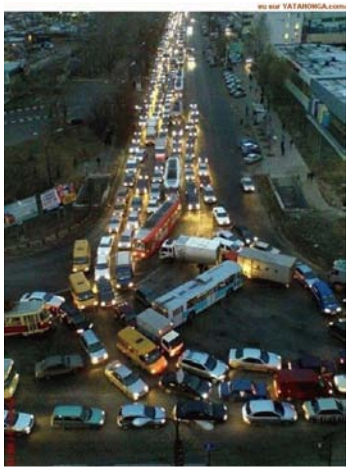
Energy efficiency in transportation:

…a key element of the world's energy future…



…and so is much of the rest of the world…

Weizmann Institute

January 9. 2012

Updated August 23, 2012

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Energy efficiency in transportation:

…a key element of the world's energy future…

…and so is much of the rest of the world…

Energy is a non-recyclable resource.
Use it and it is gone.

Dr. Fred Schlachter

Lawrence Berkeley National Laboratory

American Physical Society

Thailand Center of Excellence in Physics

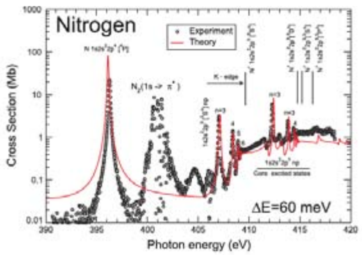
USAID Eco-Asia

Who I am…

Atomic and molecular physics. Particle accelerators. Synchrotron radiation.

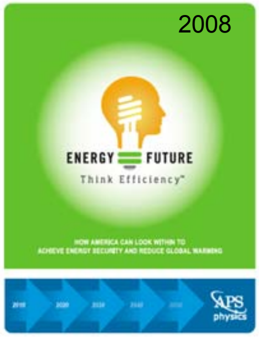
Energy efficiency. Transportation. Renewable resources.

Public outreach and education. Radiation, mobile phones….



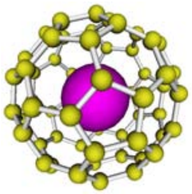
"K-shell x-ray spectroscopy of atomic nitrogen."

Physical Review Letters 2011



"Are microwaves the new tobacco?"

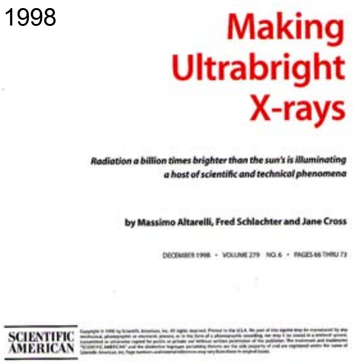
2011



"Photoexcitation of a volume plasmon in C_{60} ions."

Physical Review Letters 2005

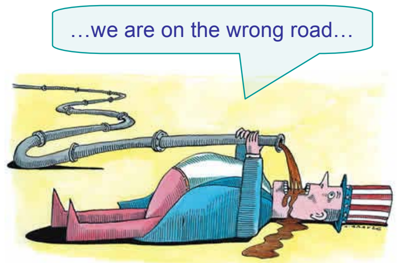
1998



Energy efficiency in transportation: outline

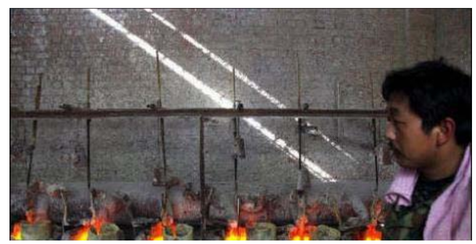
- Energy resource issues

Source (renewable?) of energy



- Technology issues

Science and technology needs



- Social/political issues

Economic/political/policy needs

Transportation and energy: key points

What stands in our way on the path to a brighter energy future?

- Energy **resource options** limited…
- **Fossil fuels** not a viable path…
- **Renewable** sources generally intermittent, thus…
- Energy **storage**: a key technology.
- Energy **efficiency** best approach.
- **Barriers**: public apathy, perceived cost, short-term thinking, poor urban planning, political divisiveness, lack of political will…

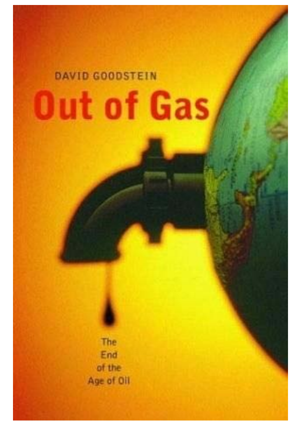
…our task is to make energy efficiency convenient and inexpensive…through science, technology, and policy….”…making it easy to do the right thing…”

Our security is threatened

Fighting …

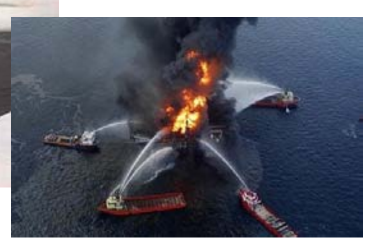
Economy…

Running out of oil…



Climate change, pollution





Turning food into fuel …


There are only four sources of energy on earth

Primary sources of energy:

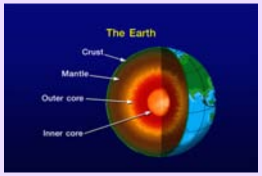
- sun

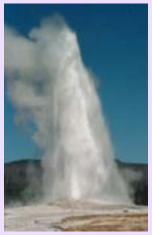
active

stored

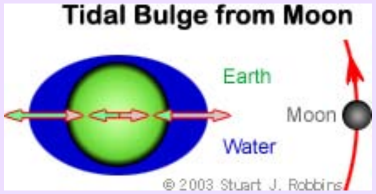
- nucleus

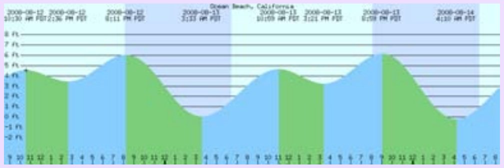
- geothermal (heat in earth)





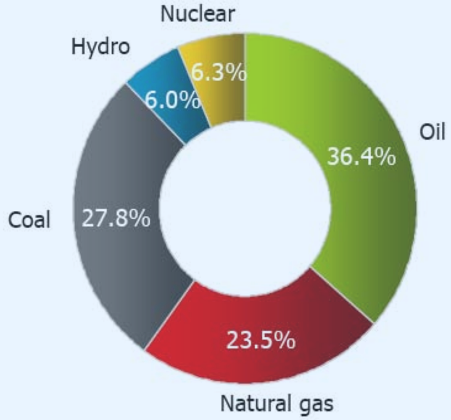
- gravity/moon (tide)





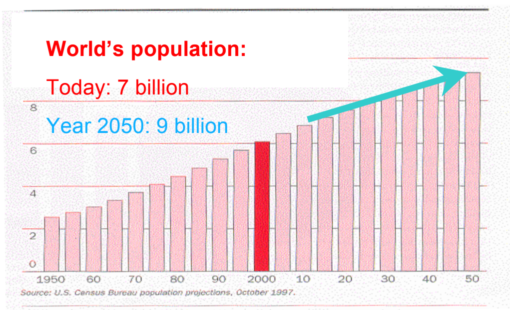
Global energy use:

88% fossil fuel

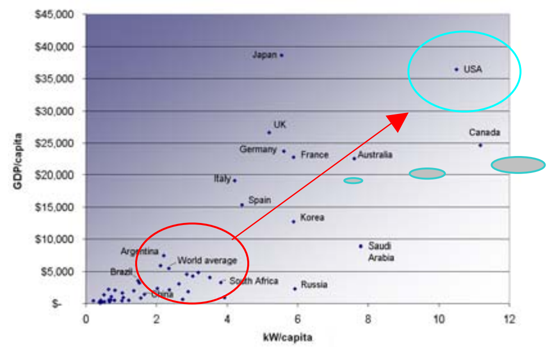


Reasons for worldwide energy problem

Demographics: population increasing

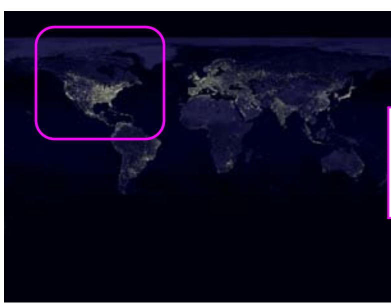


Economy: energy use increases with GDP



Everyone want to live like people in rich countries

Consumption: rich countries use too much energy

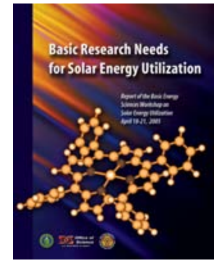


United States:

5% of the world's population

25% of the world's energy use.

Energy resources are not uniformly distributed



Using solar energy

- Making electricity directly (photovoltaic)

Produce electricity

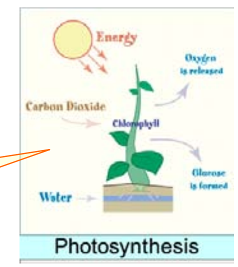
Produce hot water

- Using and storing the sun's heat (thermal)

Produce electricity

Storing energy in molten salt

Produce plants



- Storing the sun's energy in chemical bonds (photosynthesis)

<u>Issues</u>: Capital cost and efficiency

Energy capture: heat, electricity, chemical bonds

Energy conversion electricity is most useful

Energy storage* sunlight is intermittent

**key technology*

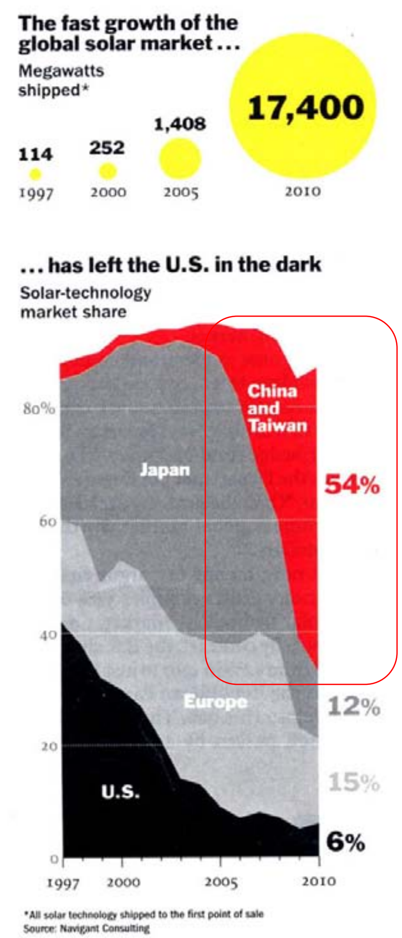
More energy from sunlight hits the earth in an **hour** than all the energy consumed on the planet in a **year**.

Solar energy: two issues

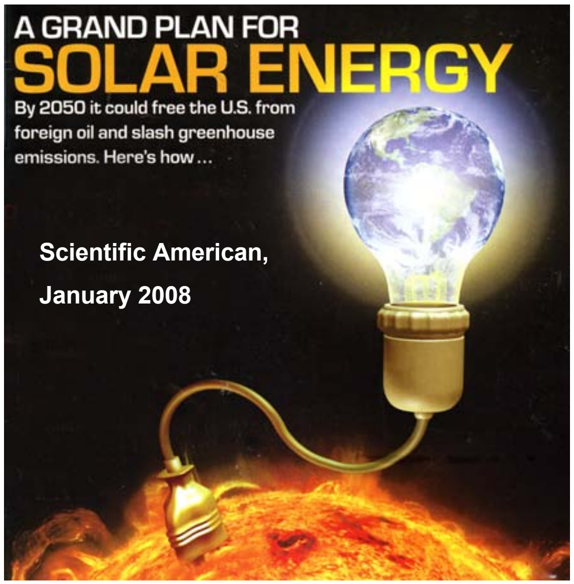
Key technology: energy storage

…the sun is not always shining…

Solar market growing: dominated by China



Utilization of solar energy: industrial scale



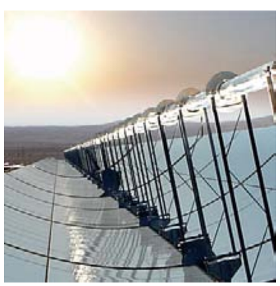
No one knows if this is sensible.

GRAND PLAN:

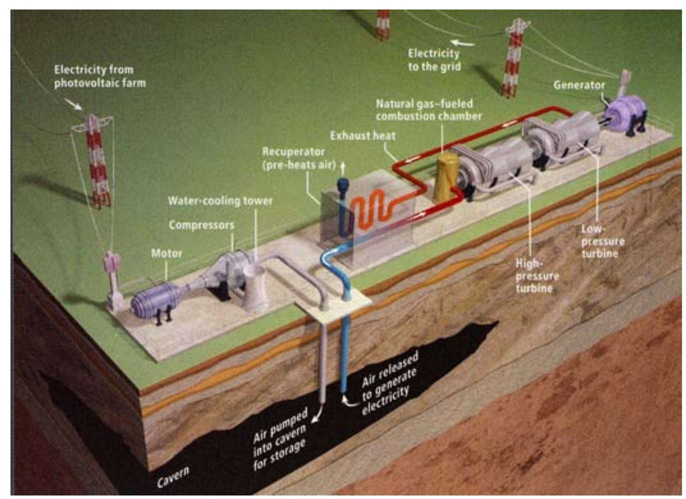
Generation: Solar thermal and photovoltaic arrays over 100,000 km^2 (60,000 square miles) in the desert generate 70% of electricity needs of U.S.

Storage: Energy stored by compressed air stored underground.

Cost: $500B (?!)



Energy storage by compressing air: *likely not feasible.*

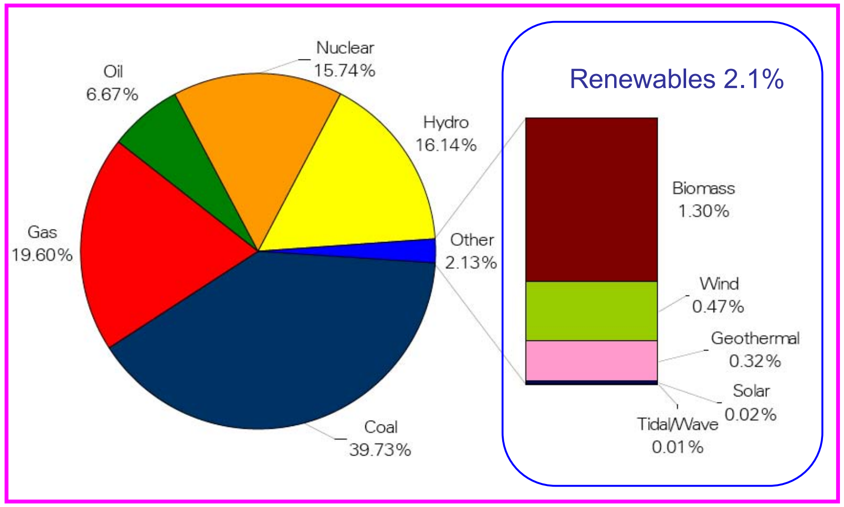


Electricity? Not an energy source

Electricity is not a primary source of energy:
we make electricity in a power plant.

Electricity is a means of getting energy from one place to another.

Electricity primarily from fossil fuels, nuclear, and hydroelectric



Transportation: three major issues

Vehicles

Technology:
easiest problem

Fuels

New fuels: technology
plus infrastructure
difficult problem

- *Primary source*
- *Storage*

Mobility

Markets, sociology,
urban planning, politics,
economics, human behavior:
very difficult problem

Fuel efficiency, fuel economy I

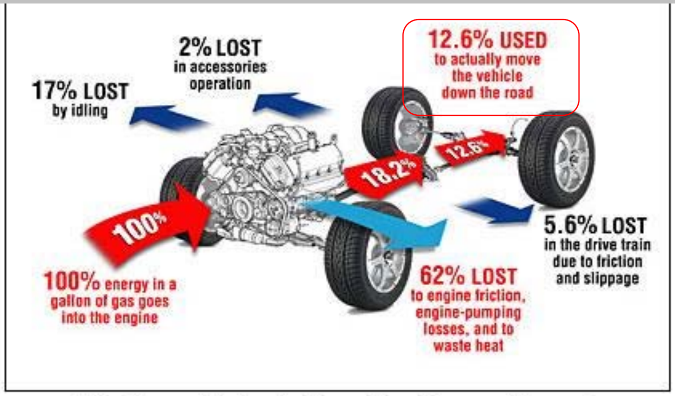
Fuel efficiency: fraction of energy content of fuel used to move vehicle.

Fuel efficiency for a car powered by an ICE is only 12.6% and it improves only 2-3% per year.

Fuel economy: vehicle miles per gallon of fuel (liter/100km)

Fuel economy is significantly impacted by vehicle weight and power.

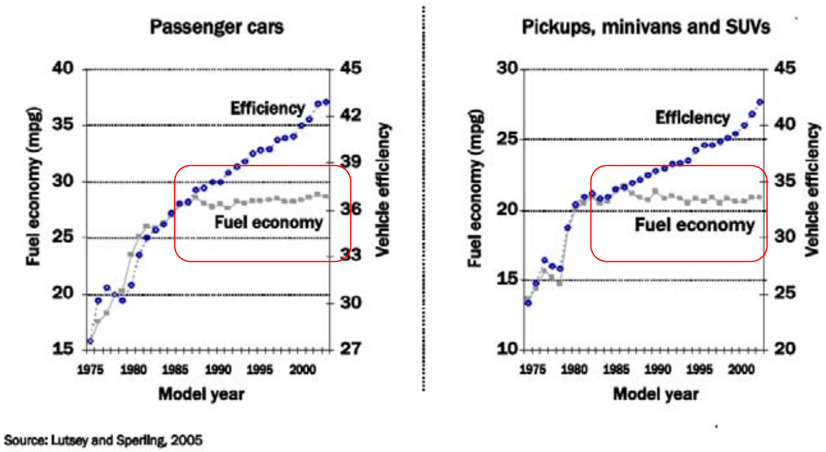
Fuel *efficiency* of a car driven by in internal combustion engine is12.6%.



Most of the energy in gasoline goes into heat, not into moving the car.

Fuel efficiency improves 2-3% percent per year.

Fuel *efficiency* improves with time while fuel *economy* has been stagnant (US) until 2010.



Fuel economy in US did not improve during 20 years due to increases in weight and power of cars.

"Fuel economy" for Corporate Average Fuel Economy (CAFÉ) standards does not correspond to actual fuel economy.

The 2012 Honda Fit must achieve a CAFÉ fuel economy of 36 mpg (6.5 l/100km) equivalent to an actual driving fuel economy of 27 mpg (8.7 l/100km).

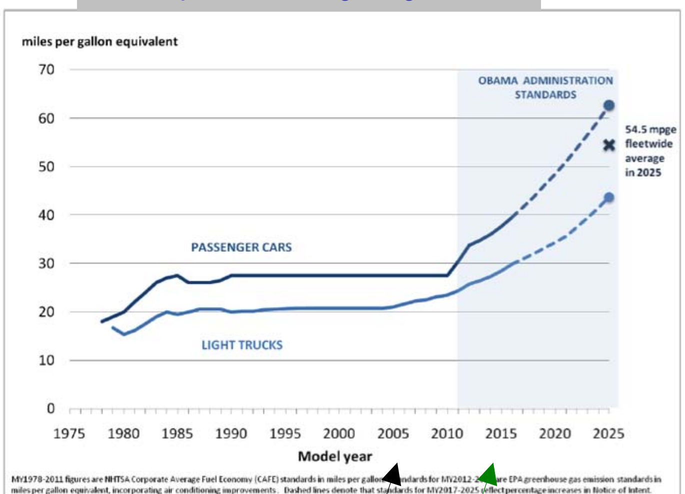
Arab oil embargo 1973

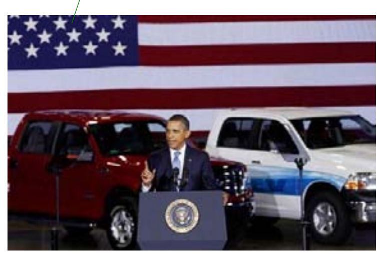
Fuel efficiency, fuel economy II

Improvement finally!

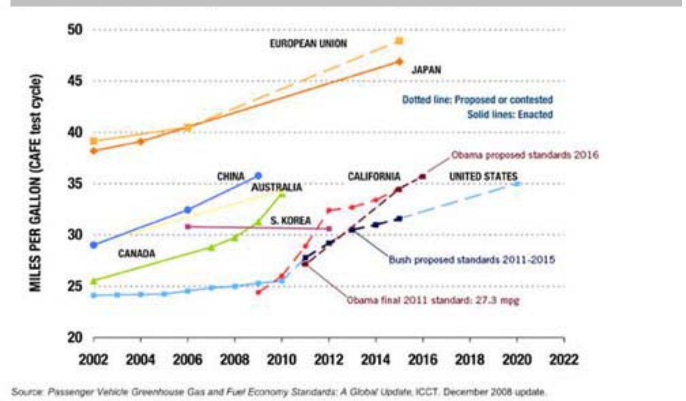
Improvement in light-duty-vehicle fuel-*economy* standards beginning in 2010

Update Dec 2011



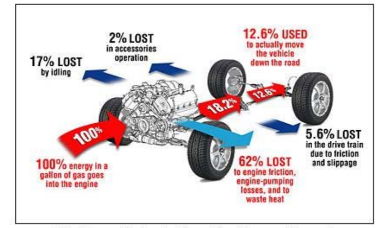


Every country in the world has better fuel economy than the U.S.



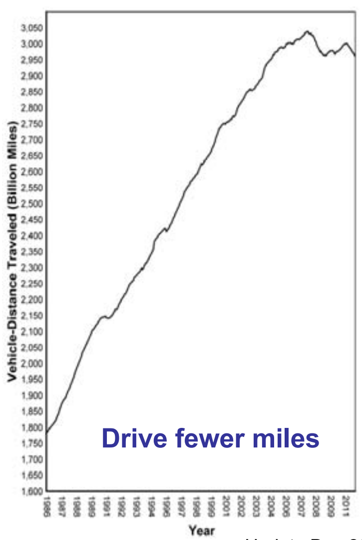
What can we do about cars?

- Drive fewer miles: carpools, public transit, land-use planning
- Make cars lighter and smaller and less powerful: stronger materials
- Make cars more efficient…like a Prius or other hybrids
- Power cars with electricity…but need batteries and infrastructure



This diagram illustrates the paths of energy through a typical gas-powered vehicle in city driving.

Vehicles miles traveled began to decrease in 2007.

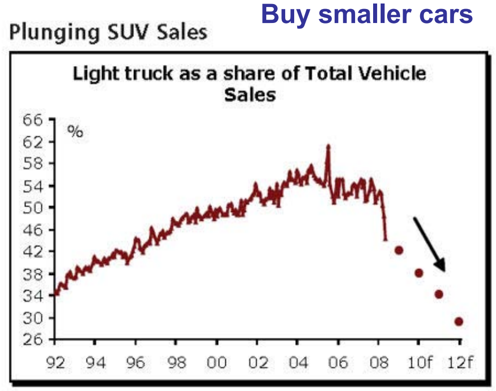


Update Dec 2011

United States

Sales of SUVs and gas guzzlers are decreasing.

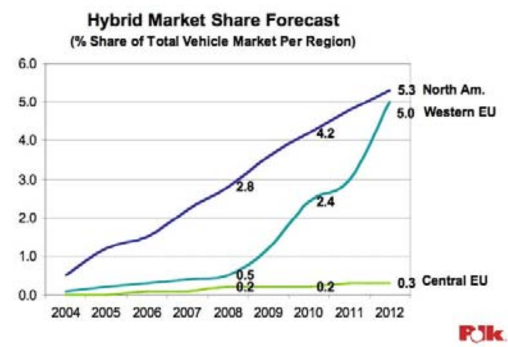
Buy smaller cars



Source: Autodata Corporation, CIBCWM

Sales of hybrid vehicles are increasing.

Buy hybrid cars



Update Dec 2011

Cars need portable fuel: options

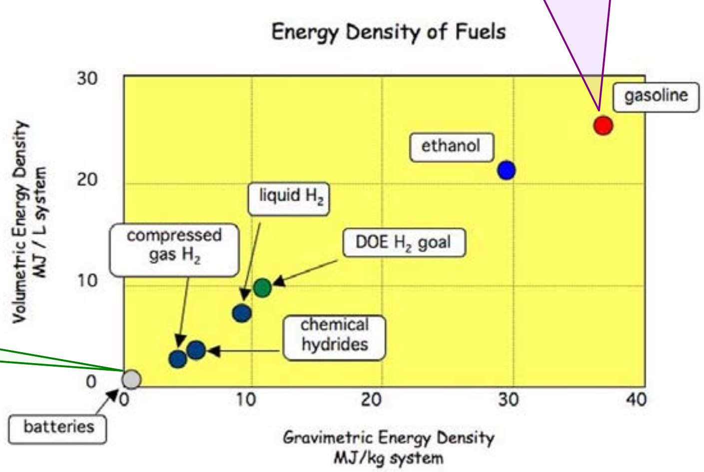
Portable fuel: options

- Gasoline/diesel
- Natural gas (combustion or fuel cell)
- (Hydrogen) (combustion or fuel cell)
- Ethanol and synthetic fuels
- (Electricity)
- Compressed air?
- Flywheel?

Gasoline is nature's ideal fuel…

Gasoline: 4000 wh/kg: Nature's ideal fuel

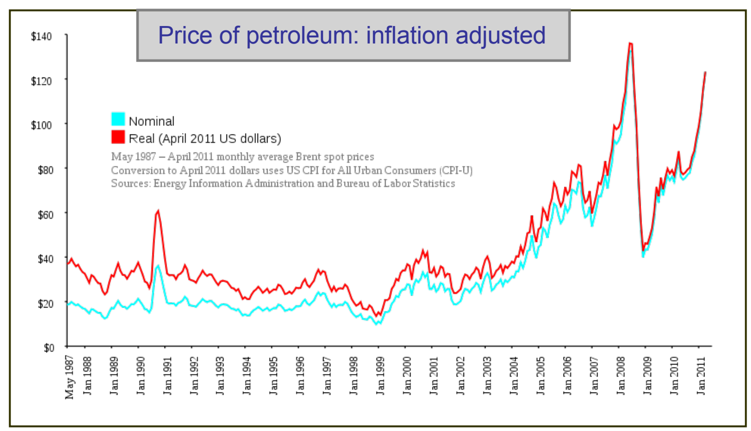
Battery: 200 wh/kg: Improving 5-6%/yr.



High price of petroleum: Wrecking the world's financial security

…and price volatility…

Figure updated from US EIA December 2011 www.eia.gov/dnav/pet/hist/



US Cost: $500 billion for imported oil in 2011

Nearly $2000 per man, woman, and child in America is being sent abroad, to many countries which are not our friends.

US is presently importing nearly 70% of our petroleum.

Electricity vs gasoline for powering cars

Production of **electricity** is relatively *inefficient*.

Utilization of electricity is very *efficient*.

Electric motor efficiency 80-90% efficient.

Electricity cannot be stored except in small quantities (batteries).

Production of **gasoline** is highly *efficient.*

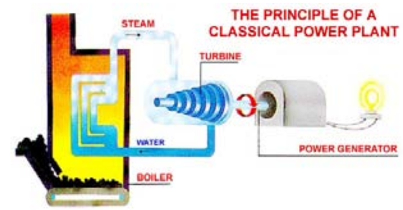
Utilization of gasoline is very *inefficient*.

Only 12.6% in internal combustion engine.

Gasoline is easily stored.

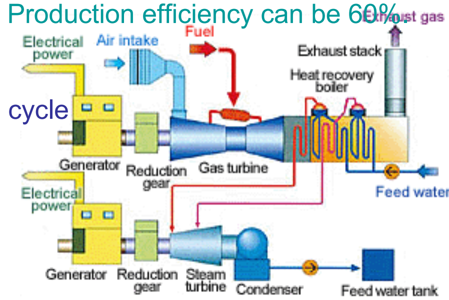
Production efficiency typically 30%

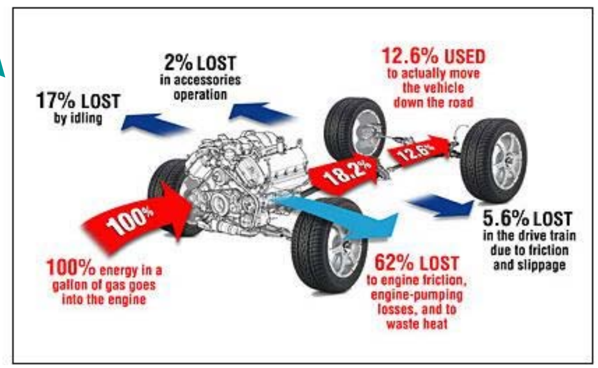
Traditional



Production efficiency can be 60%

Combined cycle





The net gain in powering a car with electricity relative to gasoline is a reduction by a factor of two in primary energy consumption.*

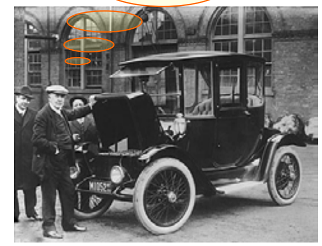
**and electricity can come from renewables…*

Electric cars: issues

technical and infrastructure needs

Thomas Alva Edison: 1900

One third of the 4200 cars produced in the U.S. powered by electricity.



An electric car is twice as efficient as a gasoline-powered car in use of primary energy.

Why are we not using electric cars?

- Batteries: high cost, limited lifetime, long charging time
- Weight: battery can be half the weight of car
- Limited range: “Range anxiety” = fear of running out of charge
- Infrastructure needs: Very dense network of charging stations required. Grid and generation capacity limitations…
- Resources: rare-earth metals and lithium availability

?

Infrastructure needs:

There are 140,000 gasoline filling stations in US.

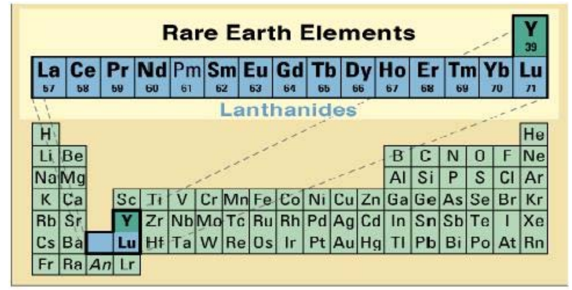
Typical range of gasoline-powered car is 250 miles (400 km).

Electric range < 100 miles (160 km). Many charging stations needed.

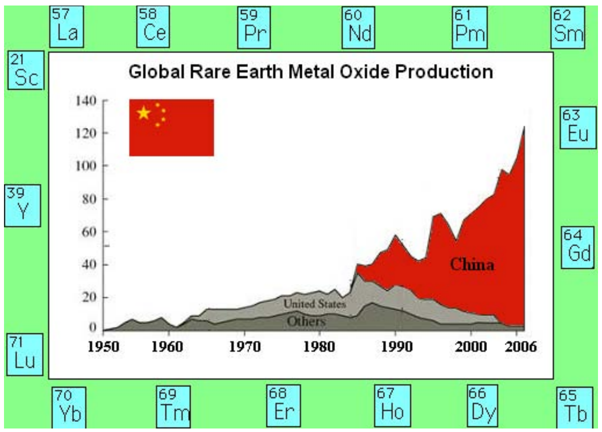
“Time-of-day charging” to utilize generation capacity and grid

Electric cars: issues

Rare-earth elements limited



Rare-earth elements are primarily refined in China.



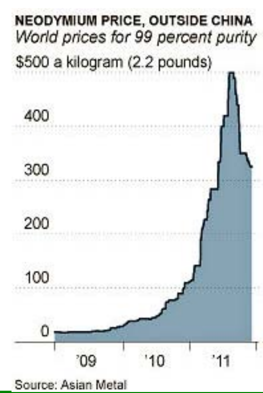

Refining lanthanum in China.

Toyoto Prius needs neodymium:

Nd in motor: 1 kg

La in Ni-metal-hydride battery 10 kg

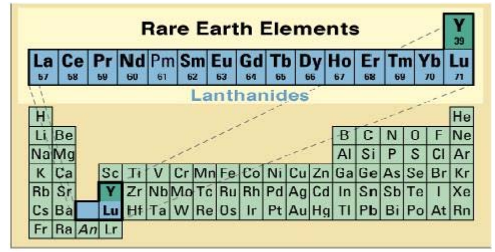
Neodymium price



Prices are very high and volatile.

Electric cars: issues

Rare-earth elements I



Importance:

• Valued for fluorescence properties as phosphors, lasing medium, and magnetic properties arising from electrons in the 4f shell.

• Neodymium-boron-iron magnets are strong and compact, while samarium-cobalt magnets have a high Curie temperature.

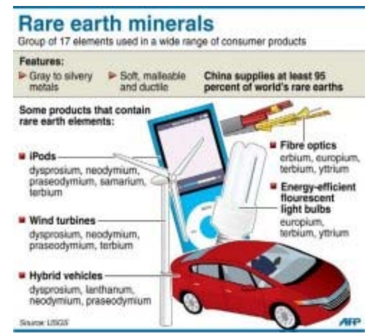
• Rare-earth elements are particularly important in making strong compact electric motors.

Production:

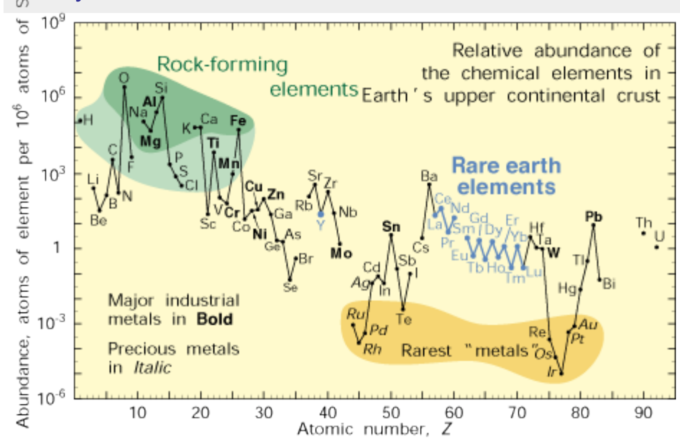
• Rare-earth elements are widely distributed in the earth.

• Refining requires stringent environmental controls…generally lacking outside China.

Rare-earth elements are necessary for many modern technologies



Many of the rare-earth elements have low abundance.

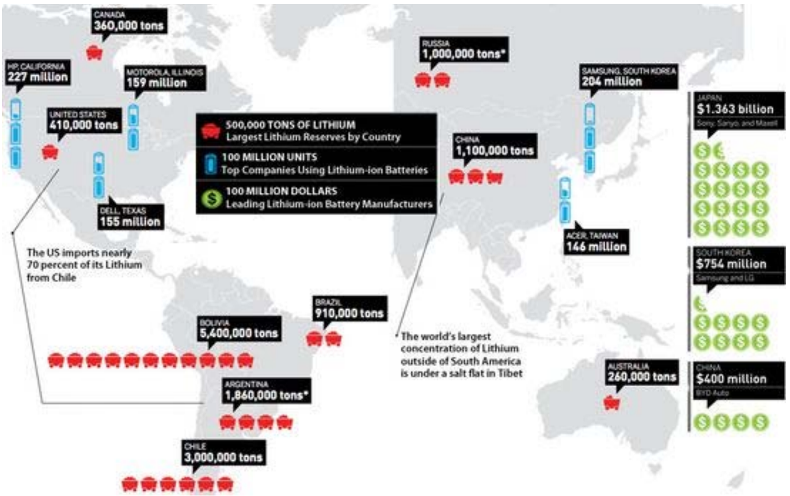


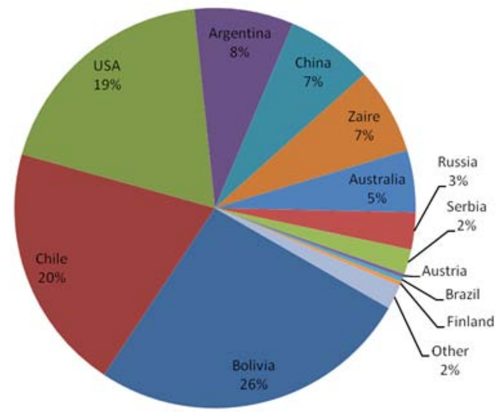

Mountain Pass Mine (California)


Refining lanthanum in China.

Electric cars: issues

Lithium supplies





Novel transportation ideas…

The 1947 Convair 118 ConvairCar
a bit like a plastic Trabant with a Cessna squashed on its roof.

Aerocar 1956: a sort of Mini-Cooper
with detachable wings and tail.

Jess Dixon flying
automobile (1940)

Maverick Flying Car

Alternative means of transportation

Personal transportation, convenient shuttles, first/last mile/km

Eliminating the need for a private car.

Personal transportation

Collective transportation:

Convenient shuttles

Going the first/last mile/km …*going between present location and public transportation*

Motorcycle taxis at BTS (Skytrain) stations.

Bikes at Métro stations

Effective use of motor transport…

America

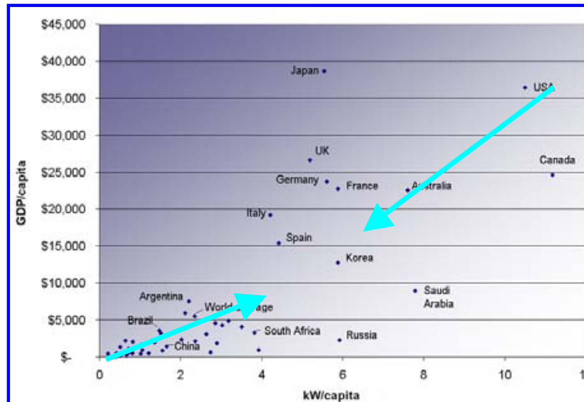
Asia

Transportation: the entire world

We all need to end up powering cars with electricity from a green grid.

Electric vehicles and charging infrastructure

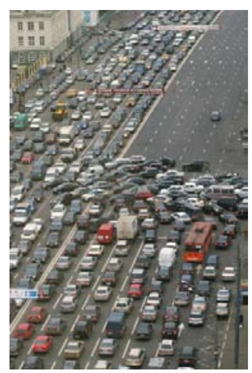
New battery and energy storage technologies need to be developed.



Improving standard of living of poor countries and saving energy in rich countries.

Renewable energy sources are needed to power a green grid.

Better planning is needed…

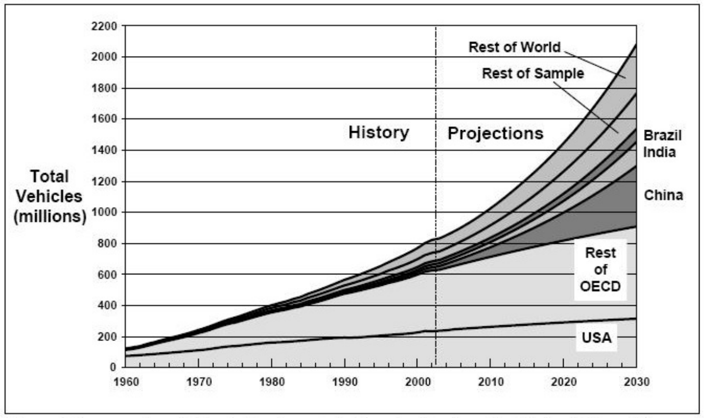


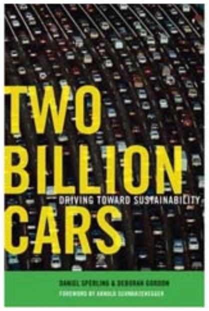
New ways of thinking and problem solving

Two billion cars…

Two billion vehicles projected by 2030.

Note large increase in developing countries…





Developing world

Imagine each bicycle, rickshaw, and motorbike replaced by a car.

The Tata Nano is failing because Indians want more prestigious cars.

Better batteries are needed for hybrid electric cars….

• Hybrid electric vehicles will allow U.S. to reach or exceed 50 mpg by 2030…as will use of strong light-weight materials.**

• Plug-in hybrid vehicles with a 40-mile electric range*** will allow U.S. to decrease fuel use by 63%.

* Fuel economy per EPA is inflated 25% relative to actual driving tests.

** Lighter-weight cars can be made more safe by careful design.

*** Range must reliably be considerably greater than 40 miles to avoid "range anxiety."

Battery:

"The product stays in the box."

Figure 16

Battery performance

This graphic compares the energy in watt hours per kilogram of vehicle power sources. The chart indicates their range, power and acceleration.

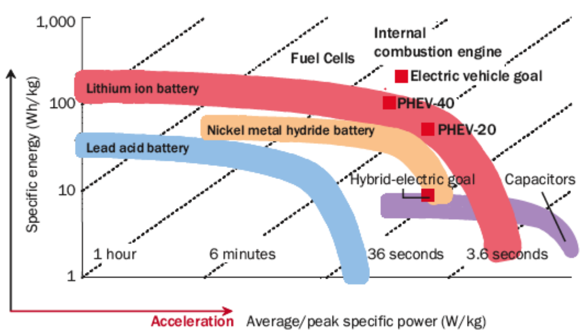
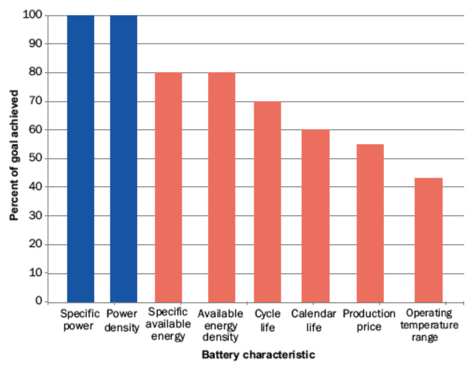


Figure 17

Battery comparisons

Comparison of present-day Li-ion batteries with DOE hybrid-electric-vehicle goals.

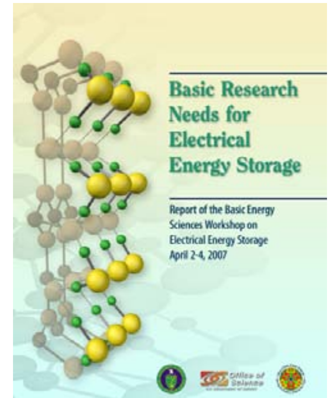


Lithium-ion batteries. Unlikely to achieve low cost and high energy density and long life.

Improvement only 5-6%/yr.

Energy storage*

*key issue



Small scale: cell phones, laptop computers

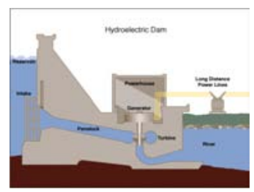
Lithium-ion batteries are expensive but effective.

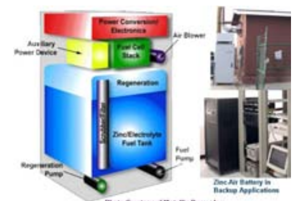
Medium scale: electric cars

Li-ion batteries provide limited range for mass-market plug-in electric vehicles.

Large scale: electric grid

Pumped-storage hydropower (25% loss) and compressed air stored underground are used.



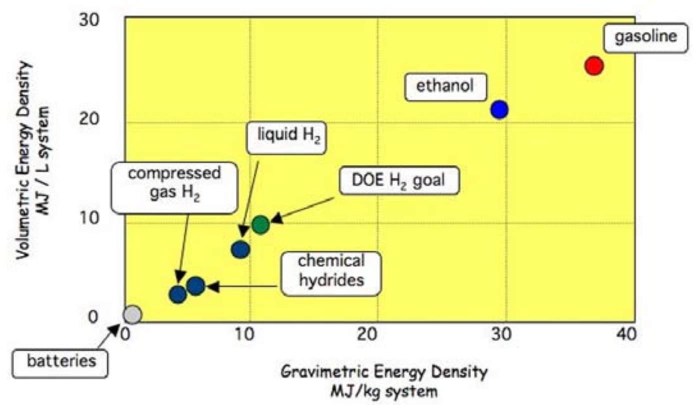


Other options: thermal storage, ice storage, flywheel, superconducting magnet, hydrogen, huge batteries (sodium-sulfur?)…

There is no effective way to store lots of energy.

Energy storage is essential for any intermittent source of power.

Batteries have low energy storage density.



The problem of energy storage: large scale*

*key issue

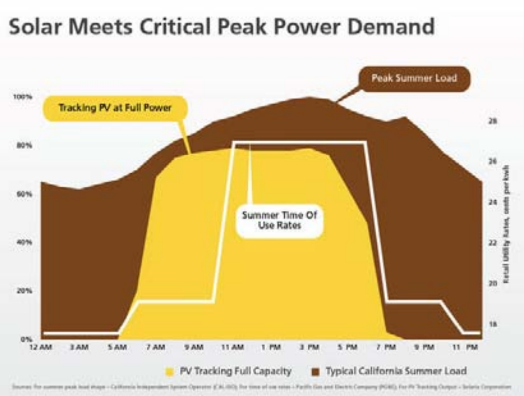
When the sun is not shining: Utility has to meet demand.

Large-scale energy storage important for intermittent energy resources (solar, wind).

A utility is required to provide electricity to meet demand at all times…thus to have large capital expenses for stand-by power generation when sun does not shine.

When the sun is shining:

A happy case: California in the summer.



Renewables will increase.

US 2011:

Wind 2.4%

Hydroelectric 7%

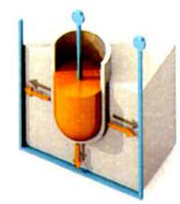
Solar and geothermal 1.6%

US 2035 goal:

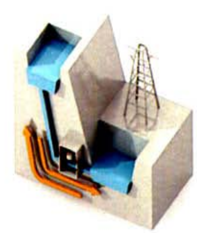
Renewables 35%.

Options

Compressed air, stored underground
An Iowa wind farm plans to pump air into sandstone formations when there's wind. Later the air can be released to make electricity.



Sodium-sulfur batteries
Pioneered in Japan, this technology can store a large amount of energy in a small space, as lithium-ion batteries do for electric cars.



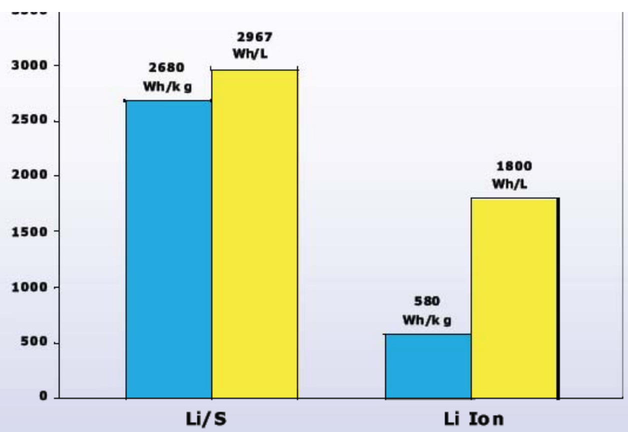
Pumped-storage hydropower
Water is pumped uphill into a reservoir when electricity demand is low and released again to turn a turbine when demand is high.

Flywheel storage
In one town in Australia, electricity from wind turbines powers flywheels; their spinning motion is used to regenerate electricity when it's needed.

Lithium-ion batteries & alternative chemistries

Lithium-ion batteries are a mature technology. Only incremental improvement is expected.

Alternative chemistries: Li/air Li/(O_2) or Li/S. These chemistries are in early stages of development.

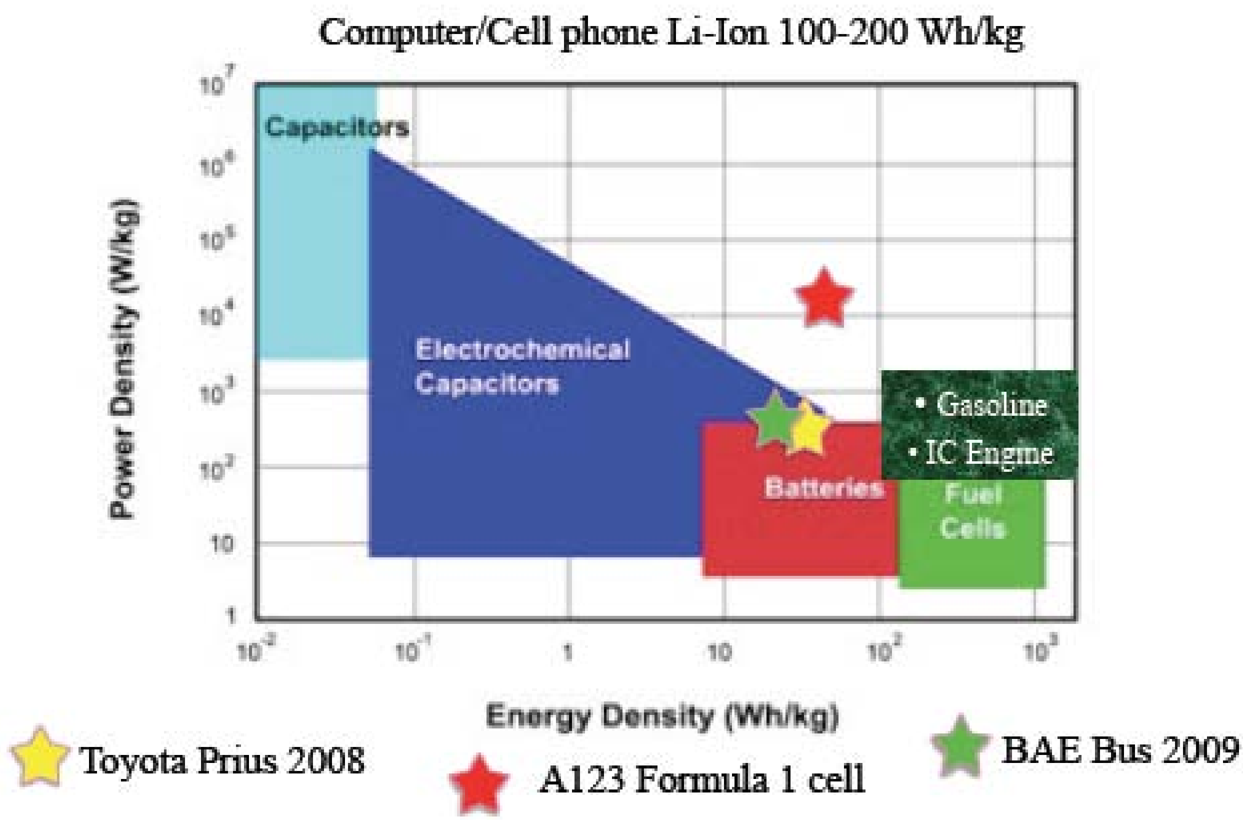


- Next-generation Li/S cell could provide 300 mile range for EV's.
- High theoretical specific energy: 2680 Wh/kg
- Low cost and high abundance of sulfur
- Environmentally benign

Courtesy: Elton Cairns

Energy Storage

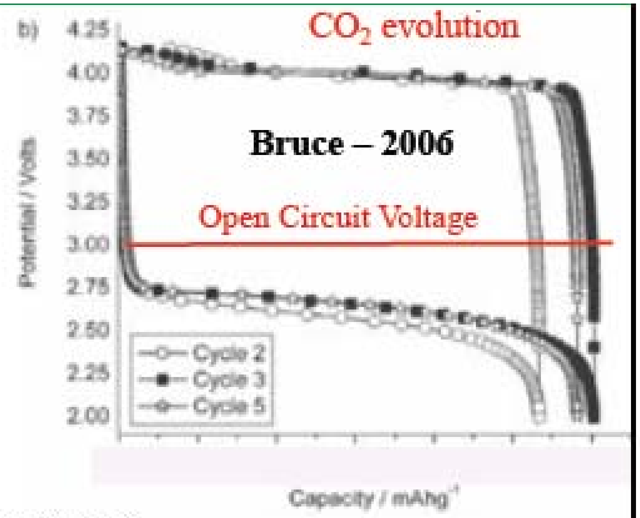
Courtesy Stan Whittingham



Lithium/air

Courtesy Stan Whittingham

$$2\,Li + O_2 \overset{MnO_2}{\rightleftharpoons} Li_2O_2$$



Opportunities:

- High capacity
- Low cost, *in principle*

Challenges:

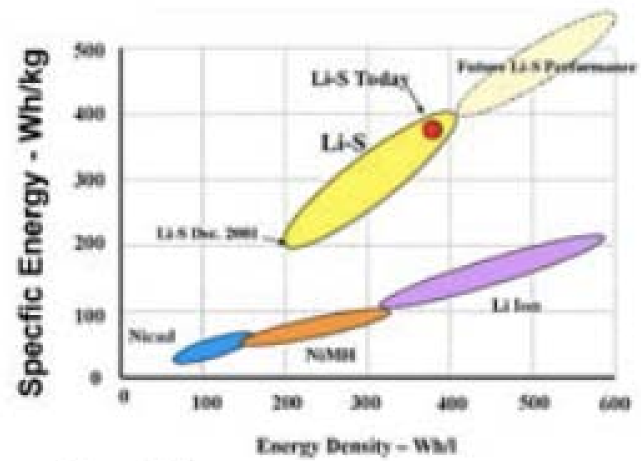
- Energy Inefficient
- Oxygen Electrocatalyst (both ways)
- Lithium protection
- Lithium electrodeposition (key to all Li batteries)
  - If C_6Li is used energy advantage may be lost
- Containment of electrolyte, if open system
- Containment of LiO_y product in cathode compartment *(finite weight)*
- What is the reaction mechanism? *Is it reversible?*
- Elimination of water and CO_2 (may need contained oxygen)

17

Lithium/air vs Li/S

Courtesy Stan Whittingham

- Lab $Li\text{-}O_2$ Energy density may be double that of Li-ion if all works out well
  - Li-S much higher than Li-ion, possibly higher than Li-air
- Lab $Li\text{-}O_2$ Volumetric energy density will be less than Li-ion
  - Li-S less than Li-ion



Sion - 2009

Has the battery bubble burst?

APS News

August/September 2012

Has the Battery Bubble Burst?

by Fred Schlachter

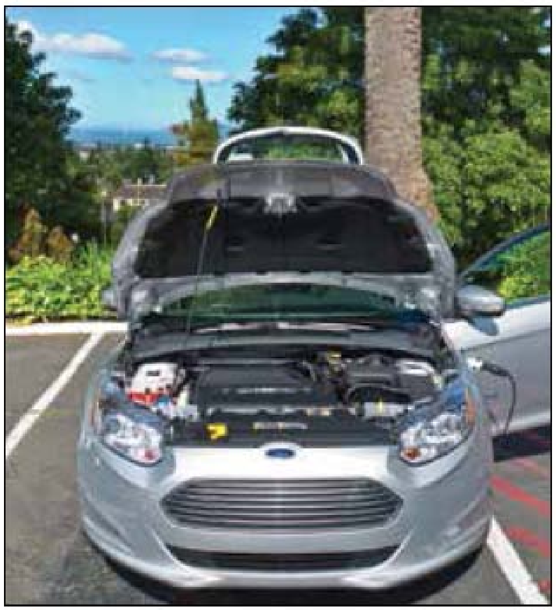


Photo by Roy Kalschmidt/Berkeley Lab

The 2013 Ford Energi plug-in hybrid, with the Golden Gate Bridge visible in the background.

"Moore's Law" for Batteries?

Isn't there some kind of "Moore's Law" for batteries? Why is progress on improving battery capacity so slow compared to increases in computer-processing capacity? The essential answer is that electrons do not take up space in a processor, so their size does not limit processing capacity; limits are given by lithographic constraints. Ions in a battery, however, do take up space, and potentials are dictated by the thermodynamics of the relevant chemical reactions, so there only can be significant improvements in battery capacity by changing to a different chemistry.

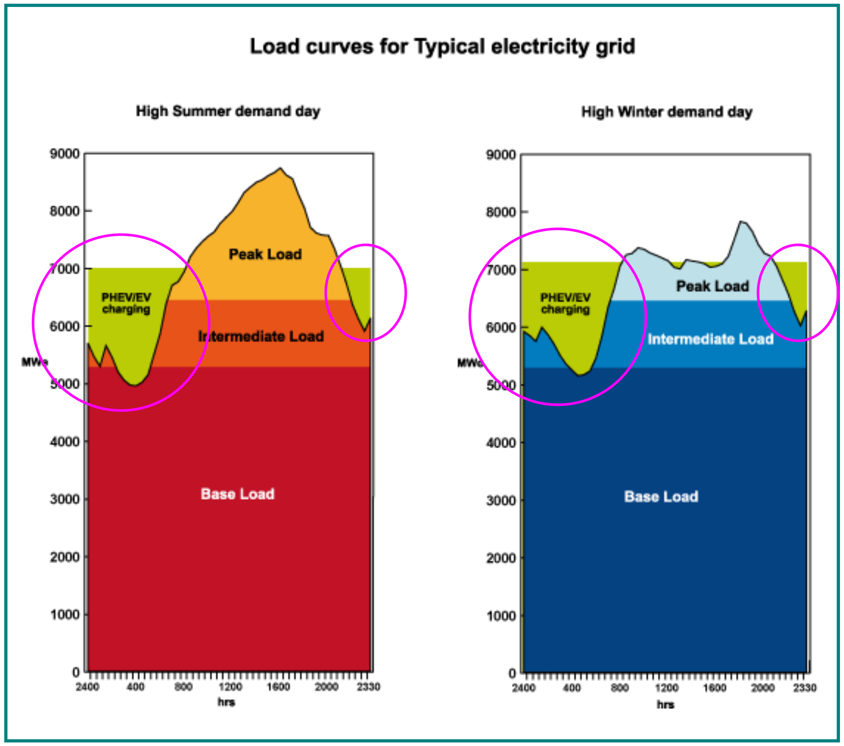
Electric cars: issues
time-of-day charging

Time-of-day charging:

Charging electric cars--PHEVs and BEVs--must be done at times when there is the least demand on electrical generation capacity and the electric grid….typically 2200 to 0800.

This precludes charging during daytime at work or shopping locations…assuming grid electricity is used.

Must be imposed by electric utility through differential pricing.



Electric cars: battery swapping

“Better Place”: Shai Agassi

Concept:

Put battery charging and swapping stations all over the United States (or Israel or Denmark…).

Potential issues:

• Electric range small (20-40 miles…30-60 km)

• Electric cars need to be standardized: Renault?

• Many swapping stations needed.*

• Batteries expensive and have a short service life -> large capital cost.

• Fear of dud battery.

• Potential failure of latching system.

* There are 150,000 gas stations in the United States. More swapping and charging stations would be needed as range is smaller.

Battery swapping: subscription model of service likely to meet customer resistance.

May only work in small isolated countries.

Israel
feasibility of charging stations

Israel (22k km^2) is about twice the size of greater Los Angeles…and 13% the size of California (164k km^2).

What is feasible in Israel is not the same as what is feasible in the US.

Test countries for battery swapping--preferably small.

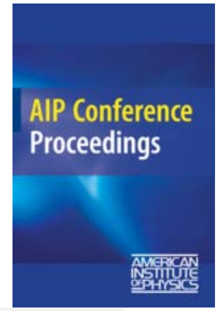
Israel: small, travel distances short, neighbors not necessarily friendly. Warm country. No oil

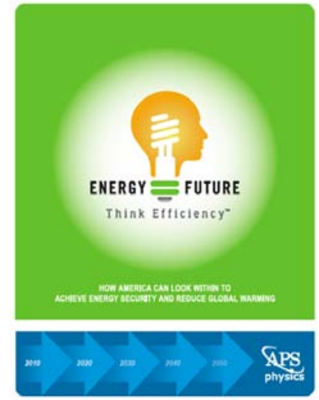
Denmark: small, very friendly neighbors. Cold country. Has oil.

Government must impose a single or a limited set of car models to keep inventory and capital costs under control.

Energy efficiency in transportation

APS 2008: update 2011. *Essentially no changes…*





- Electric cars and plug-in hybrid cars on the road.

2008: *not yet*. 2011: *nearly*.

- CAFÉ (fuel-economy standards):

2008 proposed 35 mpg for light-duty vehicles by *2020*; 50 mpg by 2030.
2011 proposed 35.5 mpg by *2016*; 50 mpg by 2030.

- Vehicle weight:

2008 recommended significant weight reduction. 2011 same.

- Plug-in hybrid vehicles

2008: noted difficulties of replacing vehicles by PHEVs. 2011 same.

- All-electric battery-powered cars

2008: noted that no battery exists to power car 300 miles (500 km). 2011 same.

- Hydrogen:

2008 unlikely. 2011 same.

- Energy R&D program:

2008: recommended broad portfolio. 2011 same.

- Time-of-use metering

2008: recommended. 2011 same.

- Social-science research: land use, transportation infrastructure…

2008: recommended. 2011 same.

www.aps.org/energyefficiencyreport (2008)

Update 2011: Lubell and Richter (AIP Conf. Proc 1401: Physics of Sustainable Energy II)

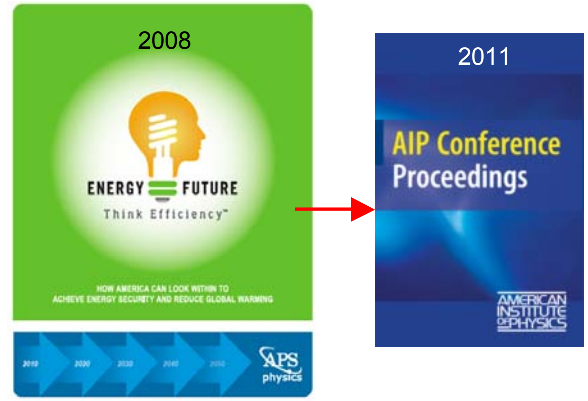
American politics

APS report 2008: update December 2011

Major changes in American politics since September 2008 report: (technology barely changed)

- President (Obama) …vs Bush ↑
- Energy Secretary (Chu) ↑
- Economy ↓
- CAFÉ (fuel-economy) standards ↑
- Climate change ↓
- Electric cars ↑
- Polarization of society ↓
- China →
- Pessimism, wars, Middle East ↓

The only positive changes since 2008 our President and Energy Secretary, plug-in hybrids, and improved fuel-economy standards…



There is a mean spirit we never saw before…

www.aps.org/energyefficiencyreport (2008)

Update 2011: Lubell and Richter (AIP Conf. Proc 1401: Physics of Sustainable Energy II)

USA: politics

…fighting over 100-watt incandescent bulbs…

Congress overturns incandescent light bulb ban. *Washington Post December 16, 2011*
"Republicans have fulfilled our promise to the American people by allowing them to continue to be able to choose what type of bulb they use at home. Consumers should drive the marketplace, not the government."

America has become so politically polarized and contentious that even the proposed phasing out of 100-watt incandescent bulbs is worth a fight in Congress.

Home Depot 2011: 60% incandescent, 25% CFL, 10% halogen incandescent, 5% LED.

Future of electric cars: my predictions

- Hybrids and plug-in hybrids will dominate market.
- All-electric cars will be a town car for rich people….short range.
- Cars will be lighter in weight and smaller.
- Charging infrastructure will have to be developed.

and time-of-use payment for charging will be necessary.

- Research area: better batteries: energy density, cost, rapid charge
- Social/mobility issues will be addressed.
- The grid will become increasingly "green."
- Research area: large-scale energy storage to allow efficient use of solar and wind energy.

Efficient use of energy is our best option…

Energy future: *think efficiency*

Improving energy efficiency is a relatively easy and inexpensive way to significantly reduce the nation's demand for imported oil and its greenhouse gas emissions.

Numerous technologies exist today to increase energy efficiency that could save individual consumers money. Need federal policies …

Increases in energy efficiency will require a larger and better-focused federal research and development program than exists today.

HOW AMERICA CAN LOOK WITHIN TO ACHIEVE ENERGY SECURITY AND REDUCE GLOBAL WARMING

September 2008

http://www.aps.org/energyefficiencyreport/

APS physics

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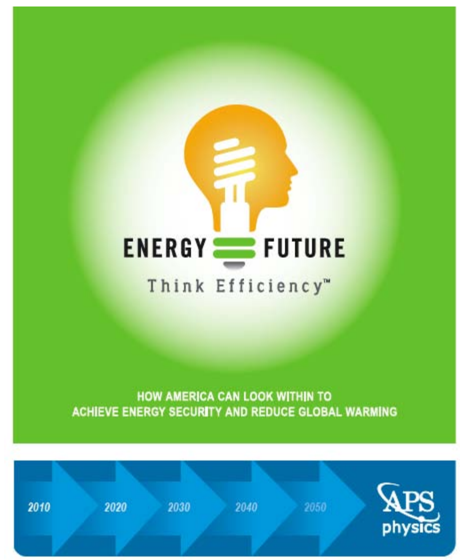

www.aps.org/EnergyEfficiencyReport/

Thank you…….

Our future and the future of our planet are in our hands.

fsschlachter@lbl.gov