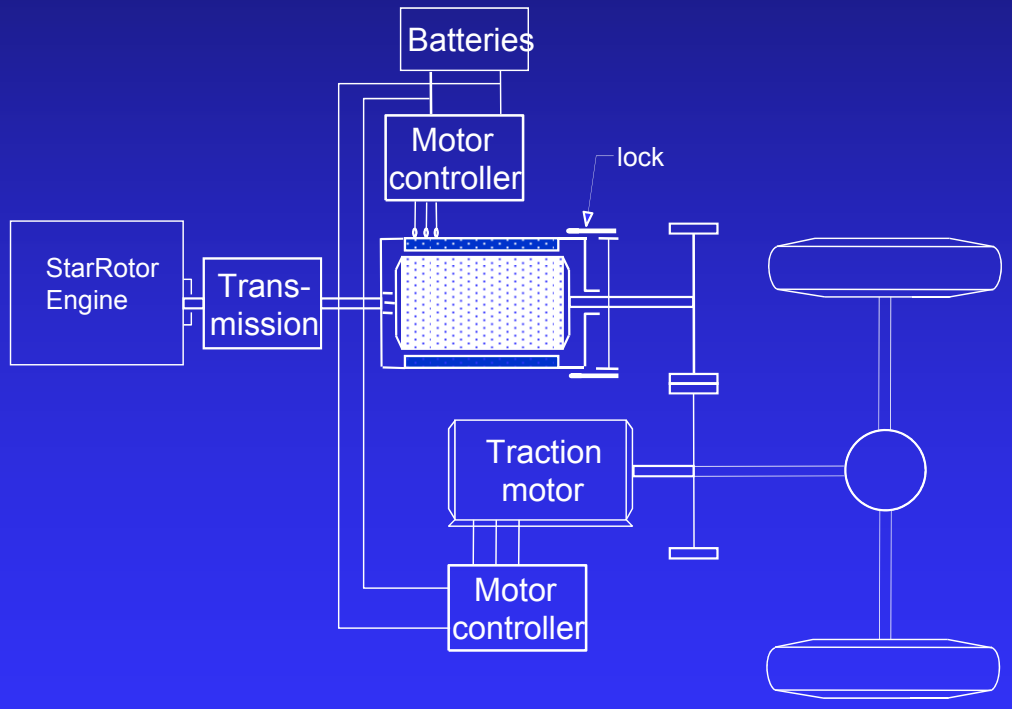
- Series hybrid
  - Mechanically decoupled engine from wheels
  - Engine operating points ARE SELCECTABLE



Series-parallel Hybrid



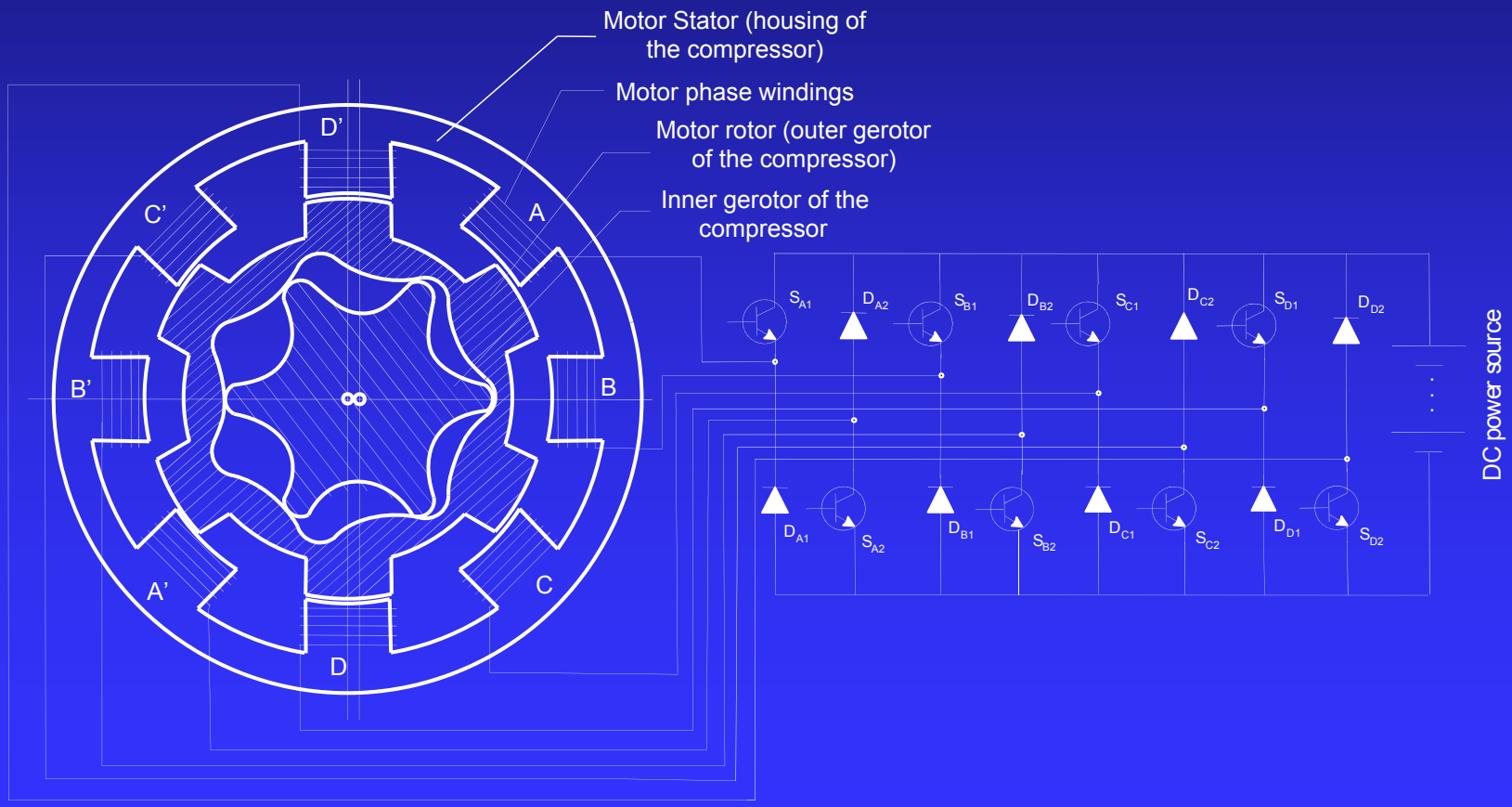
Toyota Prius



Texas A&M Transmotor

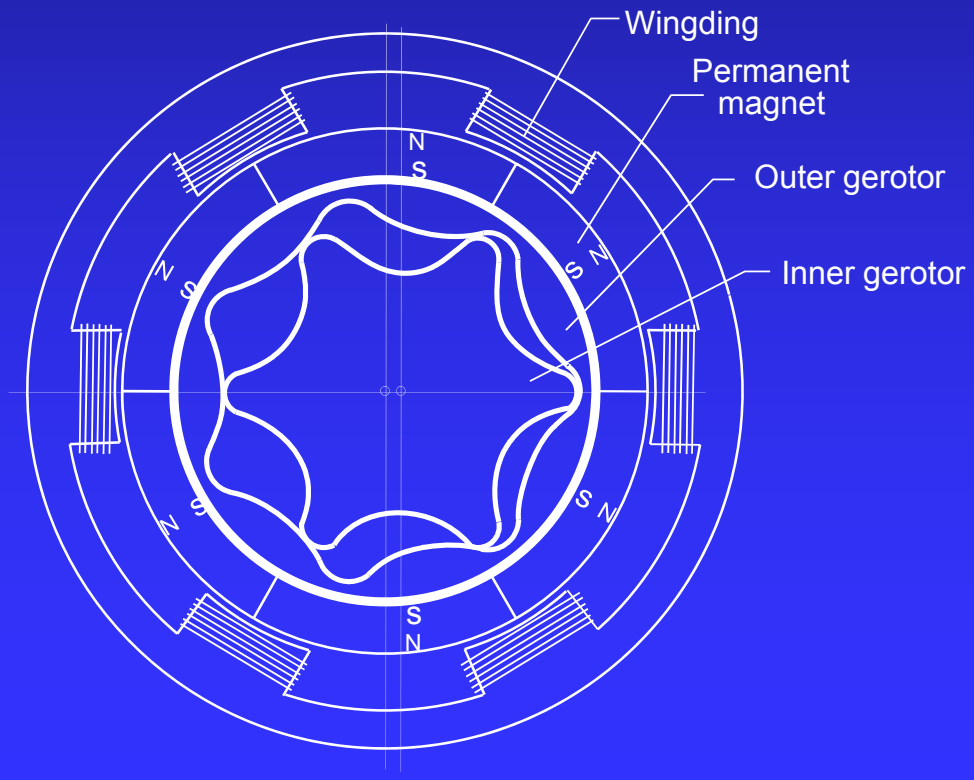
Integrated star rotor engine with electric motor/generator ----More compact structure

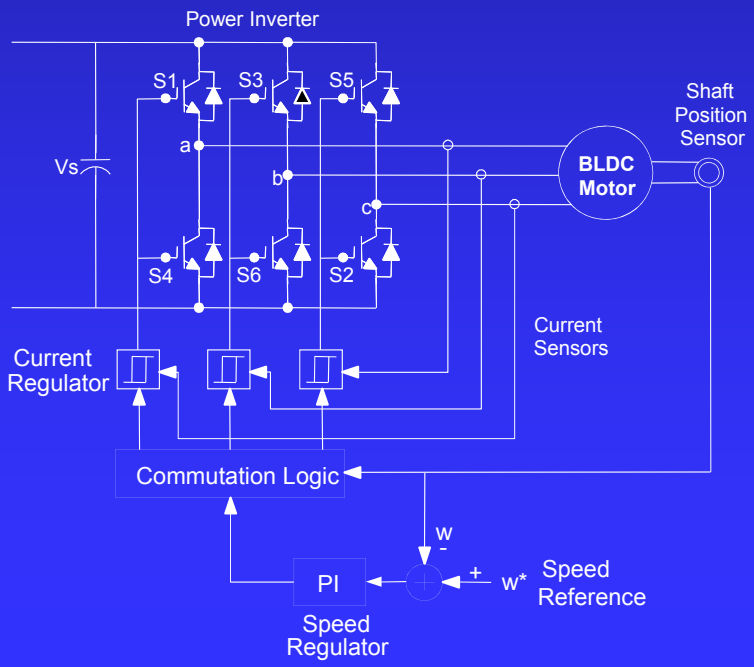
- Integrated with SR motor/generator



Integrated star rotor engine with electric motor/generator ----More compact structure

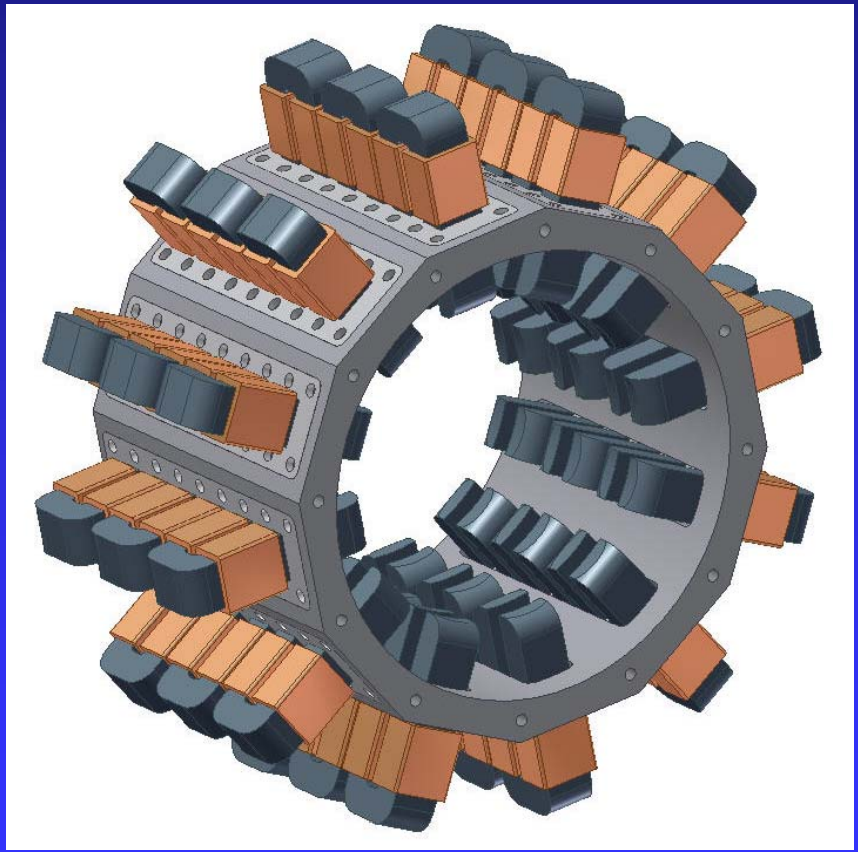
- Integrated with BLDC motor/generator





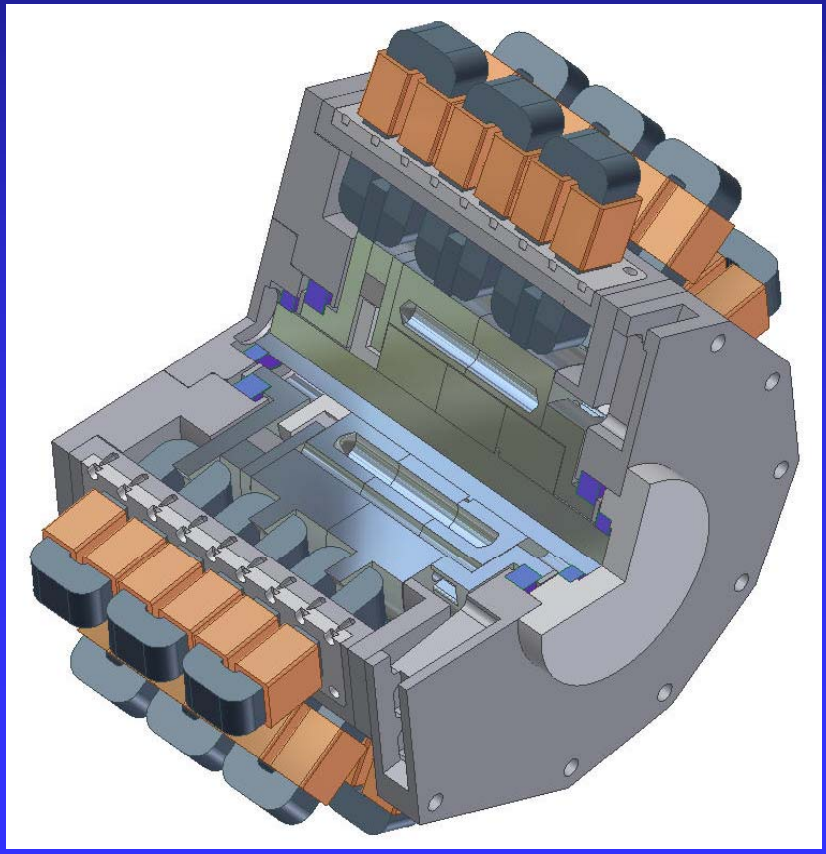
Integrated star rotor engine with electric motor/generator ----More compact structure

- Stator with cartridge style pole banks



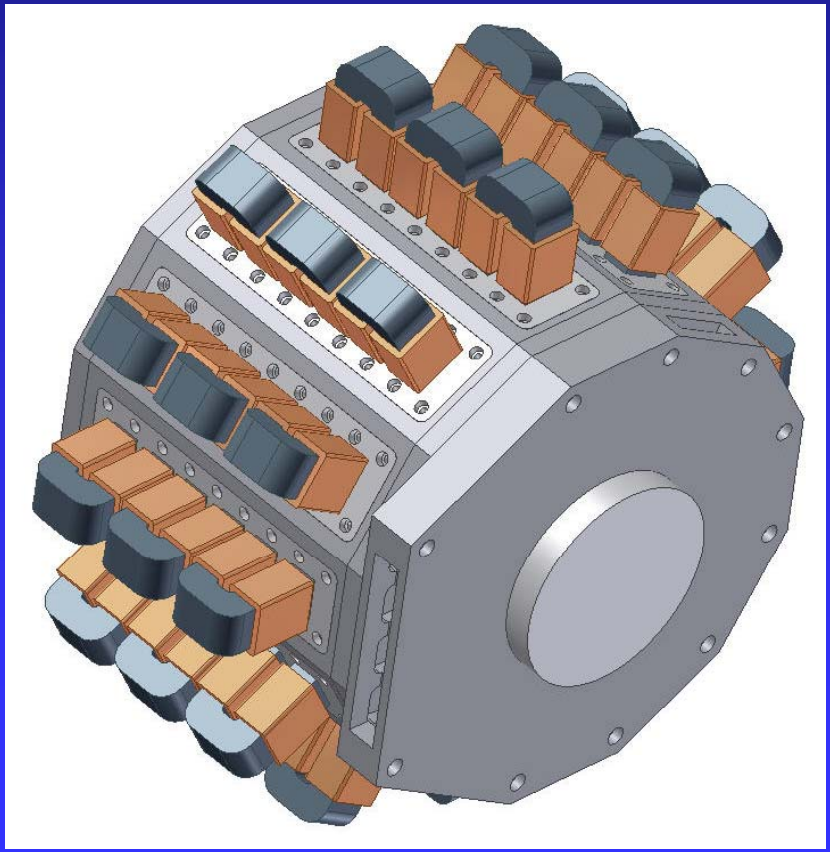
Integrated star rotor engine with electric motor/generator ----More compact structure

- Cutaway of full assembly



Integrated star rotor engine with electric motor/generator ----More compact structure

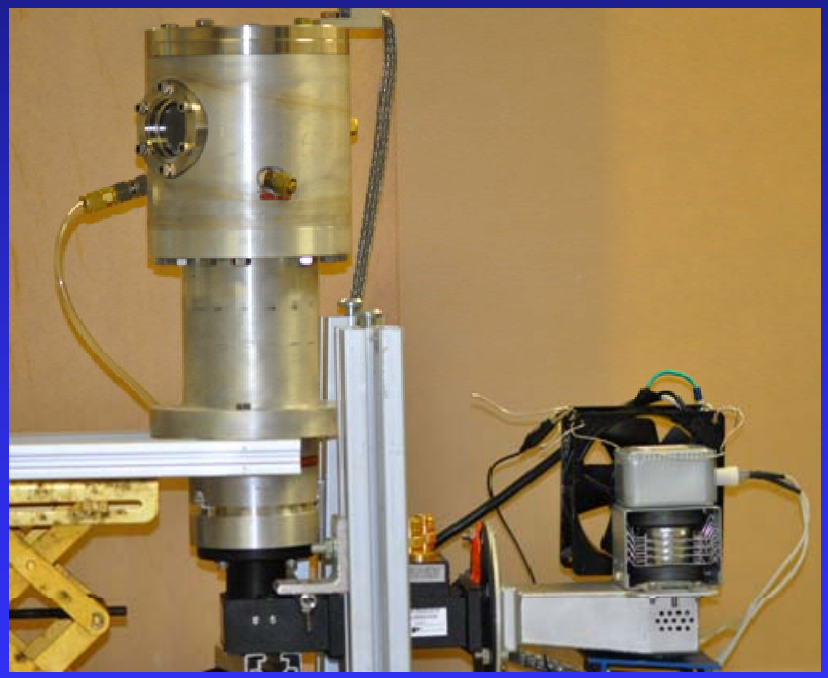
- Full assembly

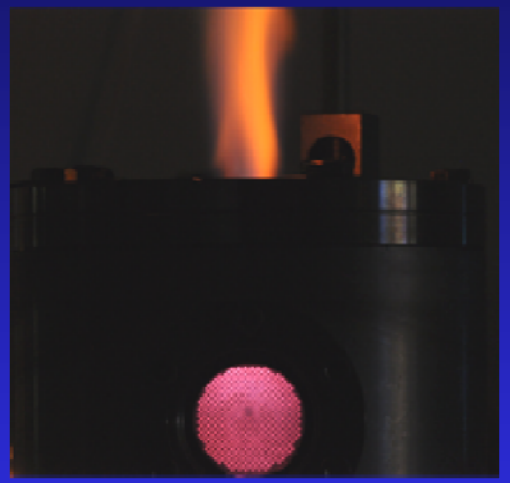


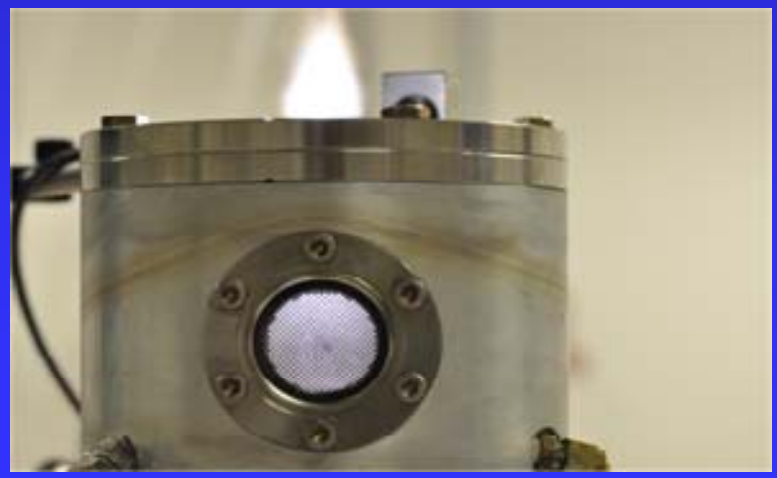
Cold Plasma Reformer Technology

- Burning hydrogen rich fuel can greatly improve ICE fuel efficiency
- Studies show 39% - 40% increase in engine efficiency with as little as a 7-10% hydrogen mix
- High ICE operating efficiency leads to higher miles per gallon and lower emissions, including a decrease in nitrogen oxides
- Production of hydrogen on board and on demand using bio-sustainable fuels and/or conventional fuels
- Applicable to fuel cell engine as well

Cold Plasma Reformer Technology







Jevons Paradox

- Efficiency has been called the fifth fuel (after coal, petroleum, nuclear, and renewables) a cost-free tool for sustainable energy economy
- The first fuel economy regulations for US cars in 1975 were followed by a long term rise in fuel consumption as well as increases in engine power, curb weight, vehicle miles traveled (up 100% since 1980 alone), number of cars (we have 50 million more cars than licensed drivers!)
- A growing number of economists and others have argued that efforts to improve energy efficiency can more than negate any environmental gains due to faster increase in consumption: an idea that was proposed 150 years ago (1865) and is known as the Javons paradox
- Javons stated that *"It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth."*

Jevons Paradox

- Increasing energy efficiency is equivalent to increasing the productivity of energy
- Increasing the productivity of anything is equivalent to reducing its implicit price
- With fixed real energy price, energy efficiency gains will increase energy consumption above where it would be without these gains
- This means that the demand goes up

Jevons Paradox

- Example: The UK, like many other countries, has increased energy efficiency in an attempt to reduce greenhouse emissions. Yet, energy consumption and carbon output in Britain, as in the rest of the world, has continued to rise.

- Between 1993 and 2005 the US energy efficiency of residential air conditioning equipment increased 28%. But the energy consumption of A.C. by the average air conditioned household rose 37%

- As a consequence the US uses as much electricity for cooling as it did for all purposes in 1955.

Transportation Fuel Picture

- US Daily Oil Consumption: Approx. 20 M bbl/day
- US Imported Oil: Approx. 50% or 10 M bbl/day
- US Oil Consumption for Transportation: 70% or 14M bbl/day
- US Oil Imports can be Wiped Out by Transportation Fuel Reduction of 10M bbl/day or 10Mbbl/Mbbl14 = 71%
- Equivalently Bringing Transportation Fuel Consumption To 29% Of The Present Values
- Example: Redesigning current 20 mi/gal car to give 69 mi/gal; or a 30 mi/gal car to give 103 mi/gal
- For road vehicles this is technologically possible

Jevons Paradox at Work

- However, Jevons Paradox wipes out all of the fuel savings, from efficiency improvements, and then some
- This is due to the reduction of effective fuel cost reduction per mile driven resulting in more miles driven
- This is a fundamental law of supply and demand
- For Jevons Paradox not to wipe out the fuel savings effect of vehicle fuel efficiency improvement the effective cost of fuel per mile must remain the same
- This means improving the fuel consumption by 3.4 times (71%) must accompany a 3.4 times rise in fuel cost
- This means gasoline must rise to $12/gal and oil must rise to $344 bbl !

Conclusions

- "Sustainability" must be defined more rationally and holistically
- "Global warming" is not a reliable motive for sustainable energy initiative because oil and other hydrocarbon fuels are fungible commodities
- Shortage of fossil fuels is not a reliable motive for sustainable energy initiative because of the availability of 1000 years of hydrocarbons and the ever advancing technologies of accessing them.
- For example, we have over 300 years of coal in the US, over 120 years of natural gas (fracking) and over 300 years of unconventional oil in US and Canada

Conclusions

- "sustainability" must be motivated by other sound principles
- Equitable World Energy Access
- World Political Peace
- Population Control and Human Development
- Critical materials shortages