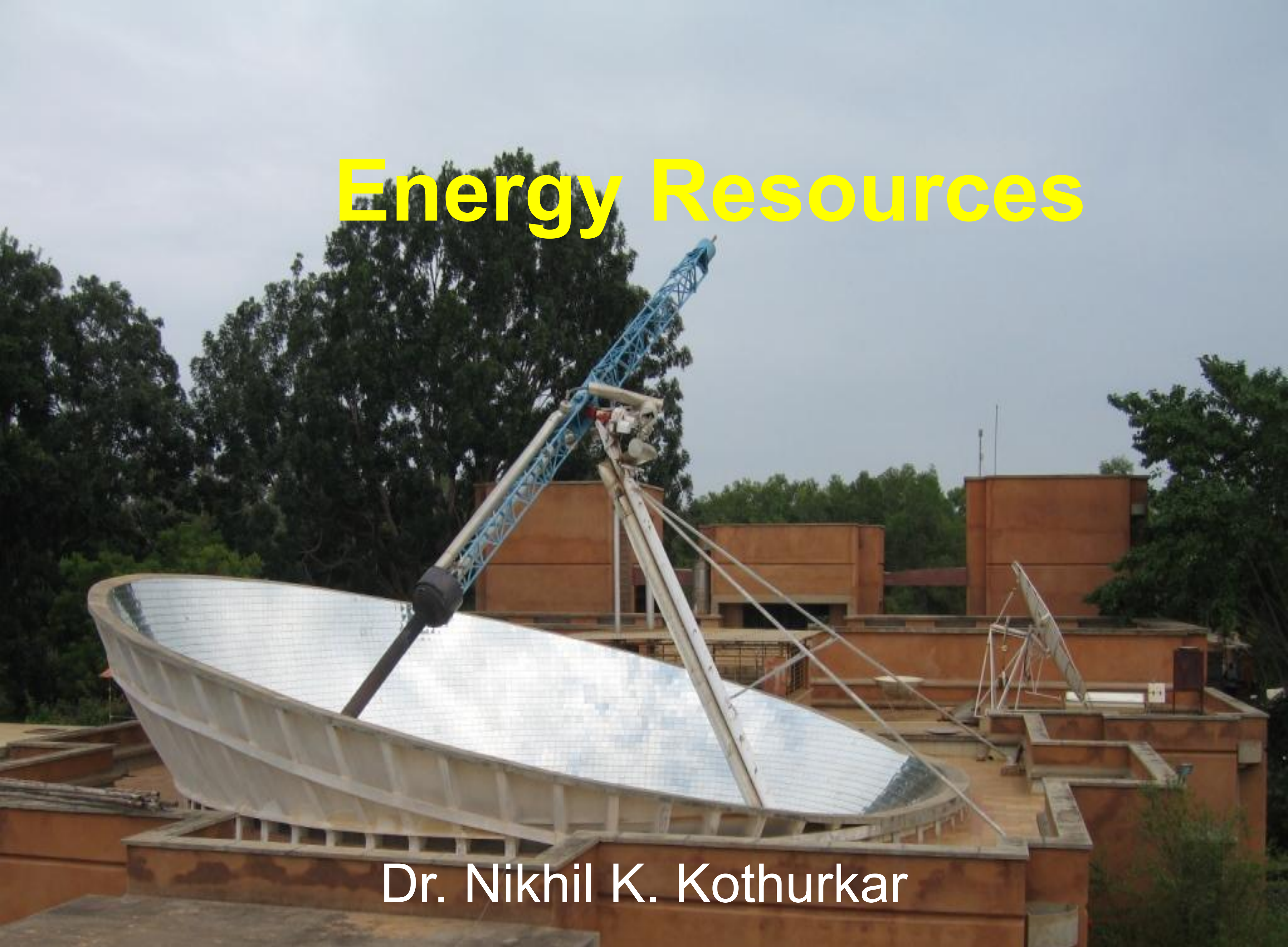
Energy Resources



Dr. Nikhil K. Kothurkar

Outline

- Units and Terms
- Energy Resources, Depletion and Risks
- Environmentally Benign Forms of Energy
- Efficiency Measures
- Reduction in Consumption—Individual Perspective

Energy units

- 1.0 joule (J) = one Newton applied over a distance of one meter (= 1 kg m^2/s^2).
- 1.0 joule = 0.239 calories (cal)
- 1.0 calorie = 4.187 J
- 1.0 gigajoule (GJ) = 10^9 joules = 0.948 million Btu = 239 million calories = 278 kWh
- 1.0 British thermal unit (Btu) = 1055 joules (1.055 kJ)
- 1.0 Quad = One quadrillion Btu (10^{15} Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent (boe)
- 1000 Btu/lb = 2.33 gigajoules per tonne (GJ/t)
- 1000 Btu/US gallon = 0.279 megajoules per liter (MJ/l)

Power Units

- 1.0 watt = 1.0 joule/second = 3.413 Btu/hr
- 1.0 kilowatt (kW) = 3413 Btu/hr = 1.341 horsepower
- 1.0 kilowatt-hour (kWh) = 3.6 MJ = 3413 Btu
- 1.0 horsepower (hp) = 550 foot-pounds per second = 2545 Btu per hour = 745.7 watts = 0.746 kW

Heating Value of a Fuel

- Energy (heat) released per unit quantity (mass or volume) of a fuel upon combustion is called its heating value.
- The lower heating value (LHV) is calculated with combustion products in the gas phase…more relevant for mobile applications
- The higher heating value (HHV) is calculated after condensing the gaseous products (mostly water)...more relevant for stationary applications
- Energy contents are expressed here as Lower Heating Value (LHV) unless otherwise stated (this is closest to the actual energy yield in most cases).
- HHV> LHV by….depending mainly on the hydrogen content of the fuel.
  - 5% (in the case of coal), 10% (for natural gas), 6-7% for biomass feedstocks

Fossil Fuels Units and Energy Content

- 1 Petroleum barrel = 42 U.S. gallons = 35 Imperial gallons = 159 L.
- **Barrel of oil** equivalent (boe) = ~ 6.1 GJ = 5.8 million Btu = 1,700 kWh.
- 7.2 barrels oil are equivalent to 1 metric tonne of oil = 42-45 GJ.
  - gasoline density (average) = 0.73 g/ml (= metric tonnes/m^3)
- Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.

Fossil Fuels Units and Energy Content

- **Gasoline:**
  - LHV = LHV115,000 Btu/US gallon = 121 MJ = 32 MJ/liter.
  - HHV= 125,000 Btu/US gallon = 132 MJ/gallon = 35 MJ/liter
  - 1 Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)
- **Petro-diesel**
  - Heating Value: 130,500 Btu/gallon (36.4 MJ/liter or 42.8 GJ/t)
  - petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m^3)

Fossil Fuels Units and Energy Content

- **Coal**
  - Bituminous/anthracite (common for power plants): 27-30 GJ/metric tonne (11,500-13,000 Btu/lb);
  - Lignite/sub-bituminous: 15-19 GJ/metric tonne (6,500-8,200 Btu/lb)
- **Natural gas:**
  - HHV = 1027 Btu/ft^3 = 38.3 MJ/m^3; LHV = 930 Btu/ft3 = 34.6 MJ/m^3
  - 1 Therm (used for natural gas, methane) = 100,000 Btu (= 105.5 MJ)

Carbon Content of Fuels

- **Coal** (average) = 25.4 metric tonnes C/TJ
  - 1.0 metric tonne **coal** = 746 kg carbon
- **Oil** (average) = 19.9 metric tonnes C / TJ
- 1.0 US gallon **gasoline** (0.833 Imperial gallon, 3.79 liter) = 2.42 kg carbon
- 1.0 US gallon **diesel/fuel oil** (0.833 Imperial gallon, 3.79 liter) = 2.77 kg carbon
- **Natural gas (methane)** = 14.4 metric tonnes C/TJ
- 1.0 cubic meter **natural gas (methane)** = 0.49 kg carbon
- Carbon content of **bioenergy feedstocks:** approx. 50% for woody crops or wood waste; approx. 45% for graminaceous (grass) crops or agricultural residues.

Outline

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- Energy Resources, Depletion and Risks
- Environmentally Benign Forms of Energy
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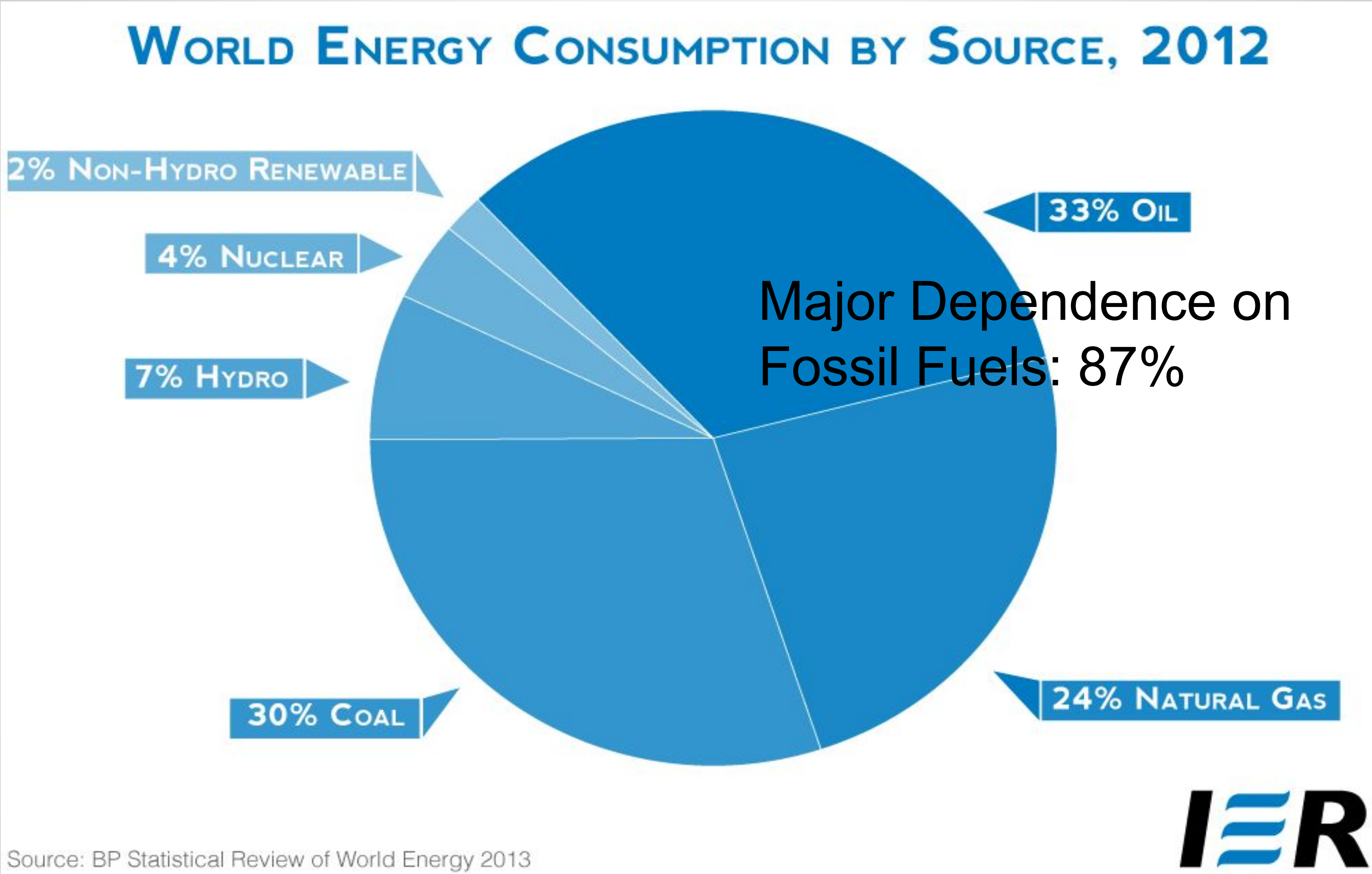
Renewable and Nonrenewable Resources

- **Perpetual/Continuous** resources are those that remain available in the same measure for an indefinitely long time e.g. Solar, Wind, Geothermal, Wave power
- **Renewable resources** can be replenished over fairly short spans of time, such as months, years or decades. E.g. Biomass energy, biofuels, Hydroelectric power generation
- **Nonrenewable resources** take millions of years to form and accumulate, e.g. All fossil fuels like coal, oil, natural gas; uranium, thorium (nuclear fuel)

Why do we have a Global Energy Crisis?

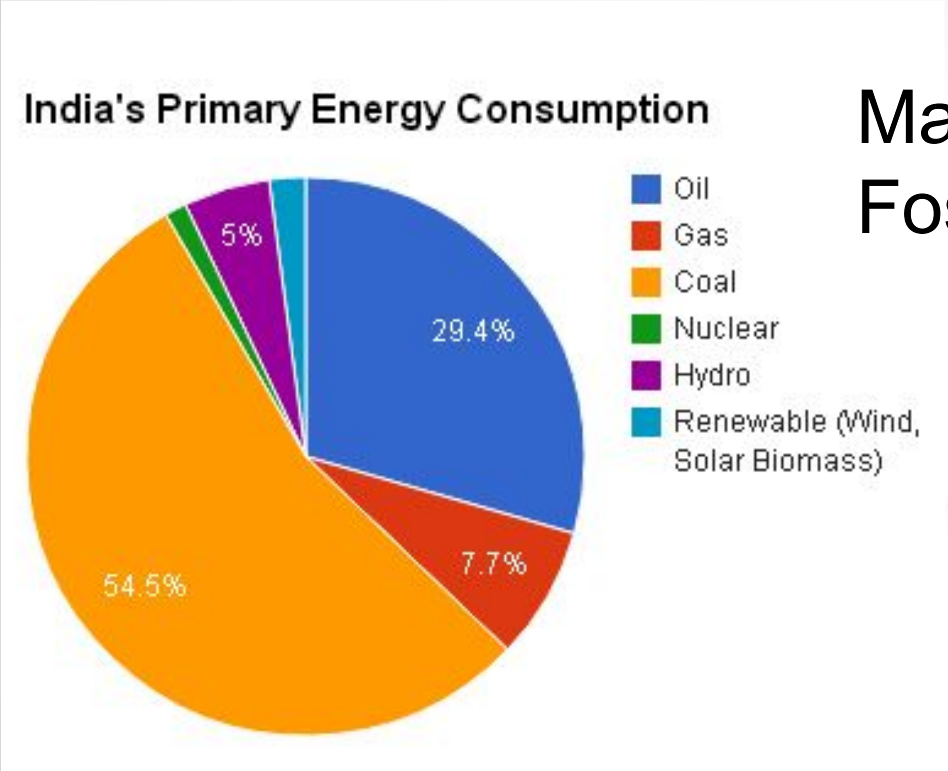
- Humanity has a **near total dependence on fossil fuels** and other ***unsustainable energy sources*** for its needs.
- Hence, energy use causes irreversible damage to Earth's 'life support system'.
  - Consequent global climate change, environmental pollution, health problems...
- The known sources of energy incl. oil, gas, coal and nuclear fuel are exhaustible (some already severely depleted)
- Energy consumption is increasing at an alarming rate—*worsening the social and environmental impacts and accelerating depletion.*
- Shares of most renewable energy forms are presently very low; technological, commercial and policy barriers exist.



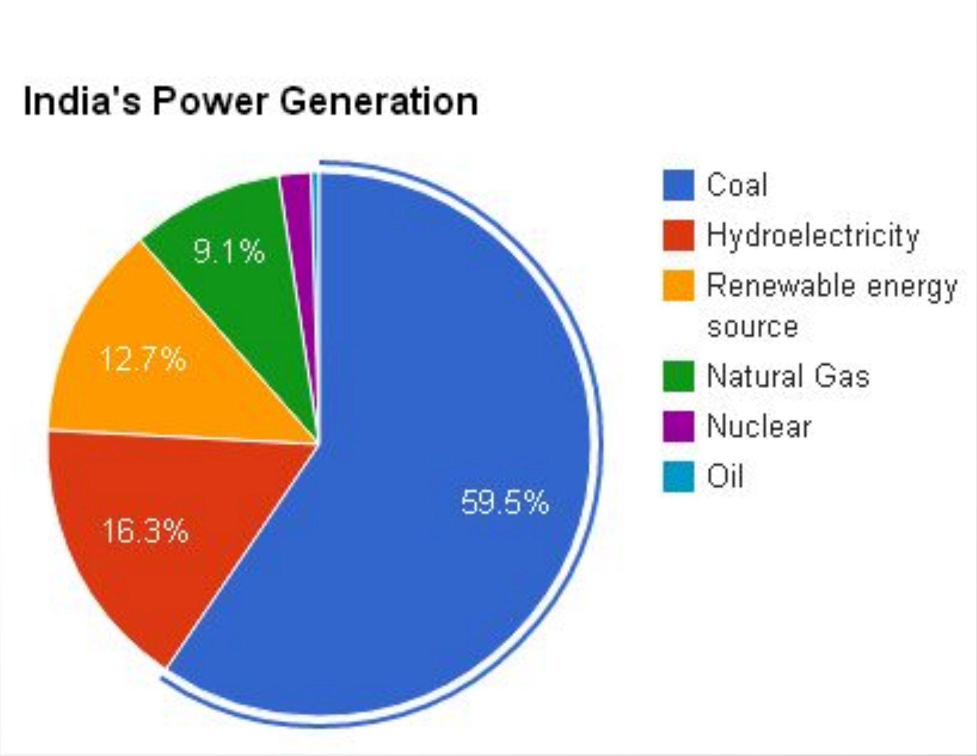
Major Dependence on Fossil Fuels: 87%

http://instituteforenergyresearch.org/analysis/statistical-review-of-world-energy-2013-viva-la-shale-revolucion/

India's Energy Consumption



Major Dependence on Fossil Fuels: 91%



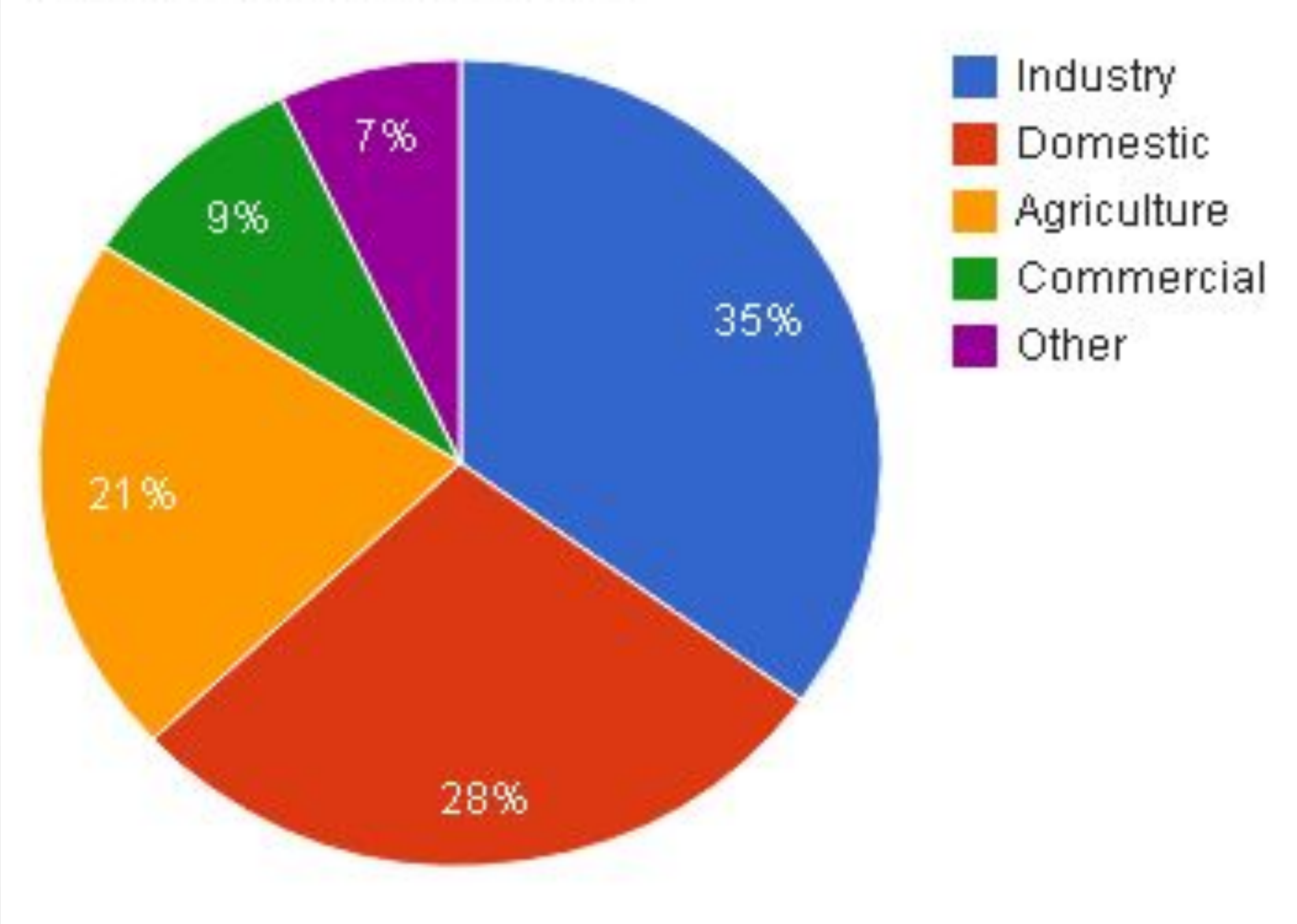
http://en.wikipedia.org/wiki/Energy_policy_of_India#Power_Generation_capacity_in_India

Electricity in India

- Overall electrification rate: 64.5%
  - 35.5% of the population without access to electricity.
- Urban: access to electricity is 93.1% (2008).
- Rural:
  - 80% of Indian villages have an electricity line
  - 52.5% of rural households have access to electricity.

http://en.wikipedia.org/wiki/Electricity_sector_in_India

India’s Electricity Use



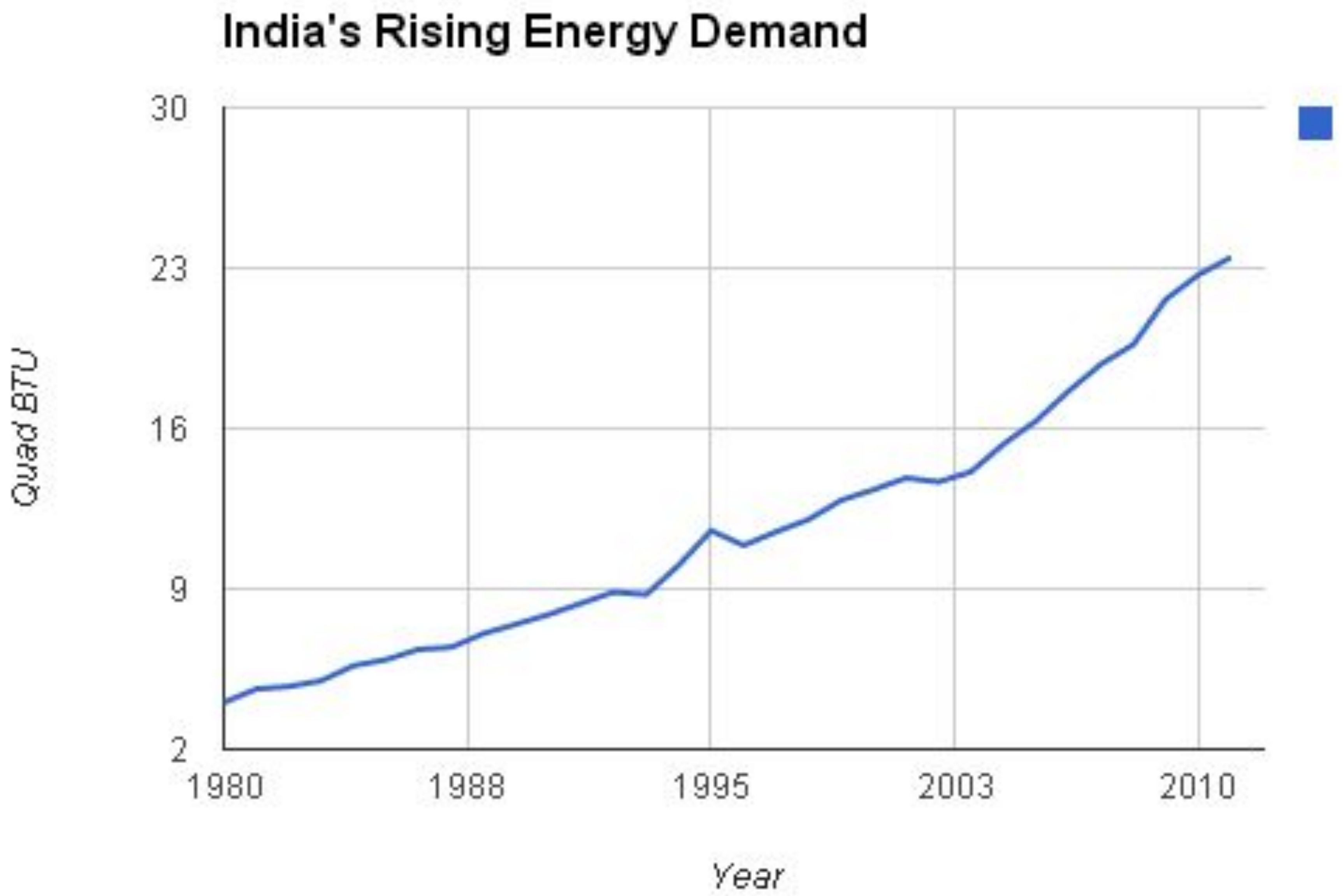
India Electricity Deficit

For 2014–15

- Installed capacity of 258.7 GW (Jan 2014).
- Avg. base load energy deficit = 5.1%
  - 12% in S
  - 17.4% in NE)
- Peaking shortage = 2%
  - 22.2% in S
  - 12% in NE

http://en.wikipedia.org/wiki/Electricity_sector_in_India

Rising Demand



http://www.indexmundi.com/energy.aspx?country=in&product=total-primary-energy&graph=consumption

Depleting Sources

- Fossil Fuels (oil, coal, gas):
  - Non-renewable.
  - Oil depleting rapidly. Peak oil
  - Coal: Mining is leading to deforestation and habitat loss.
- Nuclear:
  - Uranium depleting rapidly
  - Thorium will last somewhat longer
  - Reprocessing can “create” fuel and make it last much longer.
  - Fusion technology is still distant.
- Hydropower:
  - Most major river systems have been dammed.
  - Additional major projects might not be possible due to limited resource and pressure from activists.

But we cannot even consume all the remaining fossil fuels.

The socio-environmental costs of exhausting all the fossil reserves are extremely serious...

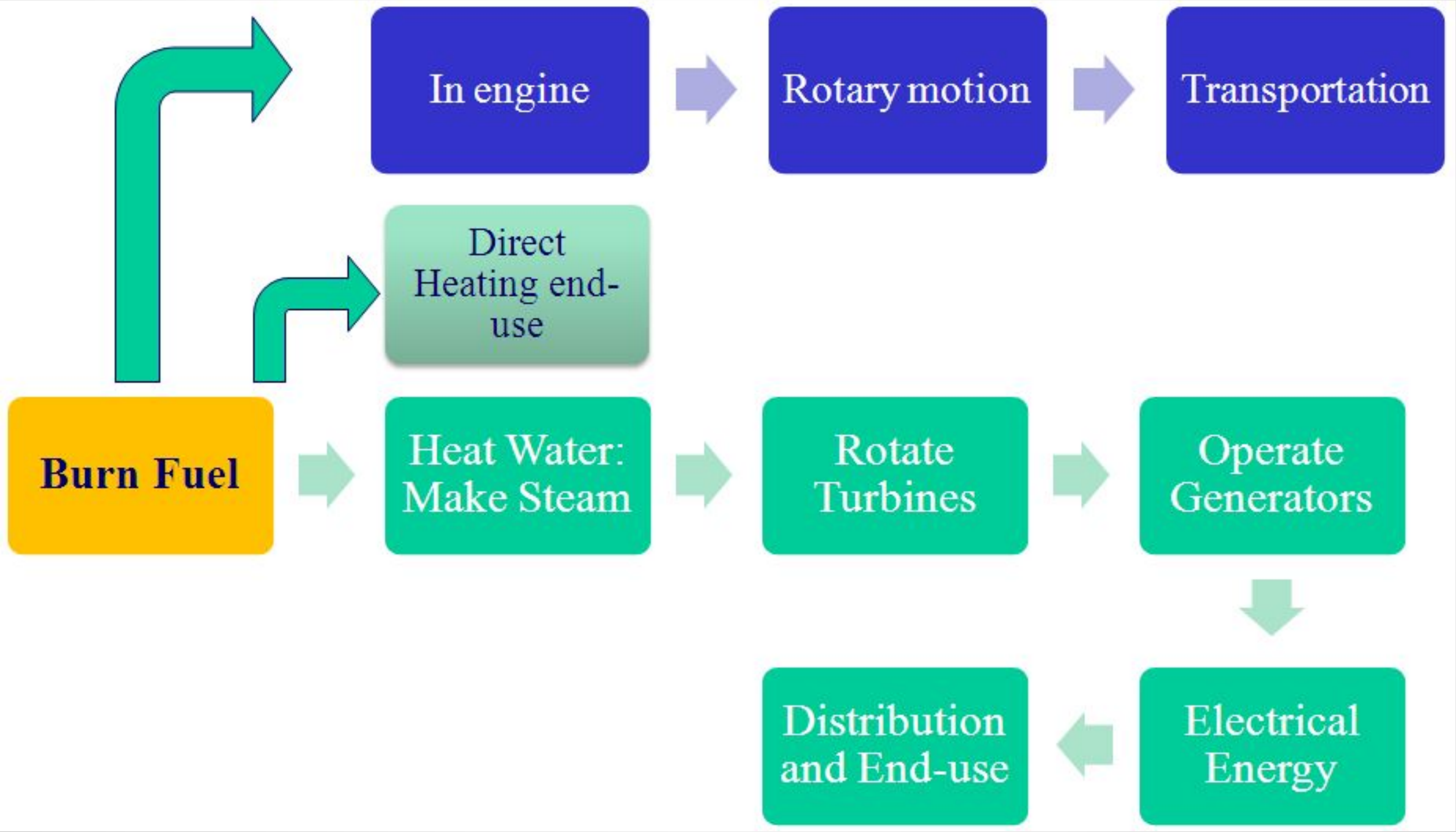
Risks and Costs of Energy Sources

- Fossil Fuels (oil, coal, gas):
  - Greenhouse Gas Emissions, Climate change.
  - Pollution of air, land and water.
- Nuclear:
  - Major accidents, minor accidental releases of radioactive materials
  - Nuclear waste problem.
  - Unaccounted costs of decommissioning and cleanup.
- Hydropower:
  - Large land submergence, loss of habitat,
  - Disruption of riverine ecosystems and floodplain agriculture,
  - Uncompensated oustees, major public agitations.

An Overwiew of Fossil fuels

- Fossil fuels are hydrocarbons that may be used as a fuel found within the top layer of the Earth’s crust.
- Coal, oil and gas are called "fossil fuels" because they have been formed from the organic remains of prehistoric plants and animals
- Coal is crushed to a fine dust and burnt.
- Oil and gas can be burnt directly.

How it works


In engine
Rotary motion
Transportation
Direct Heating end-use
Burn Fuel
Heat Water: Make Steam
Rotate Turbines
Operate Generators
Electrical Energy
Distribution and End-use

Advantages of Fossil Fuels

- Very large amounts of electricity can be generated in one place using coal, fairly cheaply.
- Transporting oil and gas to the power stations is easy.
- Gas-fired power stations are very efficient.
- A fossil-fuelled power station can be built almost anywhere, so long as you can get large quantities of fuel to it

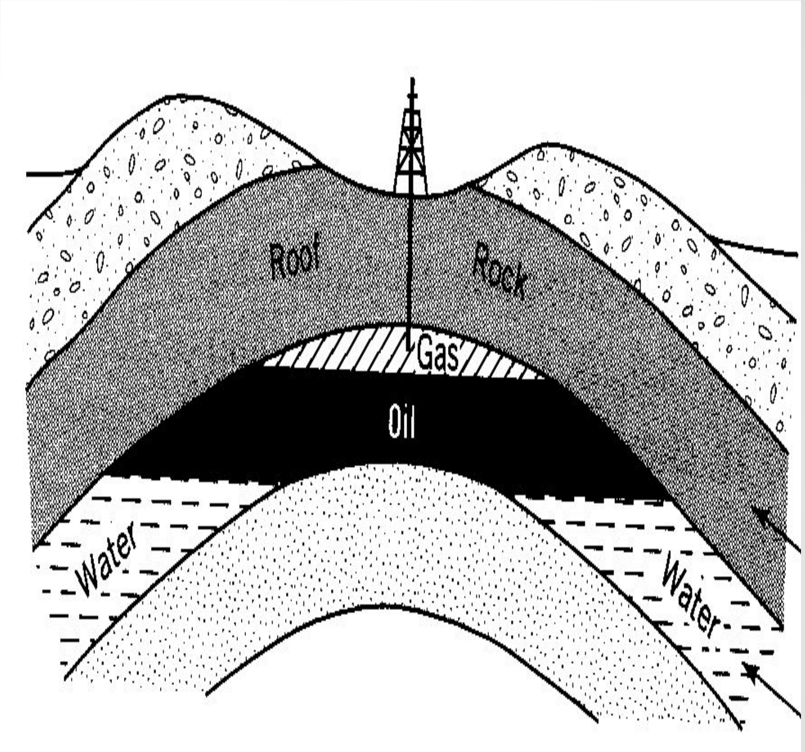
How do we get fossil fuels?

- Petroleum and natural gas—oil wells
- Coal—mining

Petroleum and Natural Gas Extraction

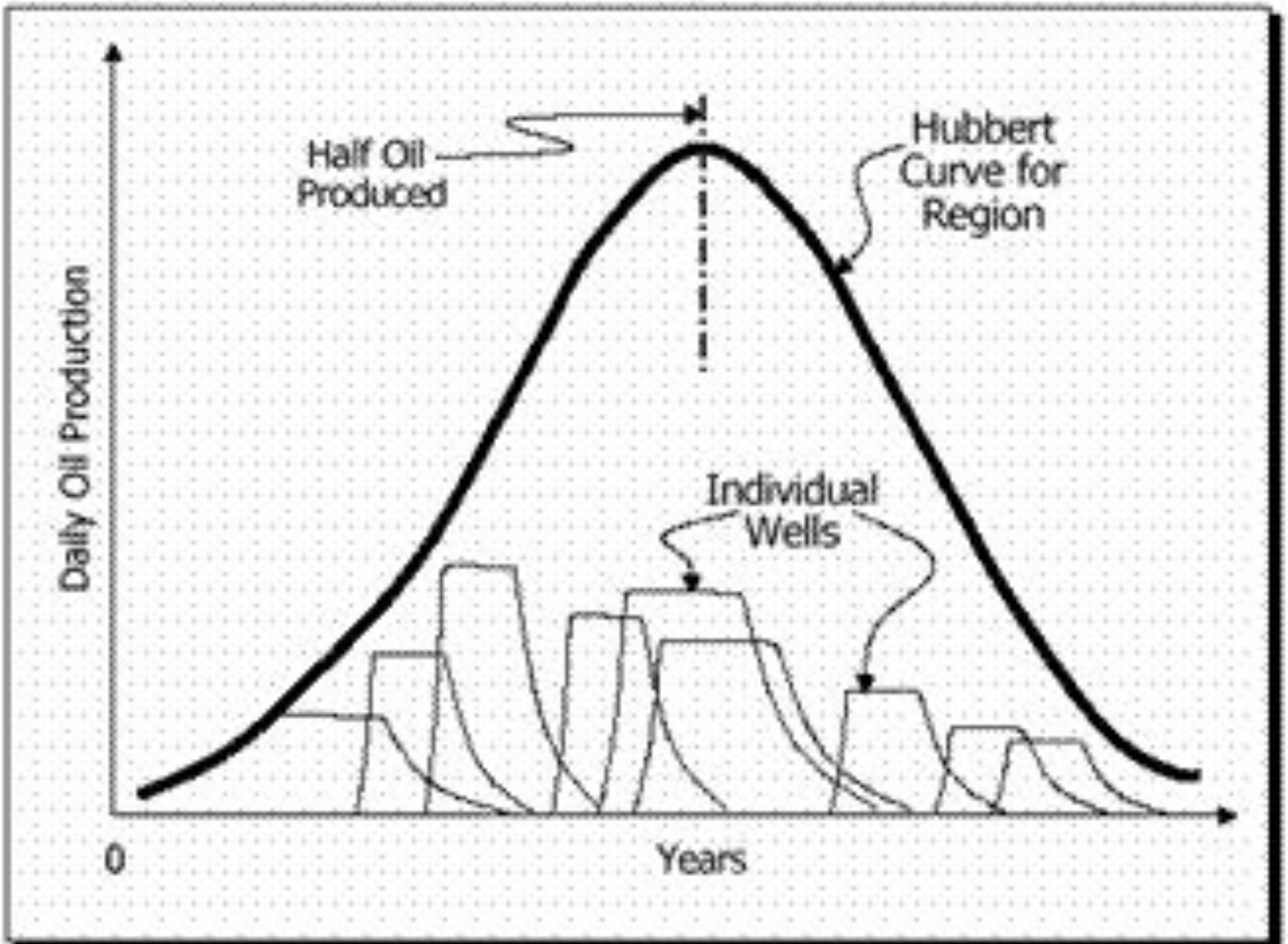
- Crude oil (called "petroleum") is easier to get out of the ground than coal, as it can flow along pipes. This also makes it cheaper to transport
- Natural gas provides around 20% of the world's consumption of energy, and as well as being burnt in power stations, is used by many people to heat their homes.
- It is easy to transport along pipes, and gas power stations produce comparatively **little pollution**

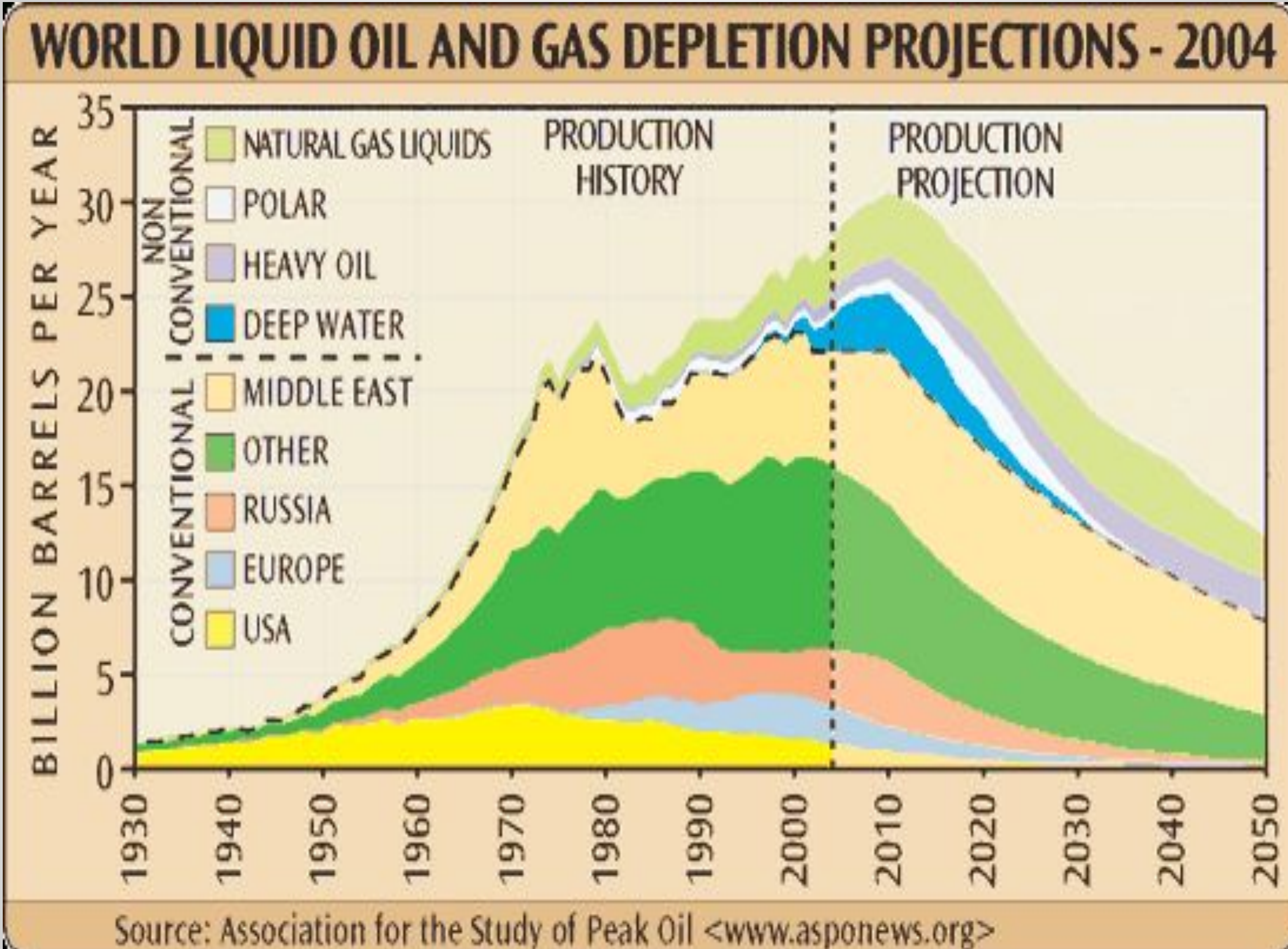
Petroleum and Natural Gas Extraction



- an average well in the US produces only 11 barrels / day
- In Saudi Arabia an average produces 9600 barrels /day well

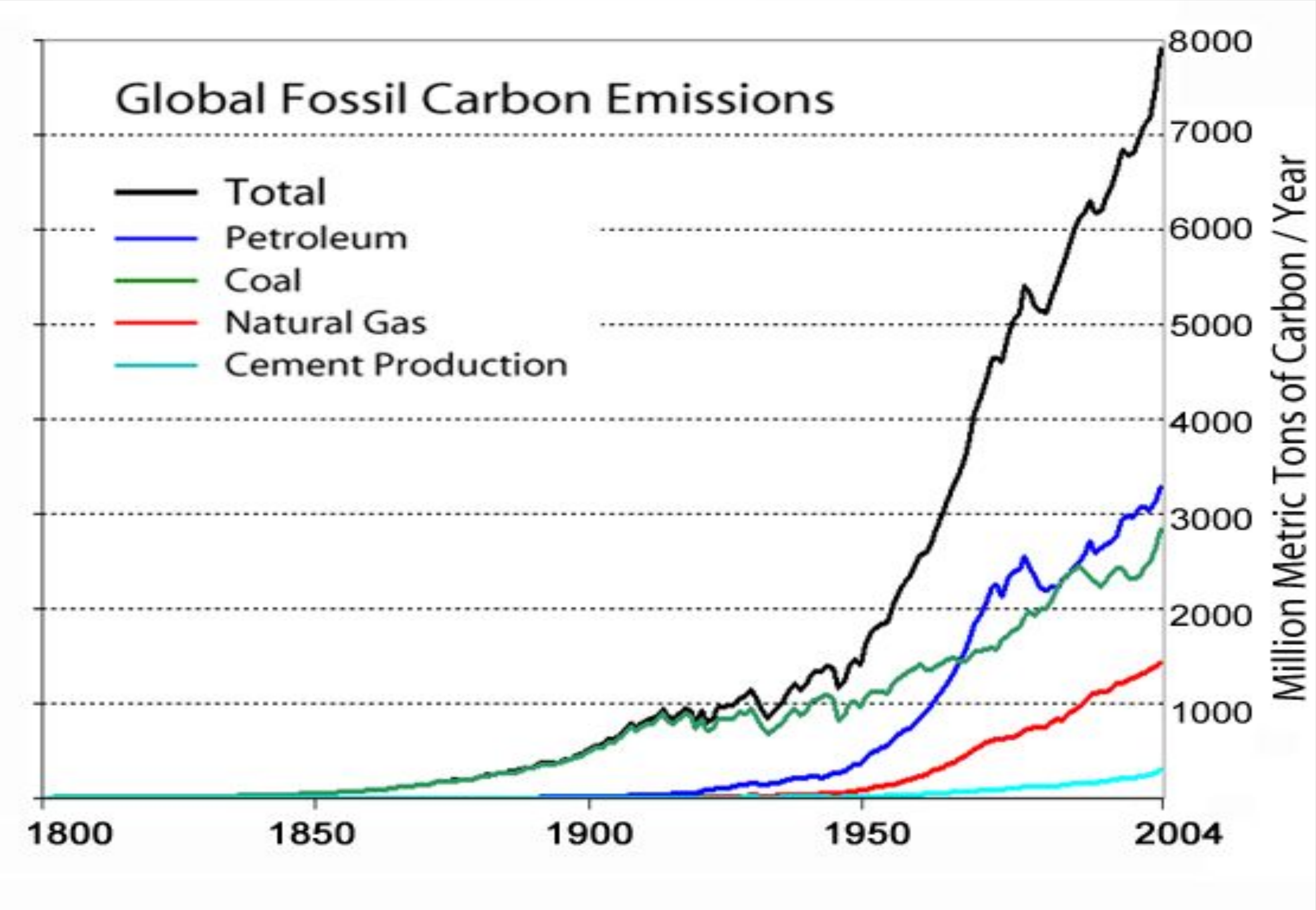
HUBBERT CURVE
Regional Vs. Individual Wells



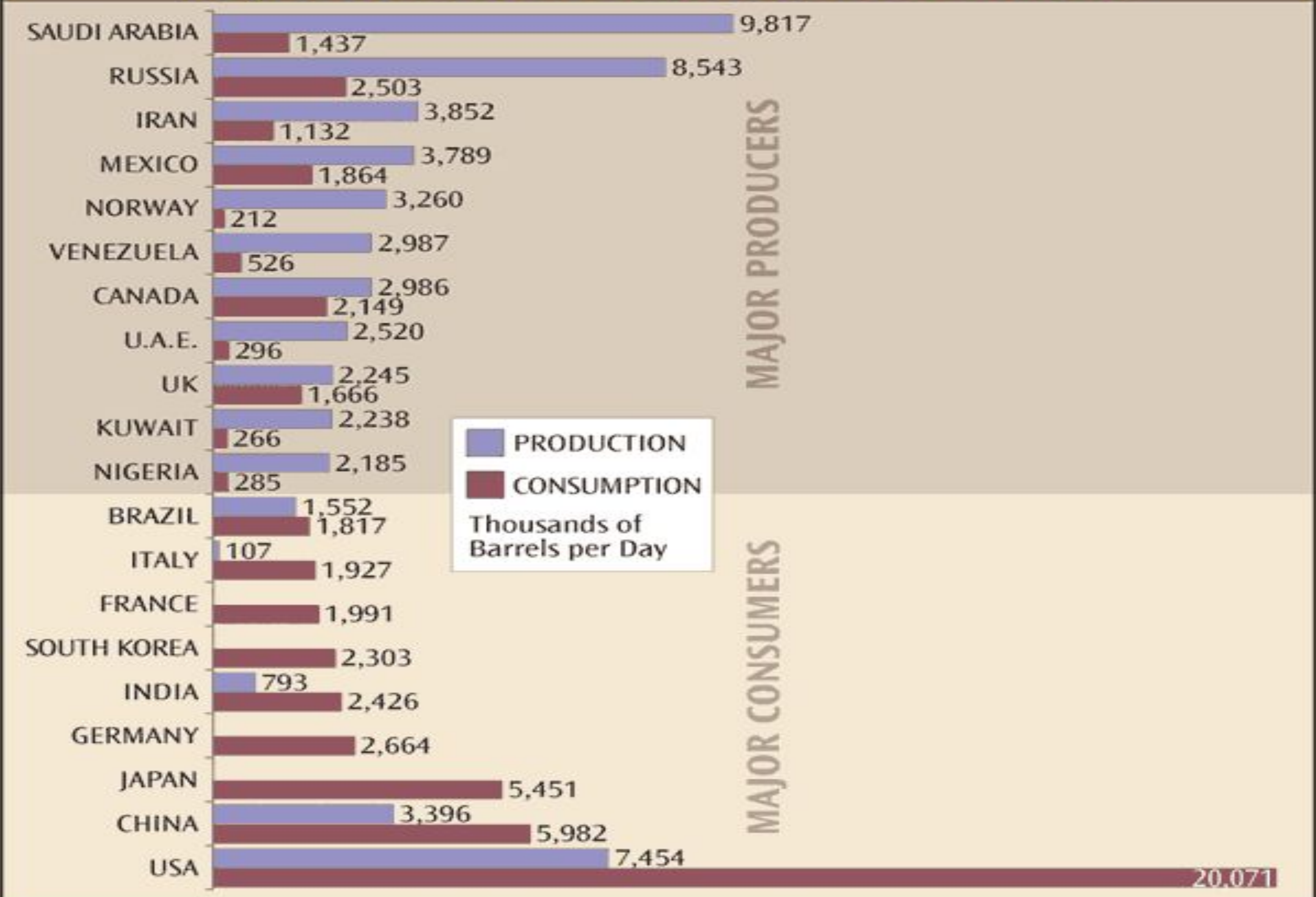


WORLD LIQUID OIL AND GAS DEPLETION PROJECTIONS - 2004
BILLION BARRELS PER YEAR
35
30
25
20
15
10
5
0
NON CONVENTIONAL
NATURAL GAS LIQUIDS
POLAR
HEAVY OIL
DEEP WATER
CONVENTIONAL
MIDDLE EAST
OTHER
RUSSIA
EUROPE
USA
PRODUCTION HISTORY
PRODUCTION PROJECTION
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Source: Association for the Study of Peak Oil <www.asponews.org>

Massive Increase in Fossil Fuel Use and CO_2 emissions.

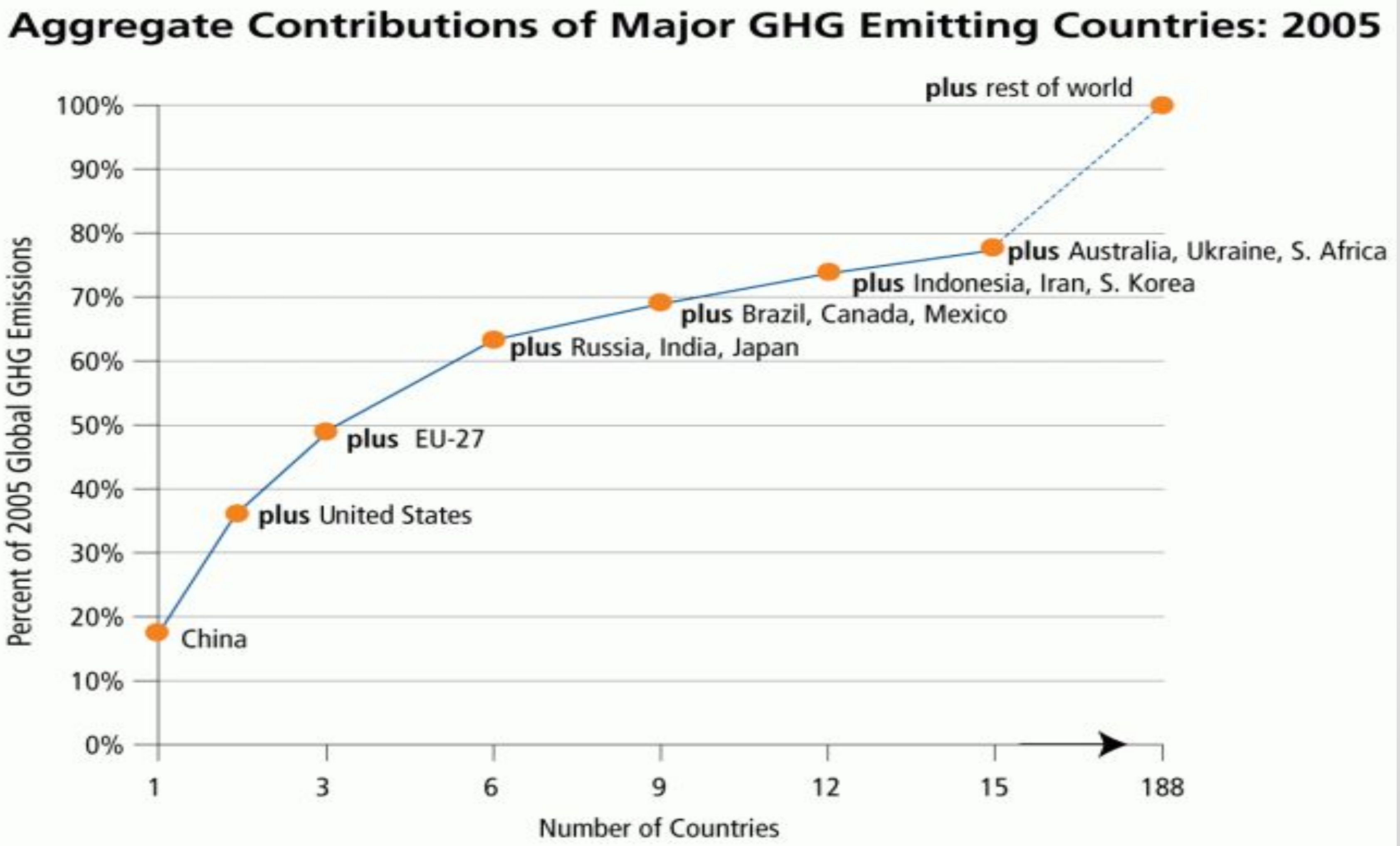


MAJOR OIL PRODUCERS AND CONSUMERS



Source: BP Statistical Review of World Energy 2004 <http://www.bp.com/statisticalreview2004>

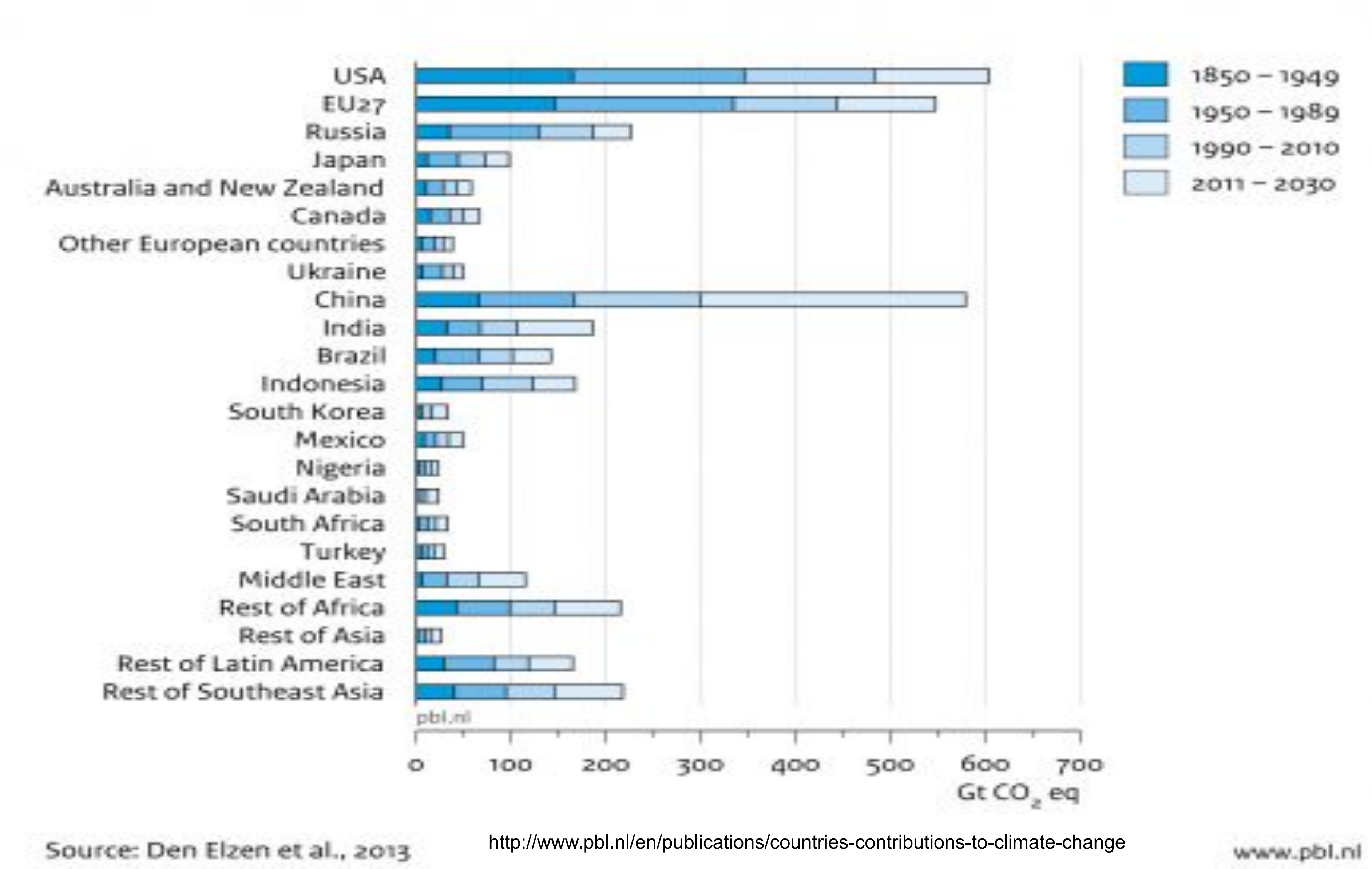
Aggregate Contributions of Major GHG Emitting Countries: 2005



Sources & Notes: WRI, CAIT (http://cait.wri.org). Percent contributions are for year 2005 GHG emissions only. Moving from left to right, countries are added in order of their absolute emissions, with the largest being added first. Figures exclude emissions from land-use change and forestry, and bunker fuels. Adapted from Figure 2.3 in Baumert et al. (2005).

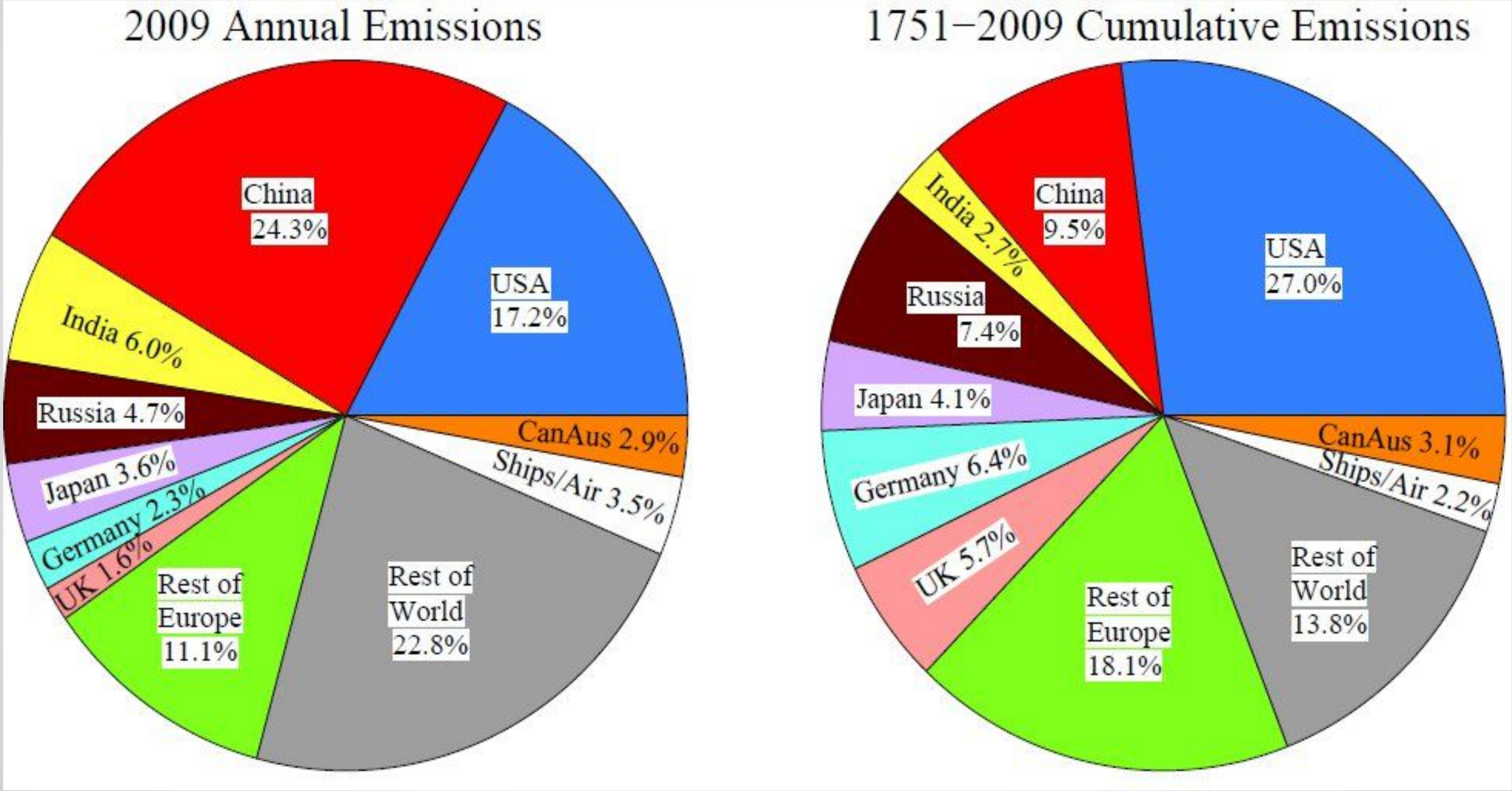
http://www.wri.org/resources/charts-graphs/aggregate-contributions-major-ghg-emitting-countries-2005

Country-Wise Total Cumulative GHG Emissions



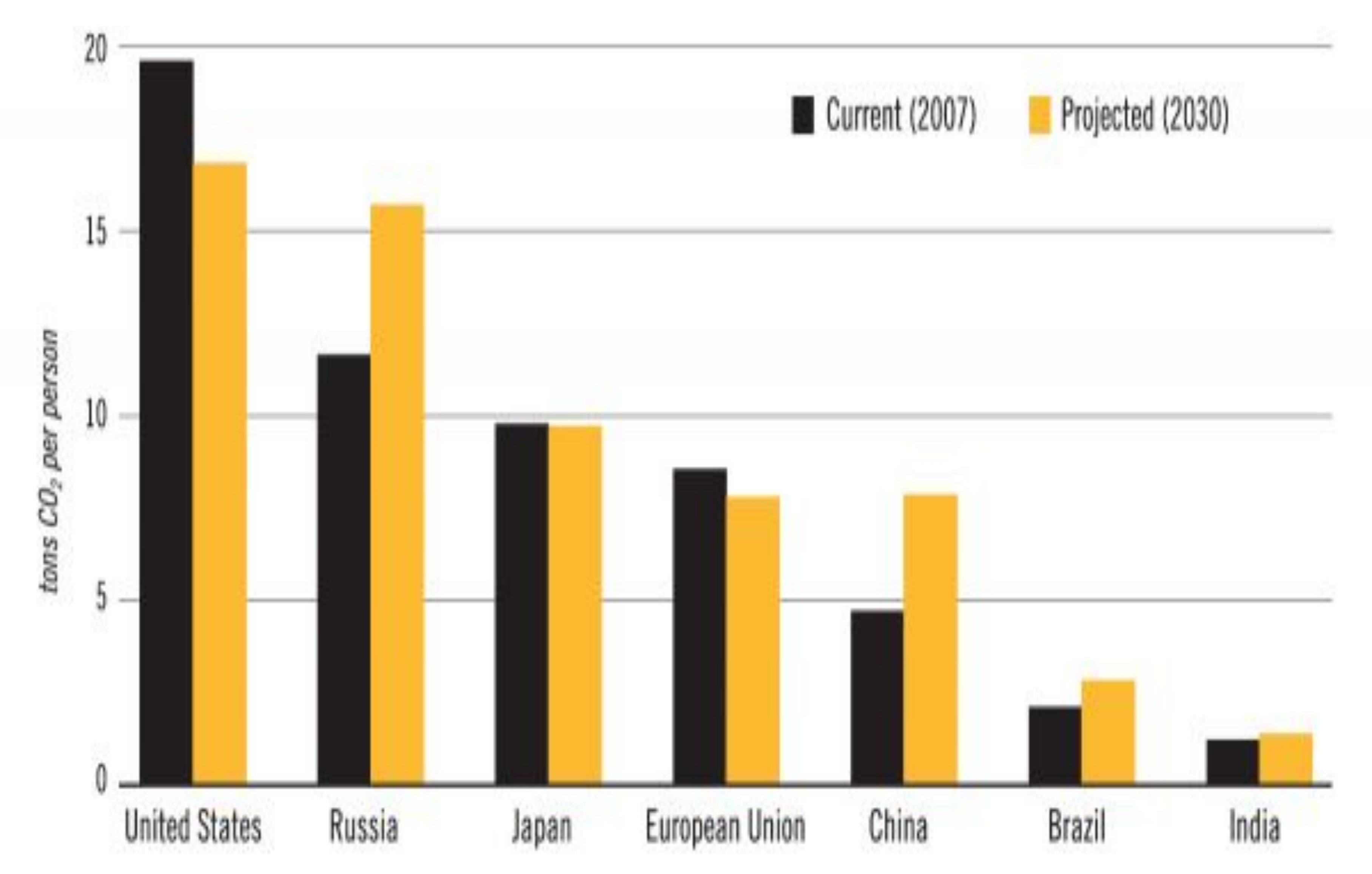
http://www.pbl.nl/en/publications/countries-contributions-to-climate-change

GHG Emissions Countries



http://www.resilience.org/stories/2010-12-09/china-can-slow-global-warming-if-us-won%E2%80%99t

Country-Wise Per Capita CO_2 Emissions



If OIL is running out, why not use COAL?

Surely, there’s plenty of it.

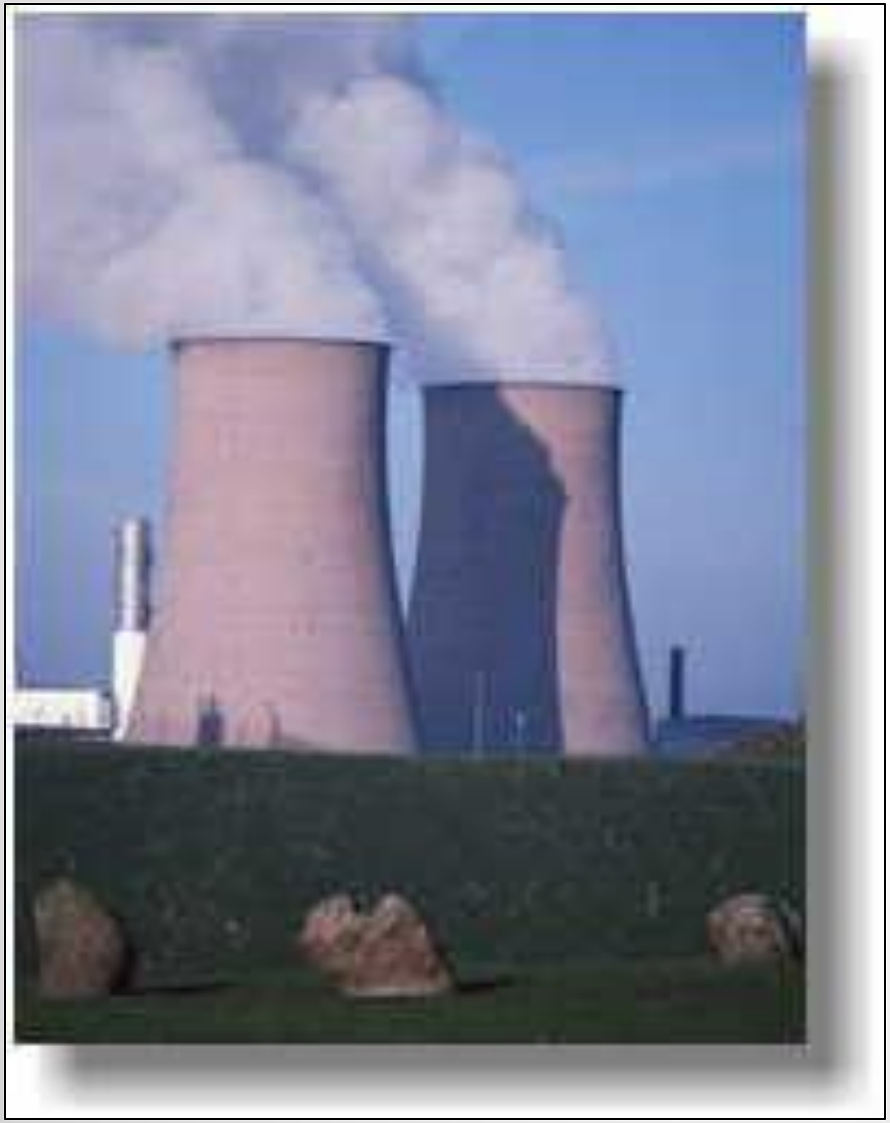
Advantages of Coal

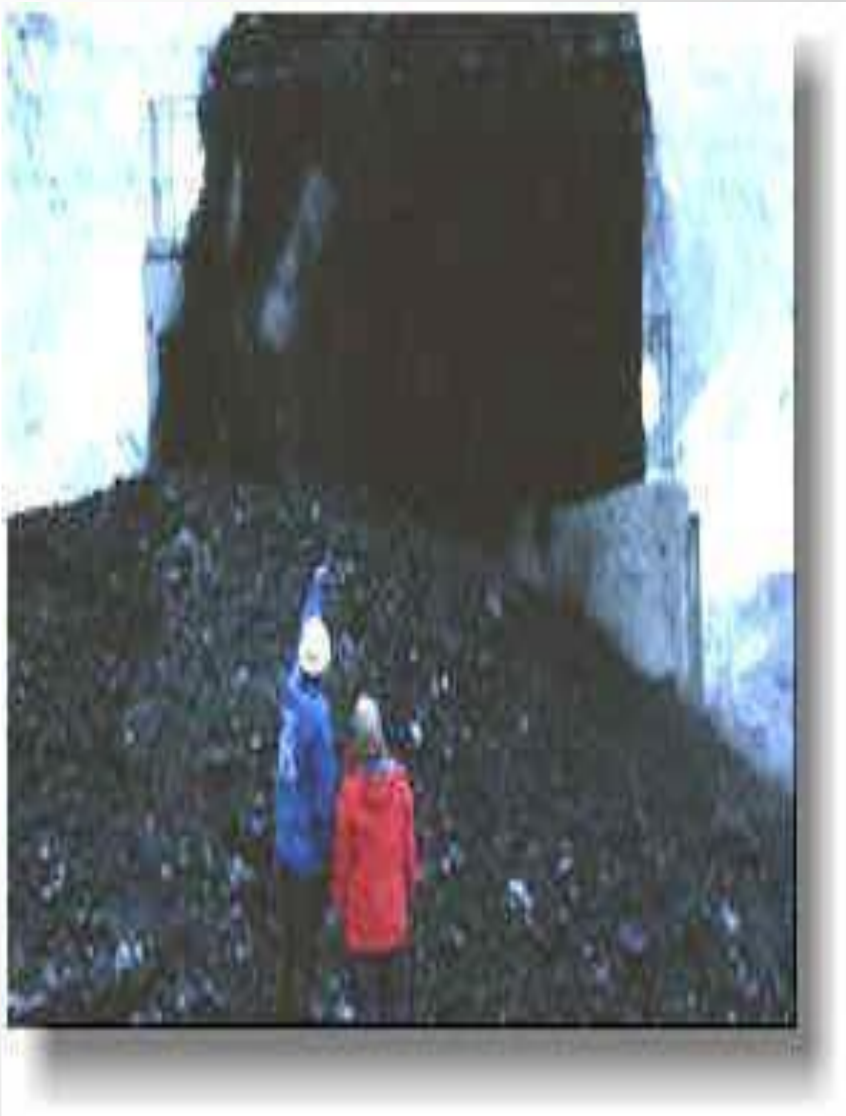
- World reserves are relatively more plentiful
- Technology is old and established
- High energy content.
- Solid fuel is easy to transport.
- New technologies such as clean coal technology, gasification, reforming etc. are coming up.

Coal Mining

- A coal mine in Bihar, India.

Emission of gases





Disadvantages of coal

- Being a C-based fuel, causes greenhouse emissions. Coal is the largest contributor to the human-made increase of CO_2 in the air.
- Will run out in 56 years (in 2065) if current acceleration in its use continues.
- Extensive land degradation and pollution due to mining.
- 100s of mi. tons of waste products (fly ash, bottom ash, flue gas desulfurization sludge) containing **mercury, uranium, thorium, arsenic, and other heavy metals**
- Acid rain from high sulfur coal
- Interference with groundwater and water table levels

http://en.wikipedia.org/wiki/Coal#Environmental_effects

Disadvantages of coal

- Contamination of land and waterways and destruction of homes from fly ash spills.
- Dust nuisance
- Coal-fired power plants without effective fly ash capture are one of the largest sources of human-caused background radiation exposure
- Diseases caused by coal-fired power plants~24,000 lives/yr in USA

Methods to control the pollution

- Clean coal technology to burn coal more efficiently and will lesser toxic pollutants emitted.
- Flue gas desulphurisation: removes the acid rain-producing sulphur oxides from the flue gas
- **Yet combustion of coal invariably leads to CO_2 emissions and global warming**

Alright, coal looks quite awful.

But what about Natural Gas?

That’s supposed to be pretty clean, right?

Natural Gas

- Natural gas (mostly CH_4) is more potent as a greenhouse gas than its combustion product, CO_2.
- Was once wasted during oil drilling.
- Often simply flared from an oil well.
- More recently it has been put to use.
- Methane does not get liquefied upon compression at room temperature: CNG is used in public transportation and private vehicles.

Natural Gas

- Low energy density
- Burns cleaner than petrol/diesel.
- NO_x emissions continue to remain a problem.
- World gas reserves: Will last 60 yrs. at current rate of consumption.—Dr. Anthony Hayward CCMI, chief executive of BP 2009.

Effects of Fossil fuels

- Global warming and climate change due to emissions from burning
- Mining, extraction and refining processes are themselves highly energy consuming, and polluting and disrupt human and natural habitats in the vicinity.
- Reduced biodiversity due to impacts on environment.
- Adverse effects on land surface and groundwater.
- Contamination of water bodies, heavy toll on marine ecosystems, due to pollution and oil spills

OK, forget about Fossil Fuels. They all seem bad.

Let’s GO NUCLEAR!

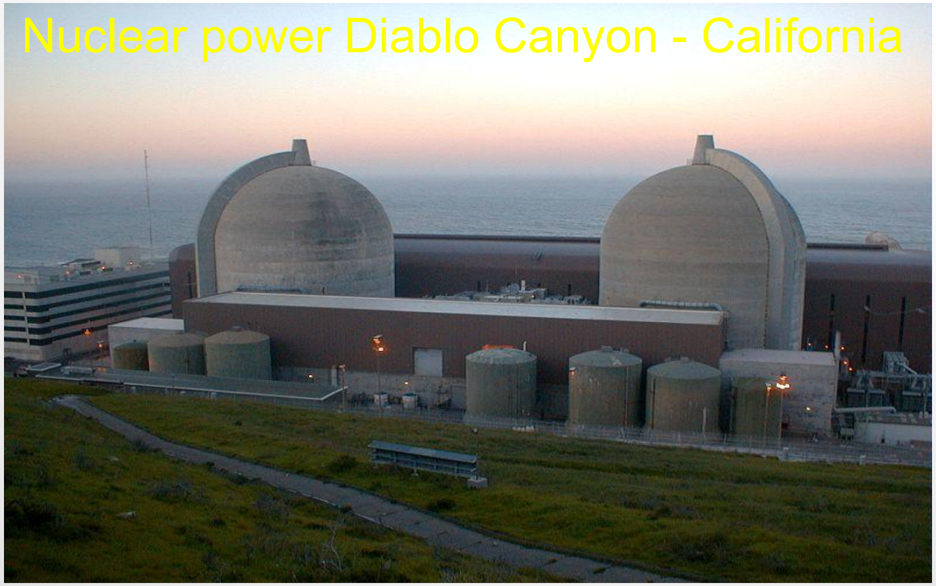
Enormous quantities of cheap energy with no emissions!

Nuclear Energy

- **Nuclear Energy** is energy released due to the splitting (fission) or merging together (fusion) of the nuclei of atom(s).
- **Nuclear power** is most commonly generated using uranium, which is a metal mined in various parts of the world.
- Some military ships and submarines have nuclear power plants for engines

Nuclear Energy

- Nuclear power: 4-largest source of electricity in India.
- As of 2010, India has 19 nuclear power plants in operation generating 4,560 MW while
- 4 others under construction and are expected to generate an additional 2,720 MW.
- In France 79% of electricity comes from nuclear reactors



Advantages

- Nuclear power costs about the same as coal, so it's not expensive to make.
- Does not produce smoke or carbon dioxide, so it does not contribute to the greenhouse effect.
- Produces huge amounts of energy from small amounts of fuel.
- Produces small amounts of waste.
- Nuclear power is reliable.

Disadvantages

- It can be extremely dangerous.
- Nuclear power is reliable, but a lot of money has to be spent **on safety** - if it **does** go wrong, a nuclear accident can be a major disaster.
- Small quantities of spent fuel wastes: huge disposal issue.
- Serious inter-generational ethical issues exist.
- “Nuclear power, which for some countries plays a strategic role in energy security, faces an uncertain future.”--World Energy Outlook 2014

Come on, the safety issue is exaggerated!

Don’t nuclear power plants follow strict safety regulations?

Accidents, if at all might have happened in the past and that too in only in the Soviet Union.

International Nuclear Event Scale

7 – Major Accident

6 – Serious Accident

5 – Accident With Wider Consequences

4 – Accident With Local Consequences

3 – Serious Incident

2 – Incident

1 – Anomaly

0 – Deviation (No Safety Significance)

Nuclear Accidents Worldwide

Event Scale	Designation	Example
7	Major Accident	Fukushima Daiichi nuclear disaster (2011), Chernobyl disaster, 26/4/1986. 56 dead; 4,000 cancer fatalities, 600,000 exposed to elevated doses of radiation.
6	Serious Accident	Kyshtym disaster at Mayak, Soviet Union, 29/9/1957. 70-80 tons of highly radioactive material into the environment. Impact on local population is not fully known.
5	Accident With Wider Consequences	• **Windscale fire** (UK), 10/10/1957. Radionuclide released , 200-240 thyroid cancer cases expected. • **Three Mile Island accident** (US), 28/3/1979Some radioactive gases were released into the atmosphere. • **Goiânia accident** (Brazil), 13/9/1987. An unsecured caesium chloride radiation source left in an abandoned hospital was recovered by squatters unaware of its nature and sold at a scrapyard. 249 people contaminated; 4 died.

Nuclear Accidents Worldwide

Event Scale	Designation	Example
4	Accident With Local Consequences	• Sellafield (United Kingdom) - 5 incidents 1955 to 1979[3] • SL-1 Experimental Power Station (United States) - 1961, reactor reached prompt criticality, killing three operators • Saint-Laurent Nuclear Power Plant (France) - 1980, partial core meltdown • Buenos Aires (Argentina) - 1983, criticality accident during fuel rod rearrangement killed one operator and injured 2 others • Jaslovské Bohunice (Czechoslovakia) - 1977, contamination of reactor building • Tokaimura nuclear accident (Japan) - 1999, three inexperienced operators at a reprocessing facility caused a criticality accident; two of them died

Nuclear Accidents Worldwide

- Worldwide 99 accidents at nuclear power plants.
- Of which 57 occurred since the Chernobyl disaster
- 57% (56 out of 99) occurred in the USA.[7]
- Serious nuclear power plant accidents include:
  - the Fukushima Daiichi nuclear disaster (2011),
  - Chernobyl disaster (1986),
  - Three Mile Island accident (1979)
  - SL-1 accident (1961).[8]
- Highest cumulative loss among energy-related accidents.

The French Atomic Energy Commission (CEA) has concluded that technical innovation cannot eliminate the risk of human errors in nuclear plant operation.

http://en.wikipedia.org/wiki/Nuclear_and_radiation_accidents

- 99 nuclear reactor accidents world-wide is not a big deal! It shows how safe the technology is!
- Auto accidents happen in millions.

- Radioactivity-related accidents/leaks can lay waste contaminated land for thousands of years.
- Immediate deaths (which are very few) are not the best way of quantifying damage.
- Affects exposed persons and future generations (mutations, birth defects).

Radioactive Waste Disposal

- The cumul. total of spent nuclear fuel > 700,000 tonnes.
- Radioactive wastes can remain a concern for thousands of years and several half-lives.
- Long term and inter-generational health impacts should be examined critically.
- Practical studies only consider up to 100 years as far as effective planning and cost evaluations are concerned.
- To date, no country has opened a permanent disposal facility to isolate the most long-lived and highly radioactive waste produced by commercial reactors--World Energy Outlook 2014
- If safe disposal as promised by various governments and nuclear agencies is so easy then why did they do this...?

Illegal Dumping—Mafia

- 'Ndrangheta mafia clan accused of trafficking and illegally dumping nuclear waste.
- A manager of the Italy's state energy research agency "Enea" paid the clan to get rid of 600 drums of toxic and radioactive waste from Italy, Switzerland, France, Germany, and the US, with Somalia as the destination, where the waste was buried after buying off local politicians.
- Enea employees are suspected of paying the criminals to take waste off their hands in the 1980s and 1990s.
- Ndrangheta claim to have been paid to sink ships with radioactive material for the last 20 years.

http://en.wikipedia.org/wiki/Toxic_waste_dumping_by_the_%27Ndrangheta

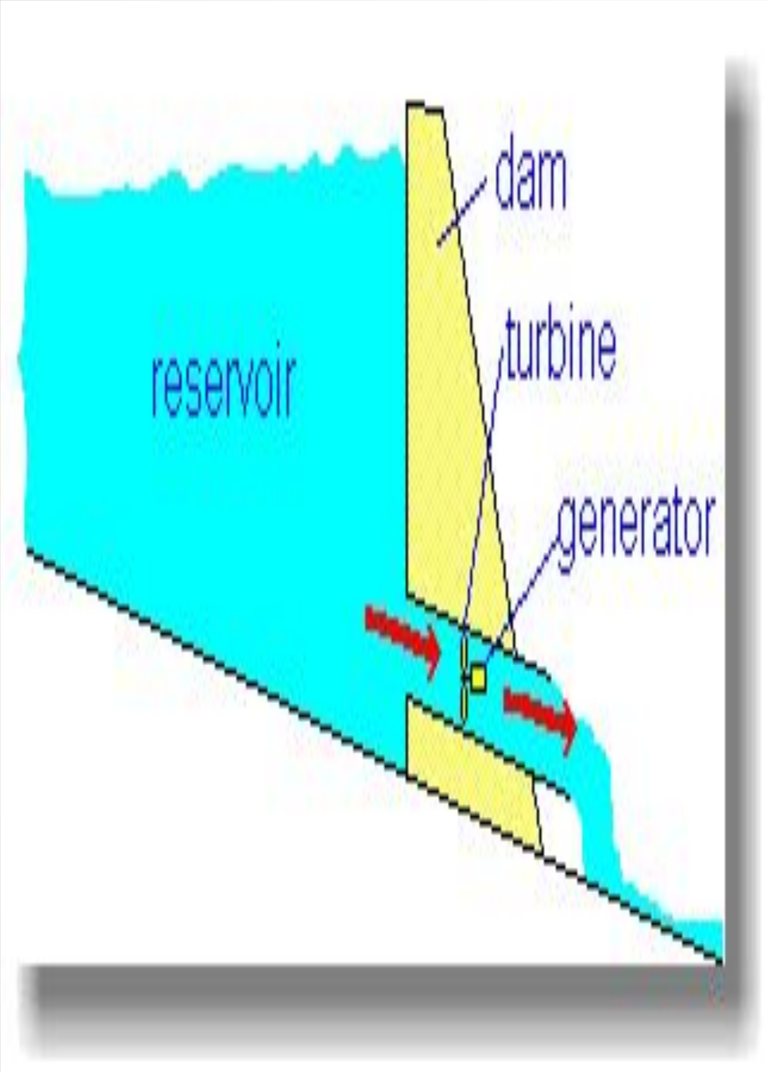
Reading Material:

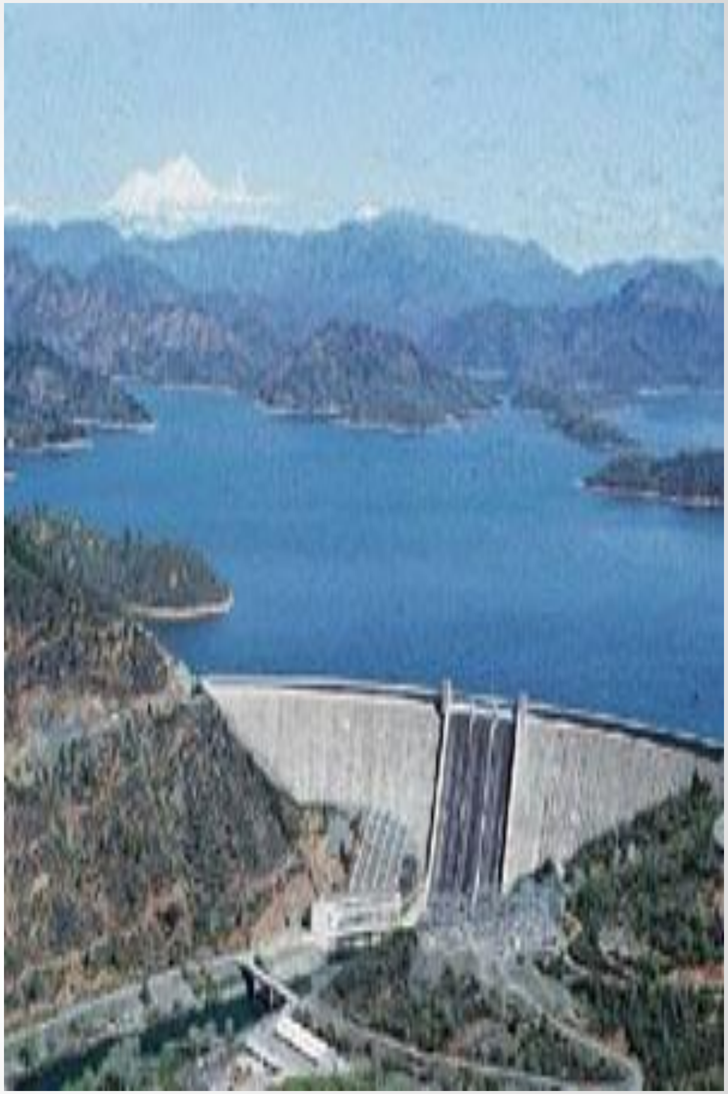
- Pros and Cons of the Nuclear Energy Debate.
- Whole Earth Discipline (pro-nuclear)
- Four Nuclear Myths: A Commentary on Stewart Brand's Whole Earth Discipline and on Similar Writings (pro-renewables)

OK, just stop!
Let’s not get into a debate...

What about plain and simple Hydroelectric Power?

There couldn't possibly be any problem with it!





Water generated – Hydroelectric
Shasta dam in California

Hydroelectric Power: Advantages

- Low running costs
- No waste or pollution.
- High reliability, continuous generation.
- Electricity can be generated constantly
- Easy to step up or step down generation to meet peak demand.
- Allied benefits related to creation of reservoirs such as irrigation, flood control, recreation.

Hydroelectric Power: Disadvantages

- High initial costs
- Huge areas submerged: displacement of thousands of people and habitat destruction.
- Deforestation in the catchment
- Loss of fertile riverbed land in catchment
- Loss of fertile land downstream due to water logging
- Greenhouse gas emissions from submerged and waterlogged land

Secure Energy Systems

- “The foundation of a secure energy system is:
    - to need less energy in the first place,
    - Then to get it from sources that are inherently invulnerable because they're diverse, dispersed, renewable, and mainly local.
- Any highly centralised energy system -- pipelines, nuclear plants, refineries -- invite devastating attack. But invulnerable alternatives don't, and can't, fail on a large scale.”

--Amory Bloch Lovins (physicist, environmental scientist, writer, and Chairman/Chief Scientist of the Rocky Mountain Institute.)

Well…then it looks like we cannot depend on any of the conventional energy sources.

But there are alternative forms of energy right?

Why can't we use them?

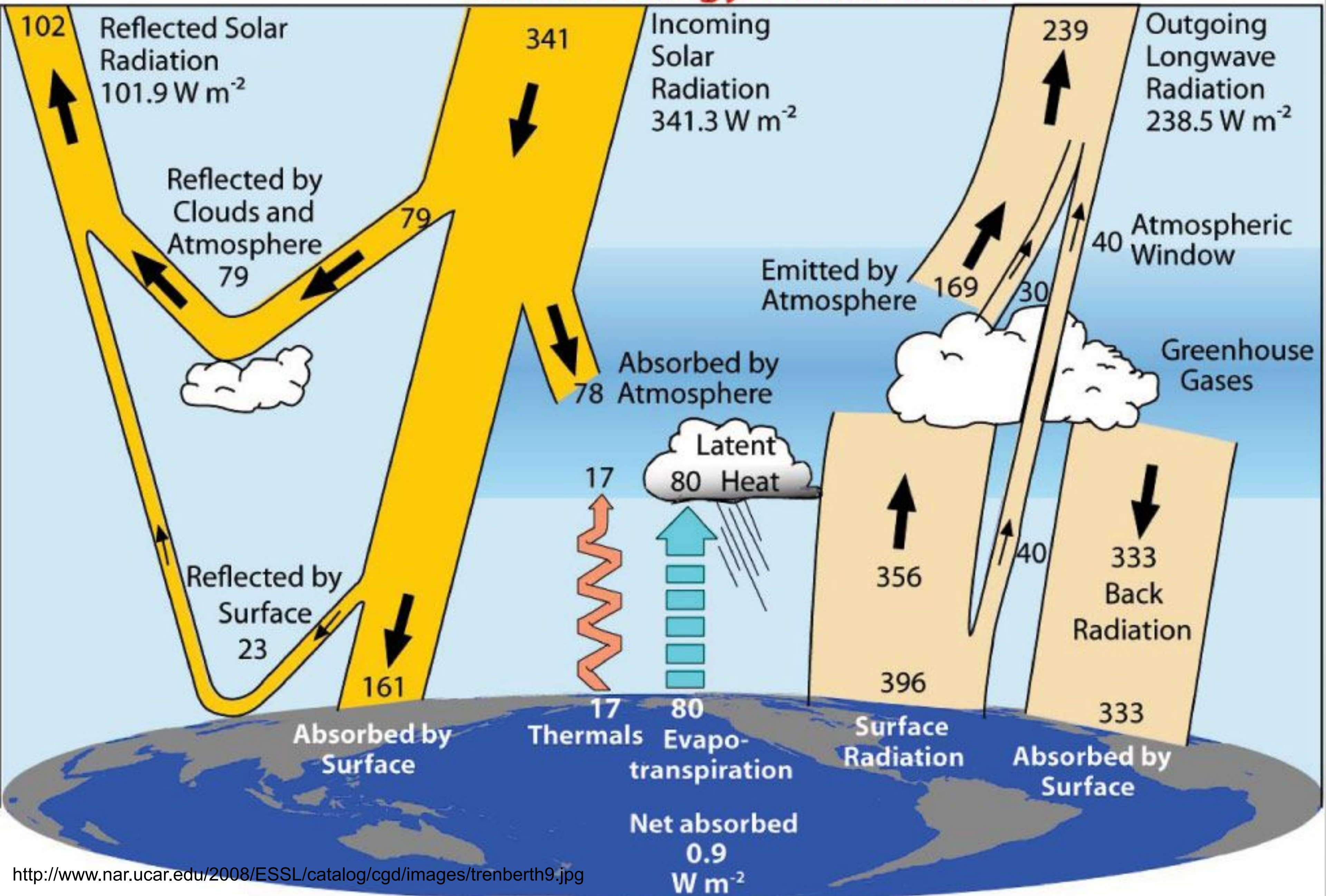
Outline

- Units and Terms
- Energy Resources, Depletion and Risks
- Environmentally Benign Forms of Energy
- Efficiency Measures
- Reduction in Consumption—Individual Perspective

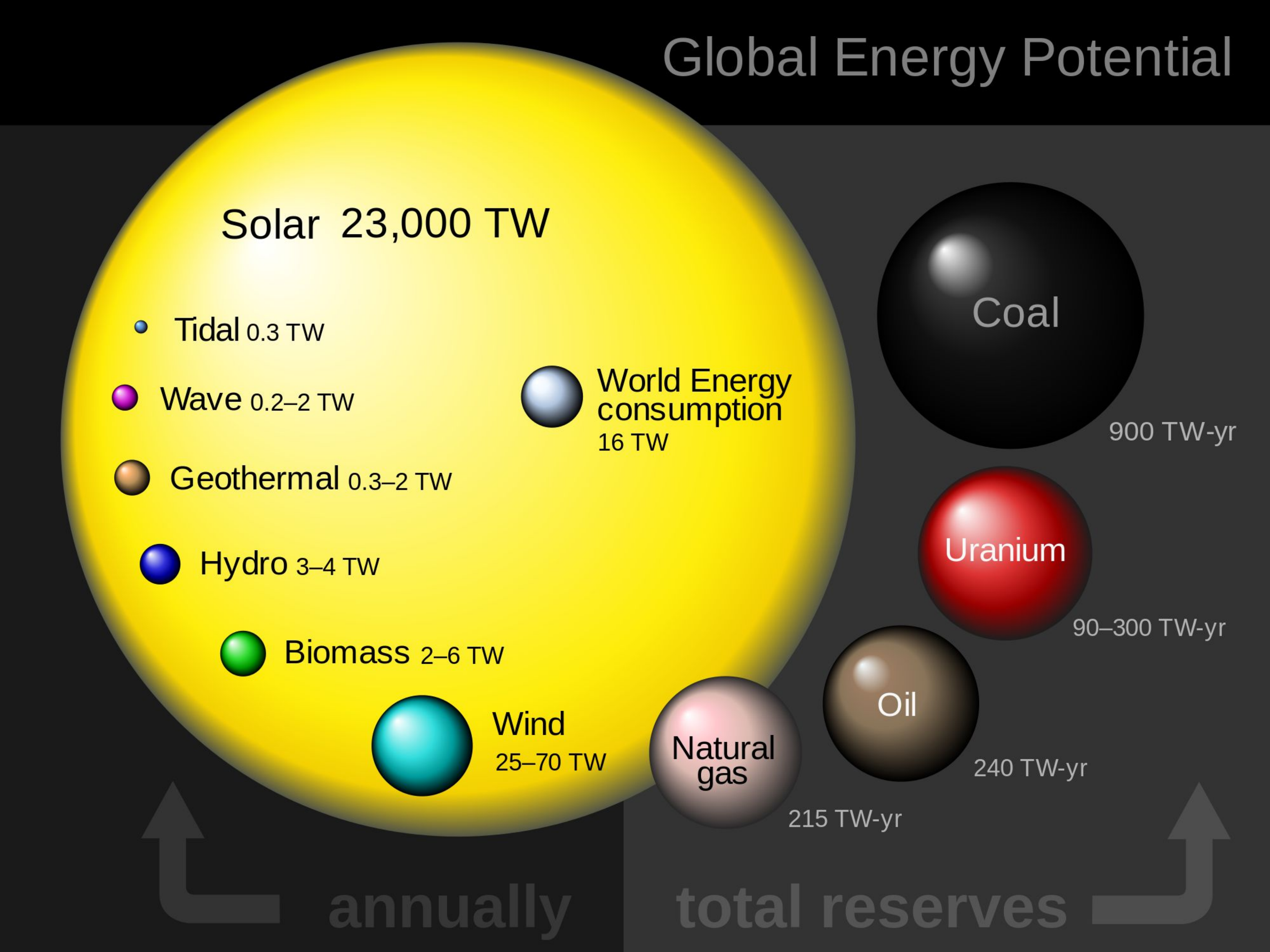
Alternative Energy: Good News

- The continuous/renewable energy resources on Earth far exceed present human needs.
- In general, we have the technology to harness them.
- But some gaps exist...
- That's where there is a tremendous scope for R&D and huge potential markets!

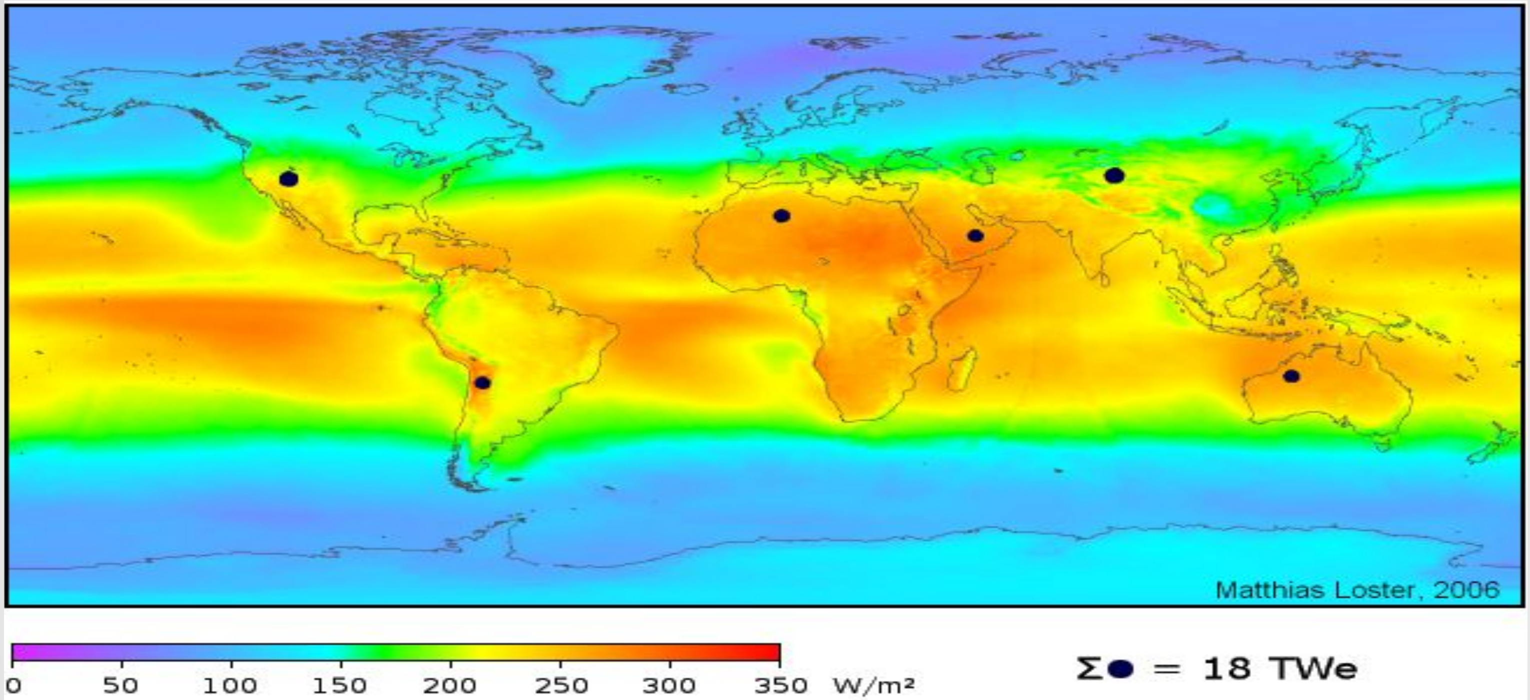
Global Energy Flows W m^{-2}



http://www.nar.ucar.edu/2008/ESSL/catalog/cgd/images/trenberth9.jpg

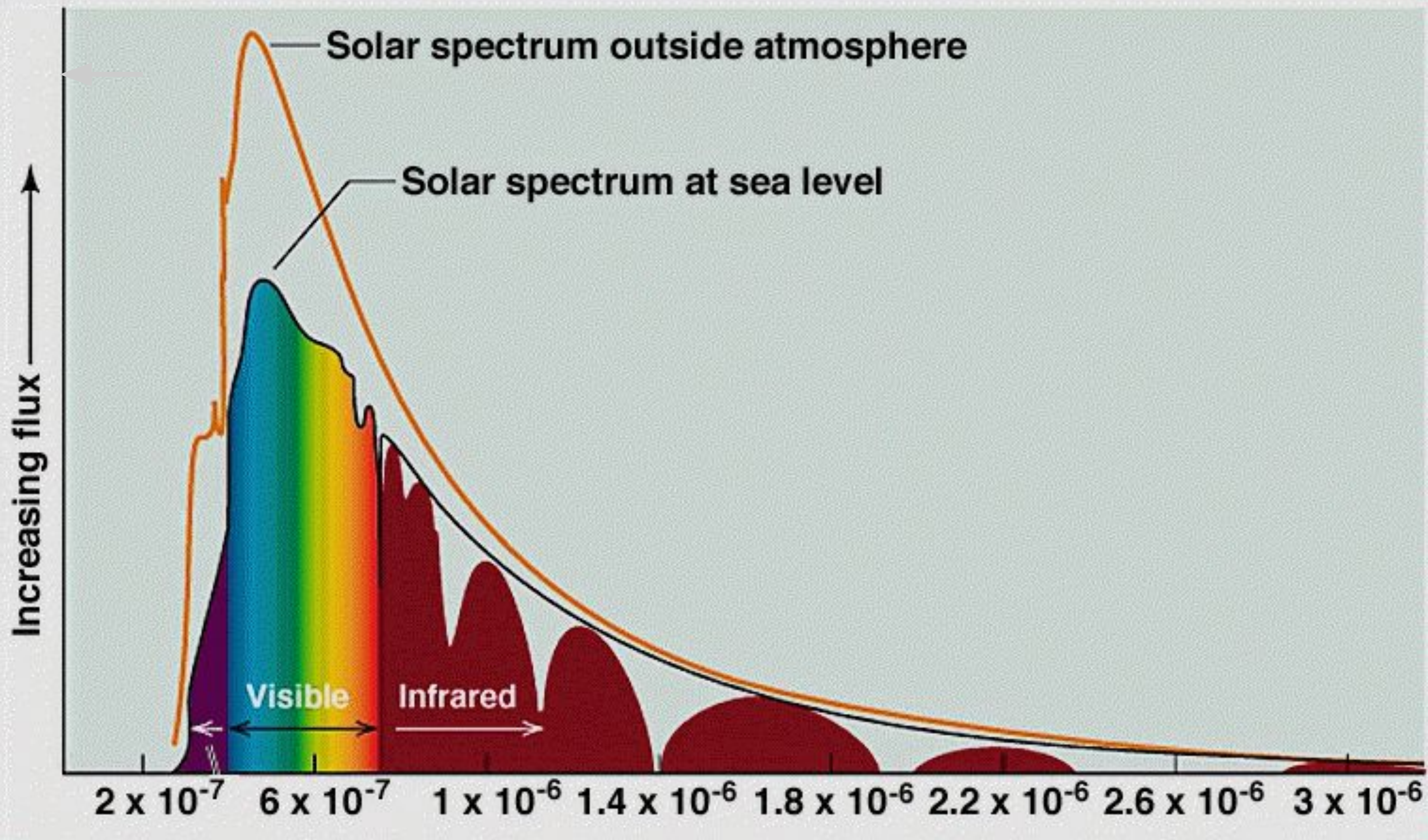

Global Energy Potential
Solar 23,000 TW
Tidal 0.3 TW
Wave 0.2–2 TW
Geothermal 0.3–2 TW
Hydro 3–4 TW
Biomass 2–6 TW
Wind 25–70 TW
World Energy consumption 16 TW
Coal 900 TW-yr
Uranium 90–300 TW-yr
Oil 240 TW-yr
Natural gas 215 TW-yr
annually
total reserves

We have Enough Renewable Energy!



- All human energy and fuel needs, supplied by black spots of solar cell areas
- At conversion efficiency of 8%; cloud cover accounted for.
- Colors show the local solar irradiance averaged over three years from 1991 to 1993 (24 hours a day)
- http://www.ez2c.de/ml/solar_land_area/

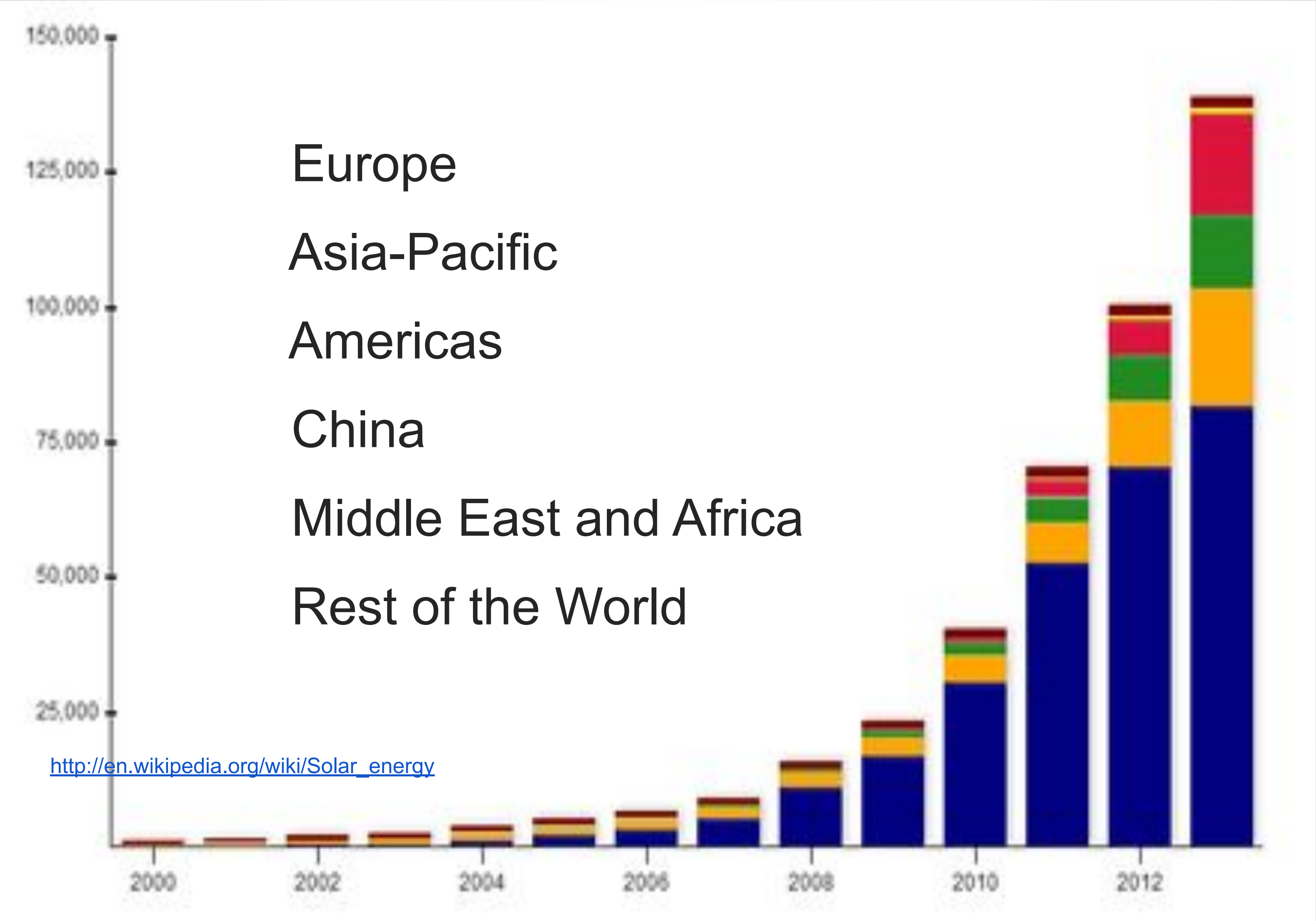
The Solar Spectrum



Applications of Solar Energy

- Heating and cooling of residential building.
- Solar water heating.
- Solar cookers
- Solar engines for water pumping.
- Food refrigeration
- Solar furnaces
- Solar electric power generation by solar ponds, reflectors with lenses.
- solar photovoltaic cells, which can be used for conversion of solar energy directly into electricity.

Worldwide Growth of PV



http://en.wikipedia.org/wiki/Solar_energy

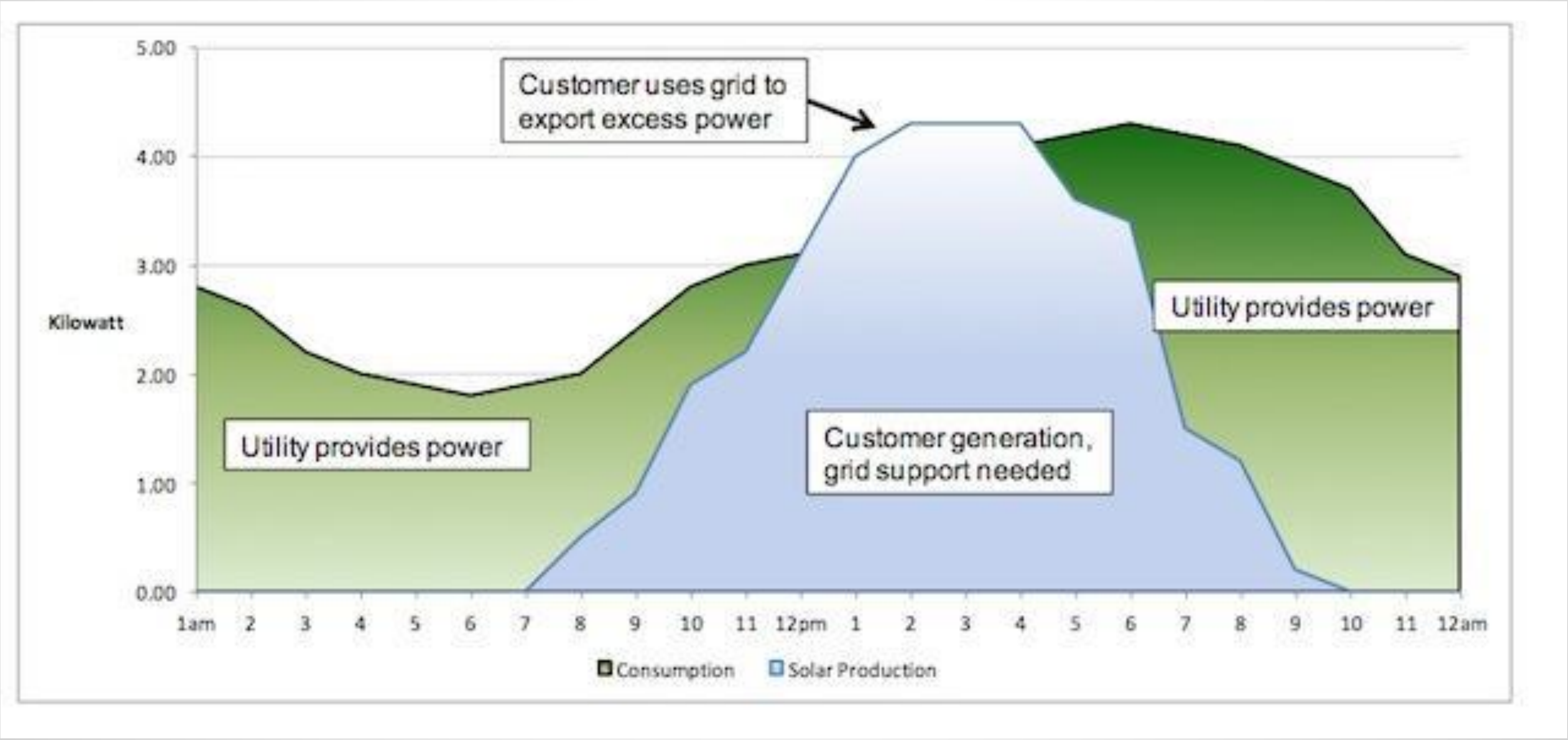
Overcoming Disadvantages (Solar)

- **Solar energy is available intermittently: dependent on weather conditions and the time of day**
- **Luckily, large amount of energy demand is during daytime.**
- **Grid-connected solar systems are most convenient.**
  - During the night and cloudy days, traditional methods (fossil/nuclear/hydel) can be used to supply power to the grid.
  - Minimize the need to store the energy. The consumer can save battery costs (~ 50% of PV system costs).
  - It will greatly decrease our dependence on fossil fuels.
  - Enables private investment in the nation's energy infrastructure.
  - Captive energy for the consumer (individual/ organization)
  - Feed-in tariffs/net metering can enable the consumer to sell extra power generated.

Overcoming Disadvantages (Solar)

- Grid connected solar systems have some challenges
  - Most states do not allow grid connected solar with feed-in tariffs/ net metering.
  - The grid in many countries including India, is unreliable and subject to frequent and extended blackouts and brownouts.
  - Adequate studies and governing standards and mechanisms for ensuring reliability and power quality of grids connected to numerous distributed micro-generation units are missing.

Net Metering



http://blogs-images.forbes.com/jamesconca/files/2014/11/SolarGrid.jpg

Overcoming High Cost (Solar)

- **High initial cost of solar cells**
  - **Coal electricity costs \$0.08-0.20 cents/kWh,**
  - **PV electricity costs \$0.50-1.00/kWh.**
- **Fossil fuel energy costs do not include the socio-environmental costs.**
  - **If all costs are internalized, solar might easily be a winner.**
- **Cheaper PV cells are available. Conversion efficiency is intimately tied to cost.**
  - **Crystalline Si and multijunction cells-- more efficient, more expensive**
  - **Amorphous Si--low efficiency but cheap.**

Building Integrated Photovoltaics (BIPV)

http://www.google.co.in/imgres?imgurl=http://media.treehugger.com/assets/images/2011/10/20090421-building-integrated-solar-tiles.jpg&imgrefurl=http://www.treehugger.com/renewable-energy/srs-energy-launches-building-integrated-photovoltaic-panels-for-clay-tile-roofs.html&h=315&w=468&tbnid=T0EGjVO6G6wA2M:&zoom=1&docid=TVp_PrG4vGc-uM&ei=K_gSVdmXC9OQuATl3oKoAg&tbm=isch&ved=0CEsQMyglMCU

h
1.jpg&imgrefurl=http://lightbysolar.co.uk/building-integrated-photovoltaics/&h=800&w=1200&tbnid=CYtiuXAIUHtKQM:&zoom=1&docid=meqc4QGMX5haHM&ei=K_gSVdmXC9OQuATl3oKoAg&tbm=isch&ved=0CEwQMygmMCY

Overcoming Low Efficiency (Solar)

- Overall efficiency of most PV systems can be is about 10-14%.
- **Some new ideas promise to be disruptive innovations (drastically more advantageous):**
  - Solar thermal, with cogeneration (solar energy utilization >60%)
  - Concentrated photovoltaics, with heat recovery (solar energy utilization > 72%)

Watch Video: Solar Co-Generation

Overcoming Disadvantages (Solar)

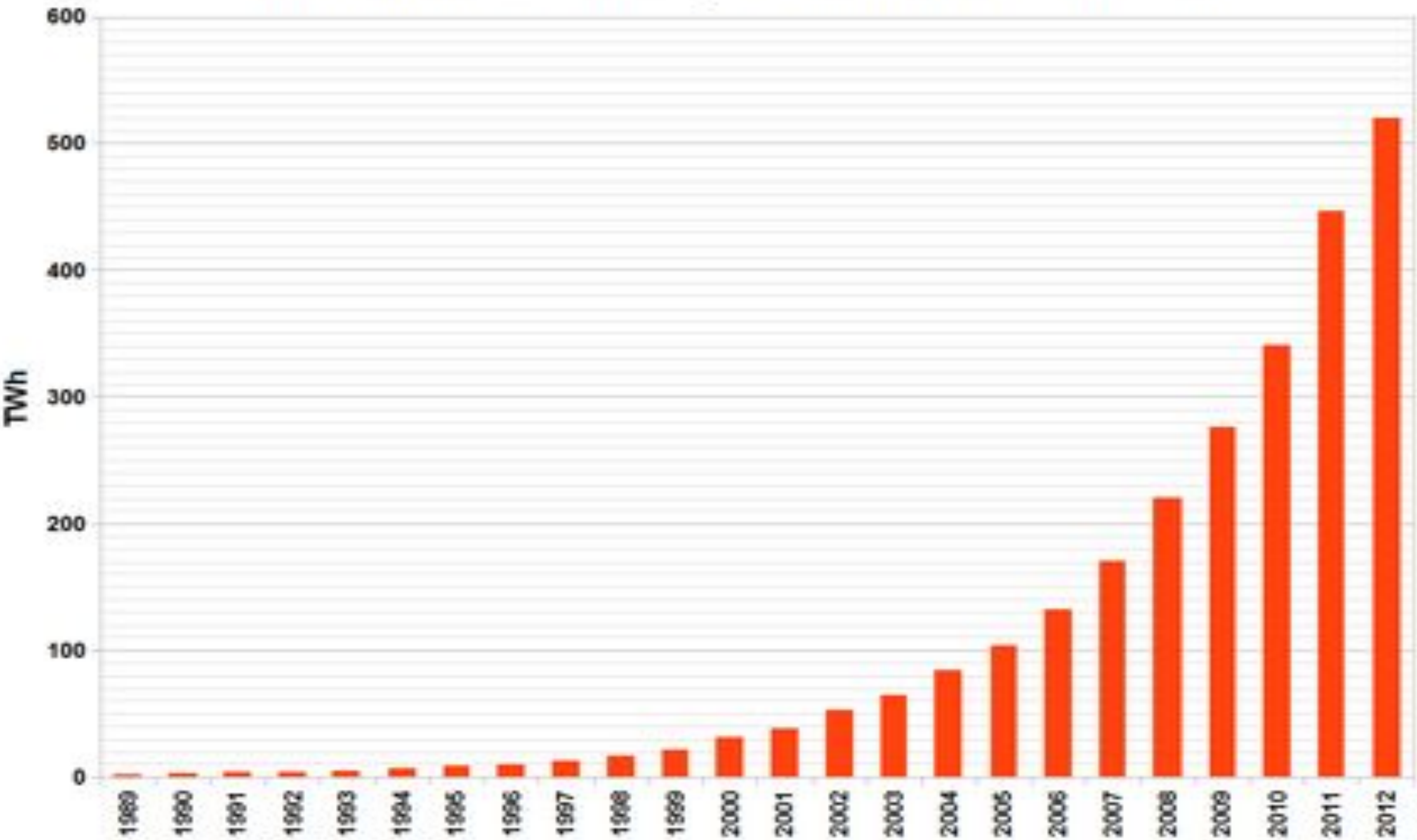
- Solar energy is a diffuse source. (low energy density).
- To harness it especially in the form of heat, we can concentrate it.
- Solar panels can be integrated into building roofs or other surfaces so that multiple functions can be served.

Solar reflector used for cooking

Solar Thermal

http://www.21stcentech.com/wp-content/uploads/2011/08/solar-thermal-9-storage-capacity.jpg

Worldwide Growth of Electricity Generation from Wind



http://en.wikipedia.org/wiki/Wind_power

Main Barriers for Renewable Energy

- Intermittence (wind, solar, wave, tidal, etc.)
- Unpredictability or poor predictability.
- Diffuseness or low energy density
  - (e.g. daily average solar insolation in India ~ 4-7 KWh/m^2)
- Lack of efficient and environmentally acceptable large-scale energy storage.
  - E.g. batteries are not practical for a very large scale and most battery materials are harmful to the environment.

Main Barriers for Renewable Energy

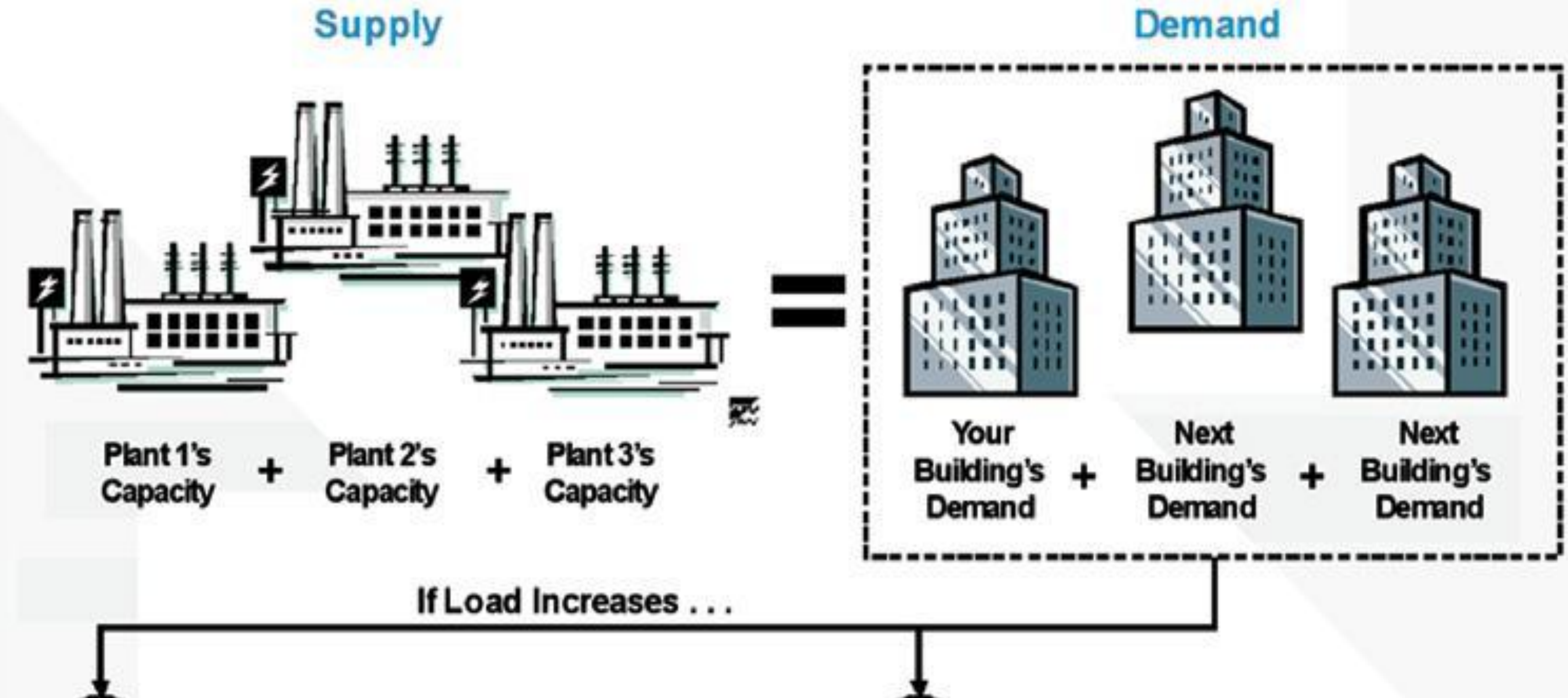
- Commercial and governmental policy factors make it difficult for any alternative energy form to compete.
  - e.g. government subsidies and support for conventional energy (fossil fuels and nuclear).
  - Fossil-fuel subsidies ($550 bi. in 2013) – more than four-times those to renewable energy – are holding back investment in efficiency and renewables. --World Energy Outlook 2014
  - Socio-environmental costs of conventional energy forms are not internalized.
  - i.e. the price we pay for it does not include the socio-environmental damage it causes.

Main Barriers for Renewable Energy

- Poor grid capability to handle high variability of renewables.
  - Better wind and weather prediction models; more locations and hourly prediction.
  - Limited capability of infrastructure to enable inter-state transfers.
  - Smart-grids to enable load balancing.

What is Demand Response?

Grid operators must meet peak demand reliably with all available resources. Enabling the demand side of the equation optimizes resources.

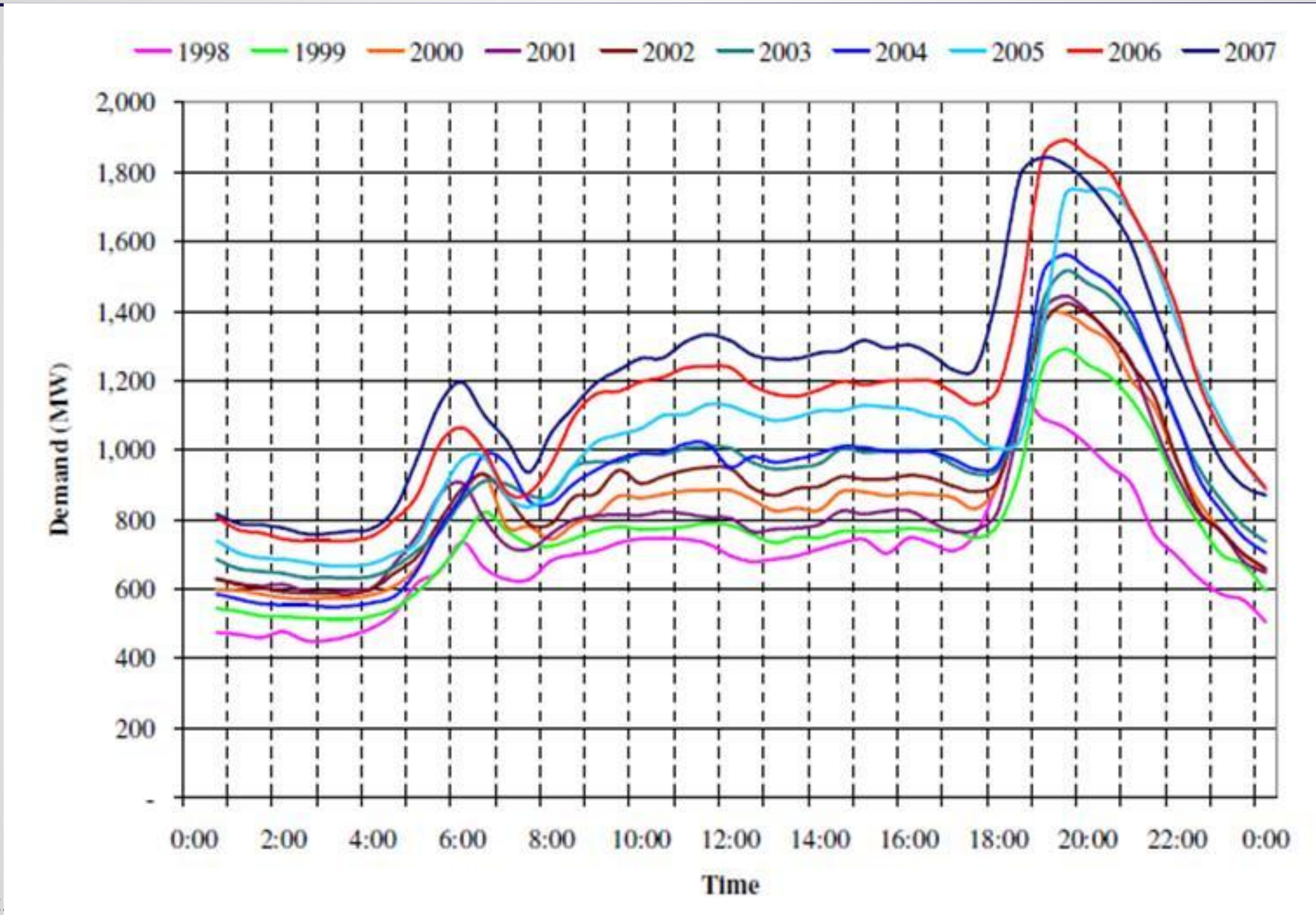


1
- Build generator
- Build transmission
- Build distribution

2
- Consume less
- Curtail during critical peaks
- Shift consumption
- Self generate

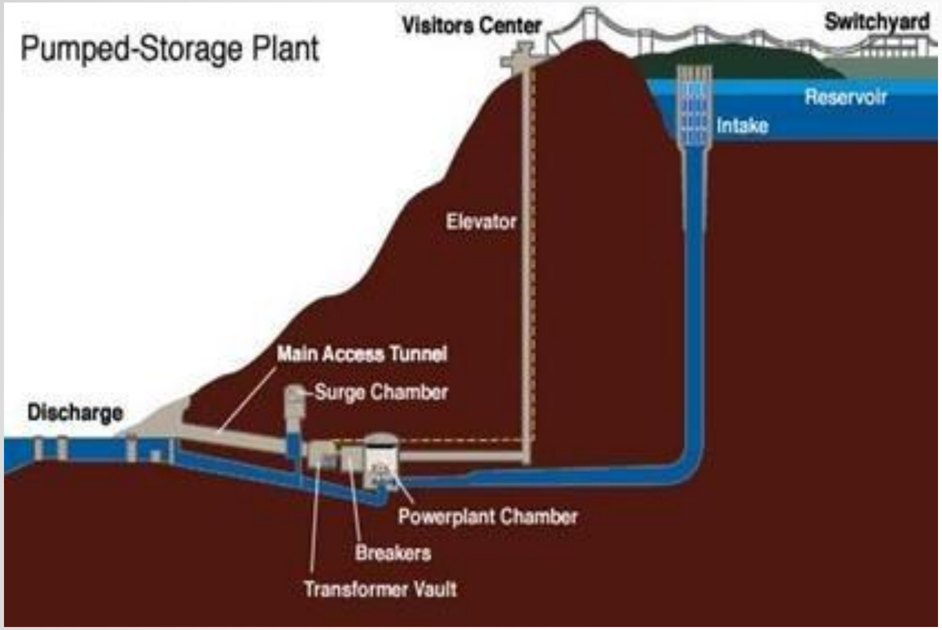
http://esm.versar.com/pprp/ceir15/images/Box_4c.jpg

Daily Load Curve



http://2. ... ka_Consumer
_Electricity_Tariff_Need_is_for_a_Long_Term_Vision_Eng_Parakrama_Jayasinghe.JPG

Need For Utility-Scale Storage



https://wattsupwiththat.files.wordpress.com/2014/07/clip_image0051.jpg

http://www.21stcentech.com/wp-content/uploads/2011/08/solar-thermal-9-storage-capacity.jpg

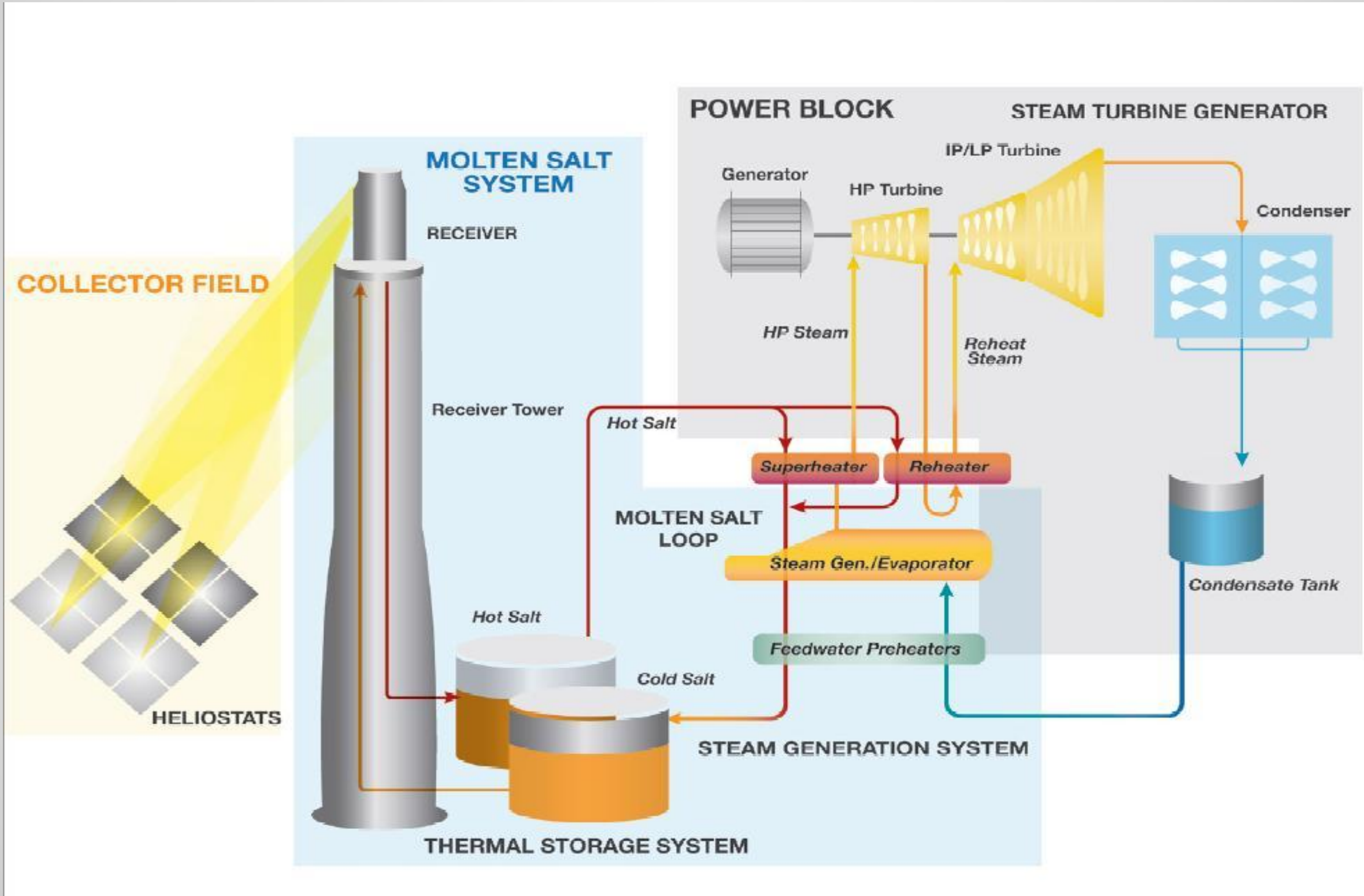
Round-trip energy efficiency: 70-80%

https://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity

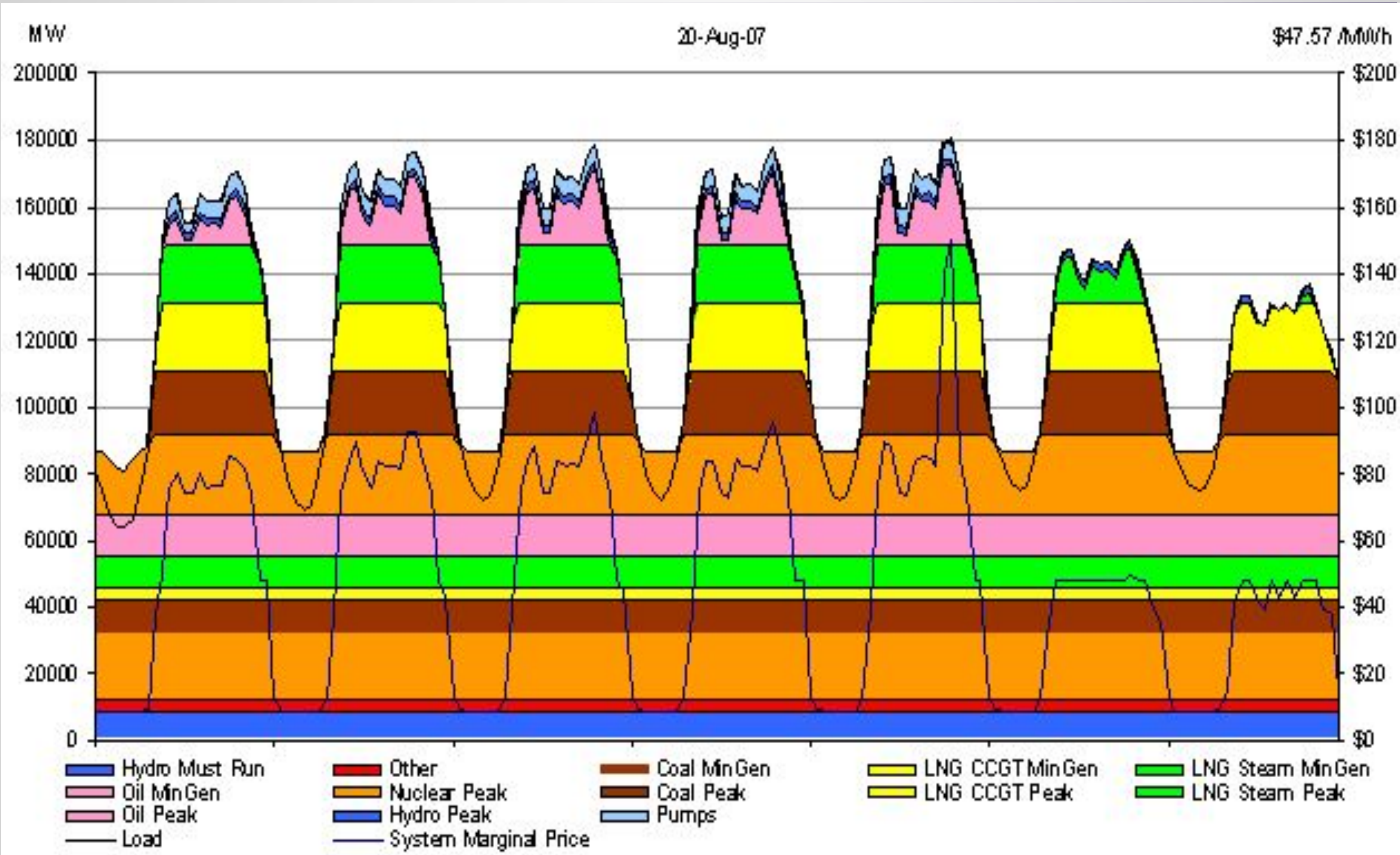
Watch Video:: Pumped Energy Storage (2.29min)

Watch Video: Solar thermal with storage (1.27 min)

Solar Thermal Energy With Storage



http://www.csp-world.com/news/20130201/00728/store-or-not-store-not-question-anymore



http://www.energyconsultants.com.au/images/International_Energy_Consultants_Graph3.gif

Smart Grid

- Integration of digital processing and communications with the power grid.
- Requires transformation in three areas:
  - improvement of infrastructure
  - addition of the digital layer
  - business process transformation
- Feature:
  - Improved fault detection and self-healing
  - Flexibility in enabling bidirectional flows and distributed generation
  - Efficiency
  - Load adjustment/Load balancing
  - Peak curtailment/leveling
  - time of use pricing

Smart Grid

- Smart grid is essential for allowing large amounts of renewable electricity on the grid.
- Can accommodate highly variable renewable energy sources such as solar power and wind power.
- Need to upgrade infrastructure to enable distributed generation.
- Fluctuations in distributed generation (due to weather) need to be stabilized by varying the output of the more controllable generators such as gas turbines and hydroelectric generators.

Reading: 3 Ways Wind and Solar Can Continue To Grow In a 21st-Century Grid by Dyson et al.

Bioenergy

- Bioenergy can form an important component in the overall renewable energy infrastructure.
- Especially useful for biofuel production.
- Need caution:
    - All renewable biomass cannot be used!
    - Energy crops should not be grown on food cropland.
    - Biomass for fuel should not be obtained from natural vegetation of natural habitats.
    - Agro-wastes and residues are potential fertilizers in food production. Their diversion for fuel production can deplete soil fertility.
    - Planted and sustainably managed energy forests and judicious use of agro and urban waste alone should be used for biofuel production.

Bioenergy Technologies

- Direct combustion
- Pyrolysis:
  - solid (char) fuel briquettes
  - liquid fuel (pyrolysis oil)…may need upgradation
  - Biomass gasification: synthesis gas ($CO + H_2$)
- Steam reformation: producer gas ($CO + H_2$)
- Biodiesel (transesterification of bio-derived) oils
- Biodigestion/Fermentation
  - Biogas (bio-methanation) can be sustainable since it gives energy while simultaneously yielding the waste slurry with fertilizer value.
  - Bioethanol

Watch Video: MIT Algae Photobioreactor (5 min)

Innovative experimental system provides multiple benefits:

- CO_2 emission reduction
- CO_2 enhances biomass growth
- NO_x removal
- Solar Energy Utilization
- Food/Fuel production

So What Have We Understood Sofar?

- All the major conventional sources of energy have unacceptably high environmental and social impacts.
- There is an urgent need for environmentally benign alternatives.
- Solar, wind, geothermal, bioenergy and others are abundant.
- Important barriers exist:
  - <u>Technological:</u> Intermittence, poor predictability diffuseness and lack of large-scale storage.
  - <u>Others:</u> Inadequate grid infrastructure, subsidies to fossil fuels and nuclear, inadequate political will.
- A sudden transition is impossible; technologies and approaches are evolving.
- For now, some amout of conventional sources will be required to meet the demand, but they must be gradually phased out.

Energy saved is energy generated!

- Until then we must immediately and drastically reduce current energy use.
  - Managing demand is as important as managing supply.
  - Conscious consumption of direct energy and products (embodied energy) and avoiding waste.
  - Designing processes, products and our lifestyles to need less energy is crucial.

Outline

- Units and Terms
- Energy Resources, Depletion and Risks
- Environmentally Benign Forms of Energy
- Efficiency Measures
- Reduction in Consumption—Individual Perspective

Choosing Where to Implement Efficiency Measures?

- Need to analyze the energy consumption by source (coal, oil, etc.) and sector (industry, residential, etc.)
- **<u>For max. benefit, identify the most energy-intensive end-uses and:</u>**
  - **Replace or supplement conventional energy with economical and environmentally benign technologies (solar, wind) wherever possible.**
  - **Employ energy conservation and efficiency methods that lead to drastic advantages. e.g. heat integration.**

World Energy Usage: By Sector 2009

S. No.	Sector (Trillion BTU)	Primary	Total	% of Total
1.	Industrial	18571	**28199**	**29.1**
2.	Residential	6606	**21207**	**22.4**
3.	Transportation	26950	**27033**	**28.5**
4.	Commercial	3974	**18147**	**19.1**
5.	Electric Power Sector	38304		
	TOTAL		**94578**	**100**

Primary energy: Energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy. For example, coal can be converted to synthetic gas, which can be converted to electricity; in this example, coal is primary energy, synthetic gas is secondary energy, and electricity is tertiary energy.

http://tonto.eia.doe.gov/merquery/mer_data.asp?table=T02.01

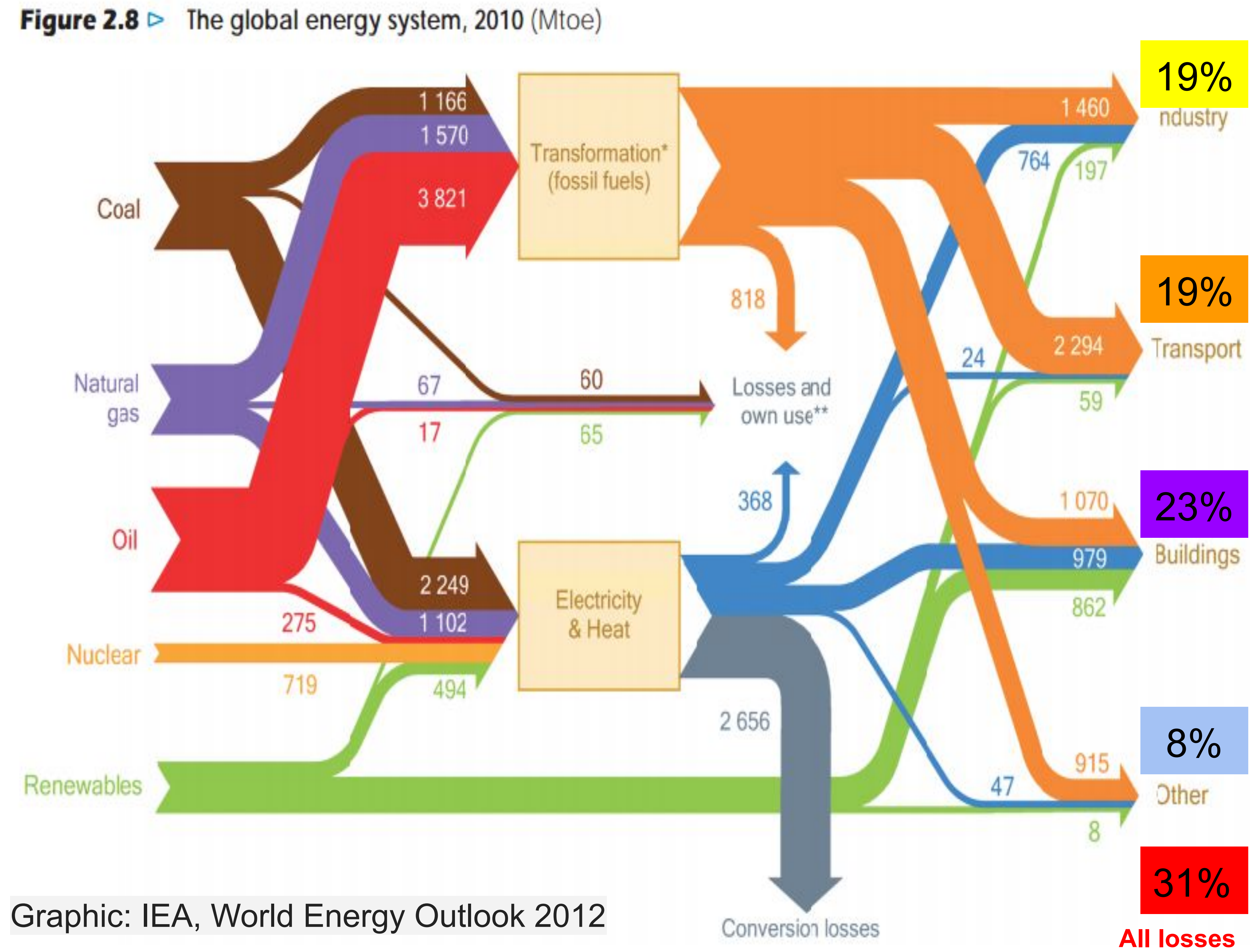
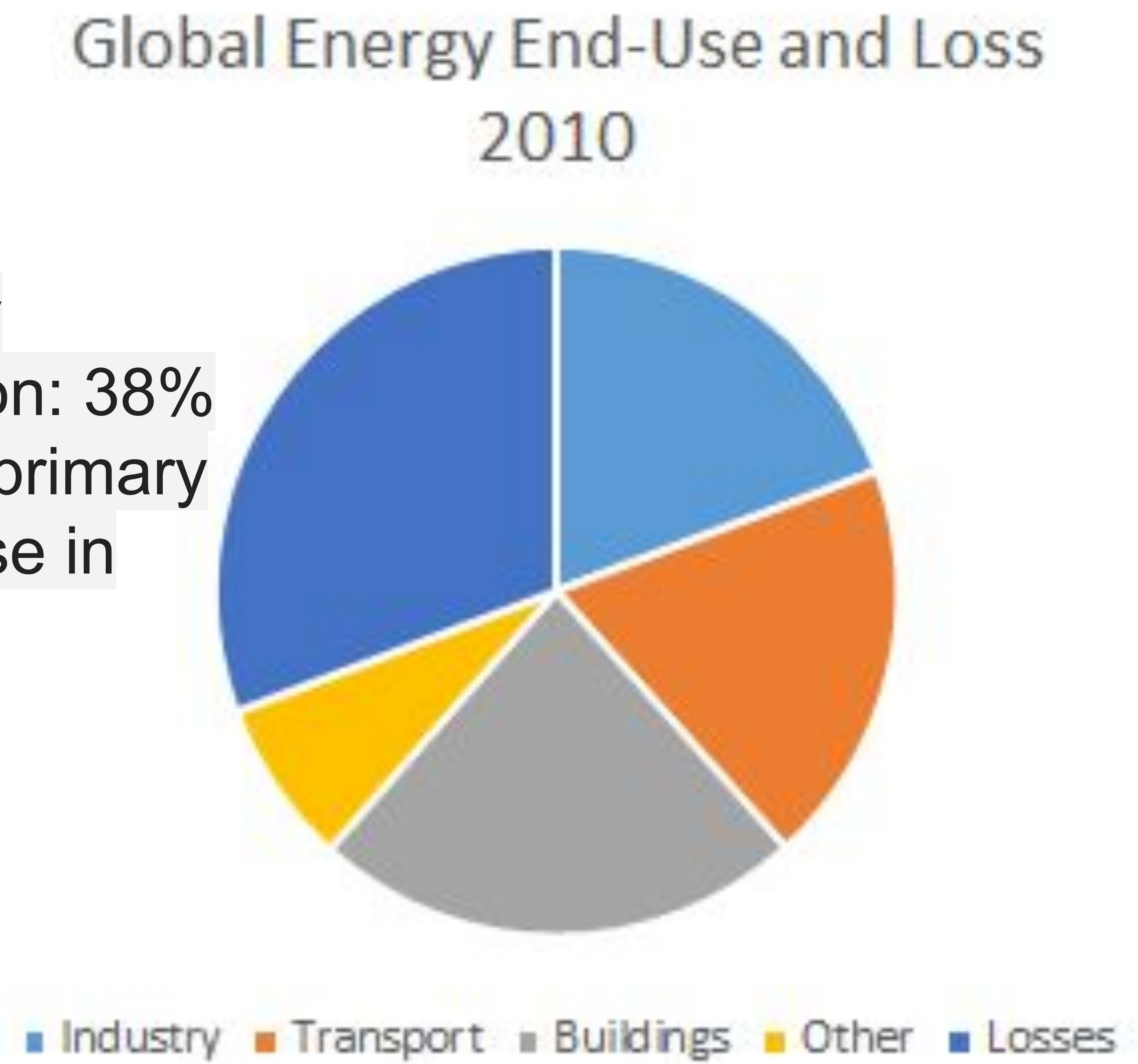


Figure 2.8 ▷ The global energy system, 2010 (Mtoe)
Coal
Natural gas
Oil
Nuclear
Renewables
1 166
1 570
3 821
67
17
60
65
2 249
1 102
275
719
494
Transformation* (fossil fuels)
Electricity & Heat
818
368
2 656
Losses and own use**
Conversion losses
1 460
764
197
2 294
24
59
1 070
979
862
915
47
8
19%
ndustry
19%
Transport
23%
Buildings
8%
Other
31%
All losses
Graphic: IEA, World Energy Outlook 2012

Electricity Generation: 38% of global primary energy use in 2010



Based on: IEA, World Energy Outlook 2012

Energy in everything we buy

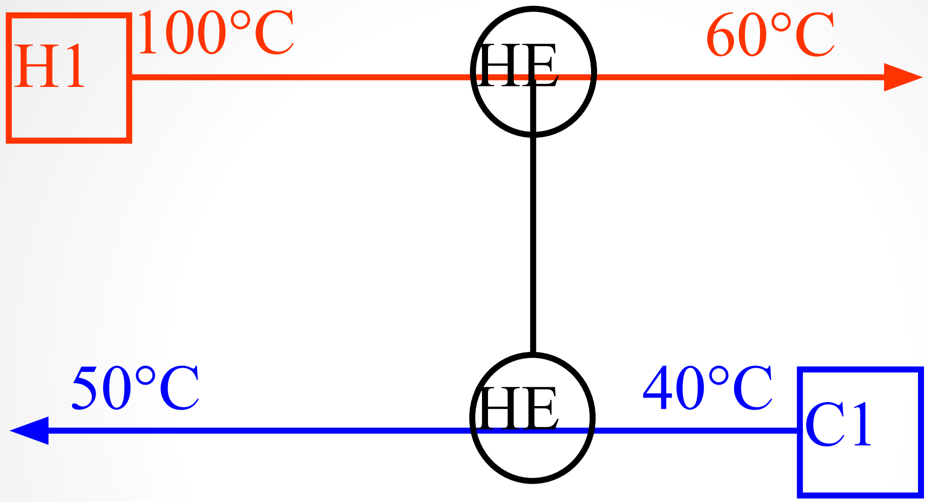
- Industry is the largest energy-consuming sector.
- So, industry must be the focus of energy conservation efforts.
    - Manufacturing our vehicles, buildings, appliances, and even our food and clothes.
    - **Embodied energy**: energy invested in a particular thing during its lifetime, from cradle to grave.
- Simply buy less and save energy!
    - Buy products with low embodied energy, high durability and only when necessary.
    - Reuse or recycle old products.

- But the manufacturing industry is essential and must go on....
- So, let's see how to reduce industry's energy use.
- Which are the most energy-intensive industries?
  - Process industries

Solar Energy for Heating/Cooling in the Process Industry

- Solar thermal energy is a mature and cost-competitive technology
- Steam generation or process heating using concentrating solar technology
- Will require a backup conventional heating module due to intermittence of solar energy.
- Solar energy for cooling can be a viable option. Two approaches:
  - Pair a photovoltaic array with a standard compression cycle based chillers.
  - Pair a solar thermal collector with an absorption chiller

Heat Integration

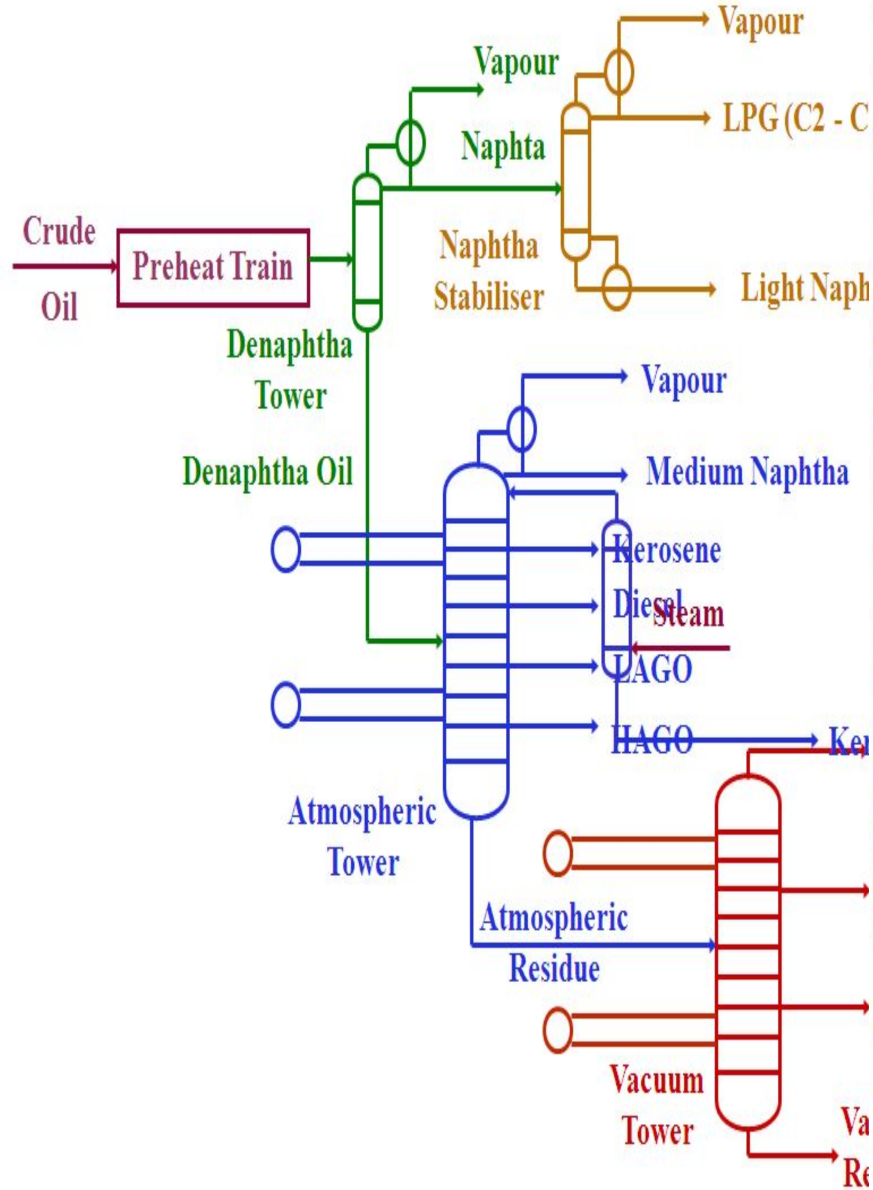


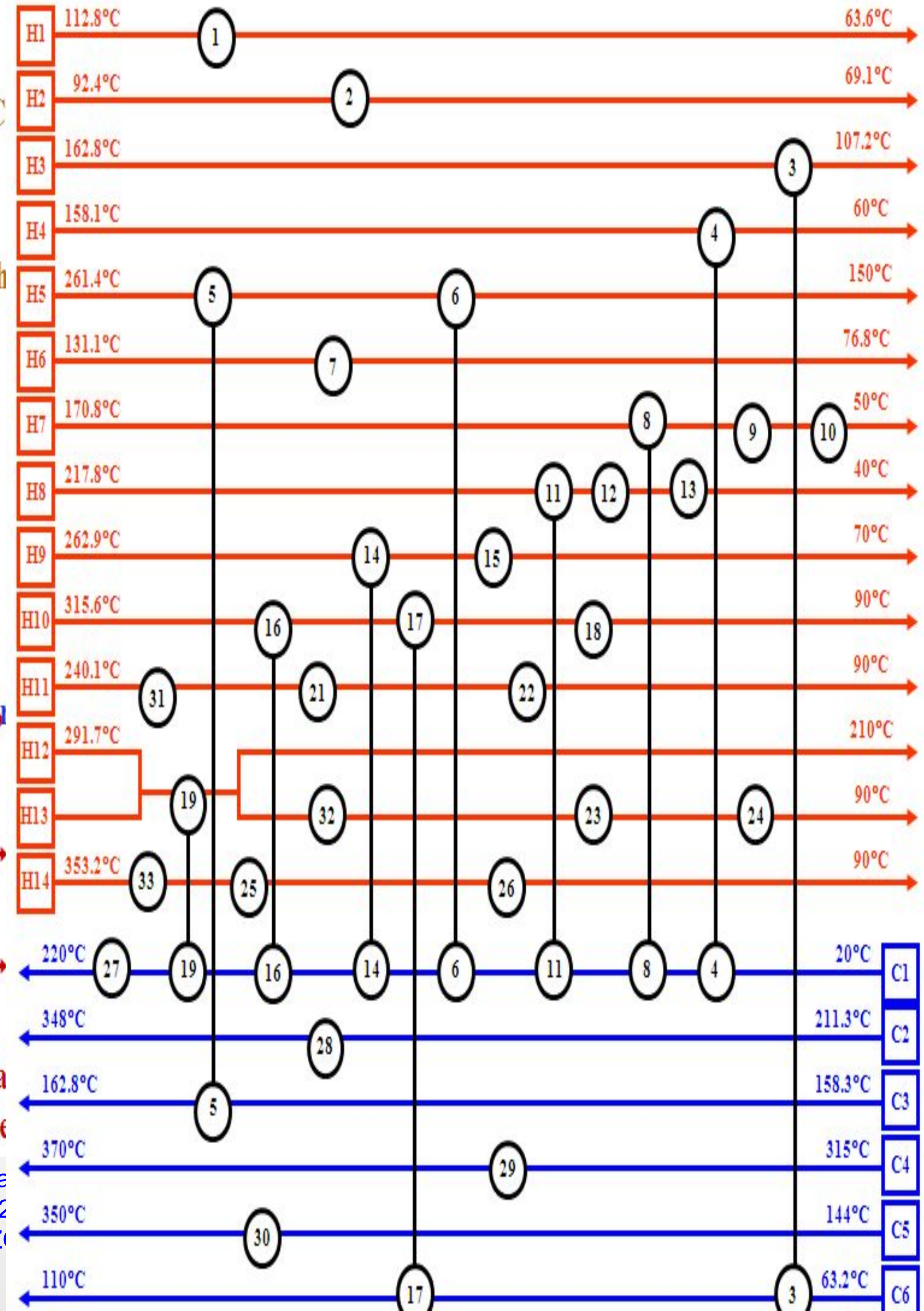
- Using the waste (or excess) heat from one product stream to heat another stream.
- HE is a heat exchanger.

Heat Integration

- Typical energy saving 15 – 45 %
- Very general – easily applicable in Power generation, Oil refining, Petrochemicals, Food and Drink Industry, Pulp & Paper, hospitals etc.
- Typical pay-back periods from a few weeks to 16 months (decision made by the client)
- Considerably contributes to Emissions Reduction including CO_2

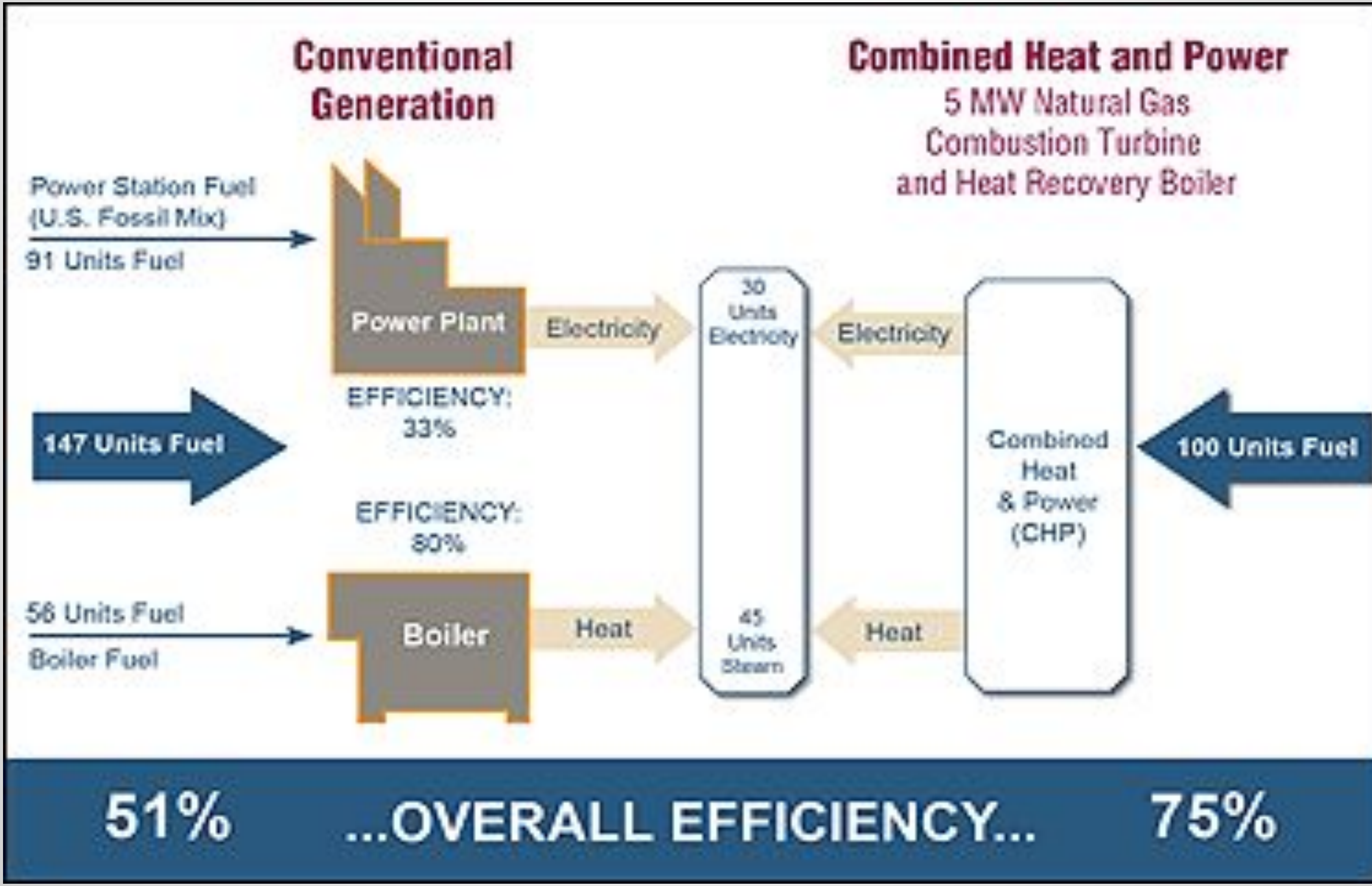
http://www.google.com/url?sa=t&source=web&cd=2&ved=0CB0QFjAB&url=http%3A%2F%2Fwww.cpi.umist.ac.uk%2Feminent%2FConfidential%2Fmeeting%2FRigaMeeting%2FRiga%2520Workshop%2FMarch%252008%2520Jiri%2520Klemes.ppt&ei=0shkTI6tJM-jcdGf8N4K&usg=AFQjCNHWPipjaJj_Uy4LGn57slZj3-fnZQ&sig2=KOve0TJ9NsWdy_p-O2li2A





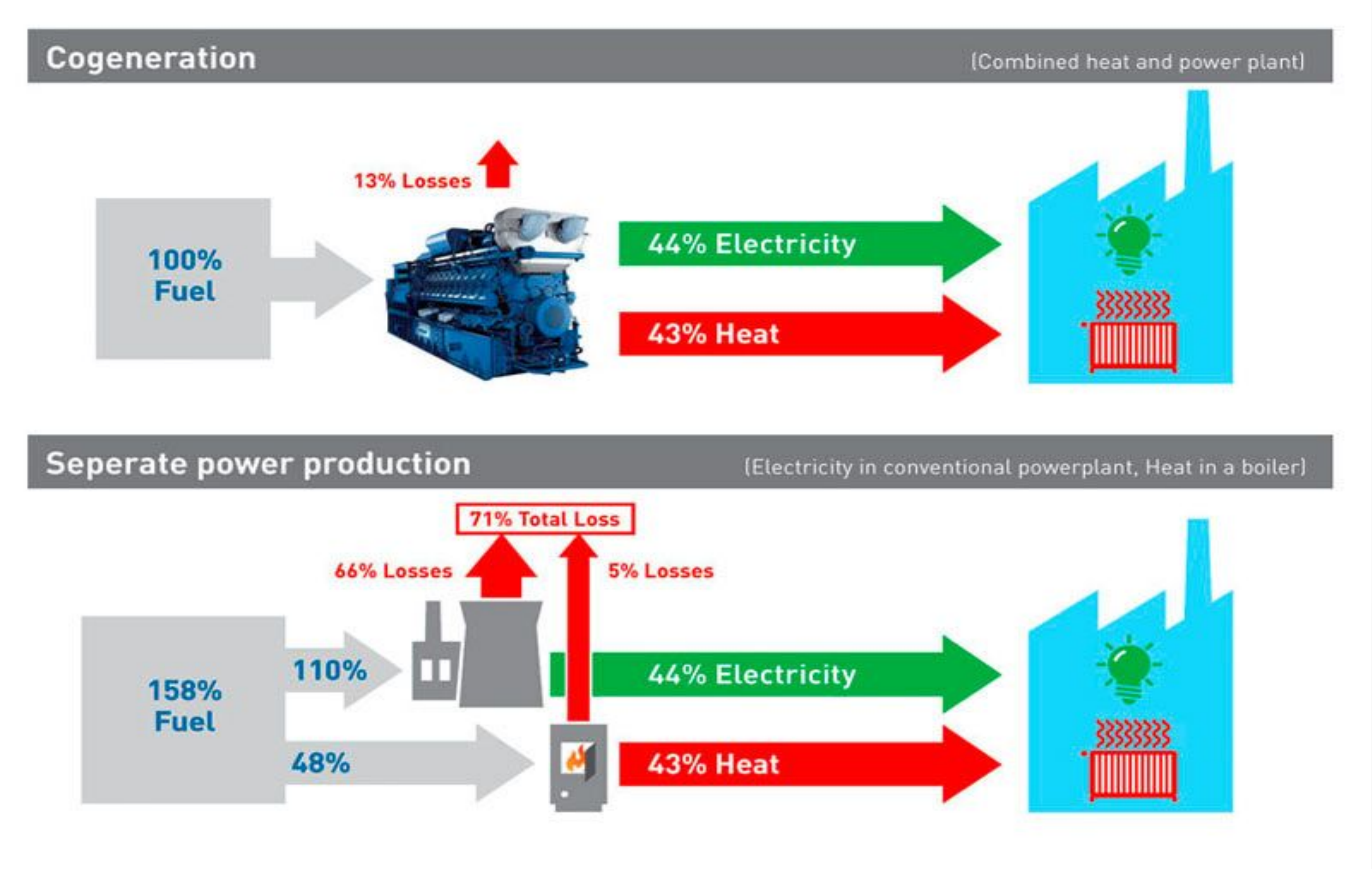
http://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ca
%2Feminent%2FConfidential%2Fmeeting%2FRigaMeeting%2FRiga%252
pdUMzoKsL3rQeN1YDICQ&usg=AFQjCNHWPipjaJj_Uy4LGn57slZj3-fnZ

CHP



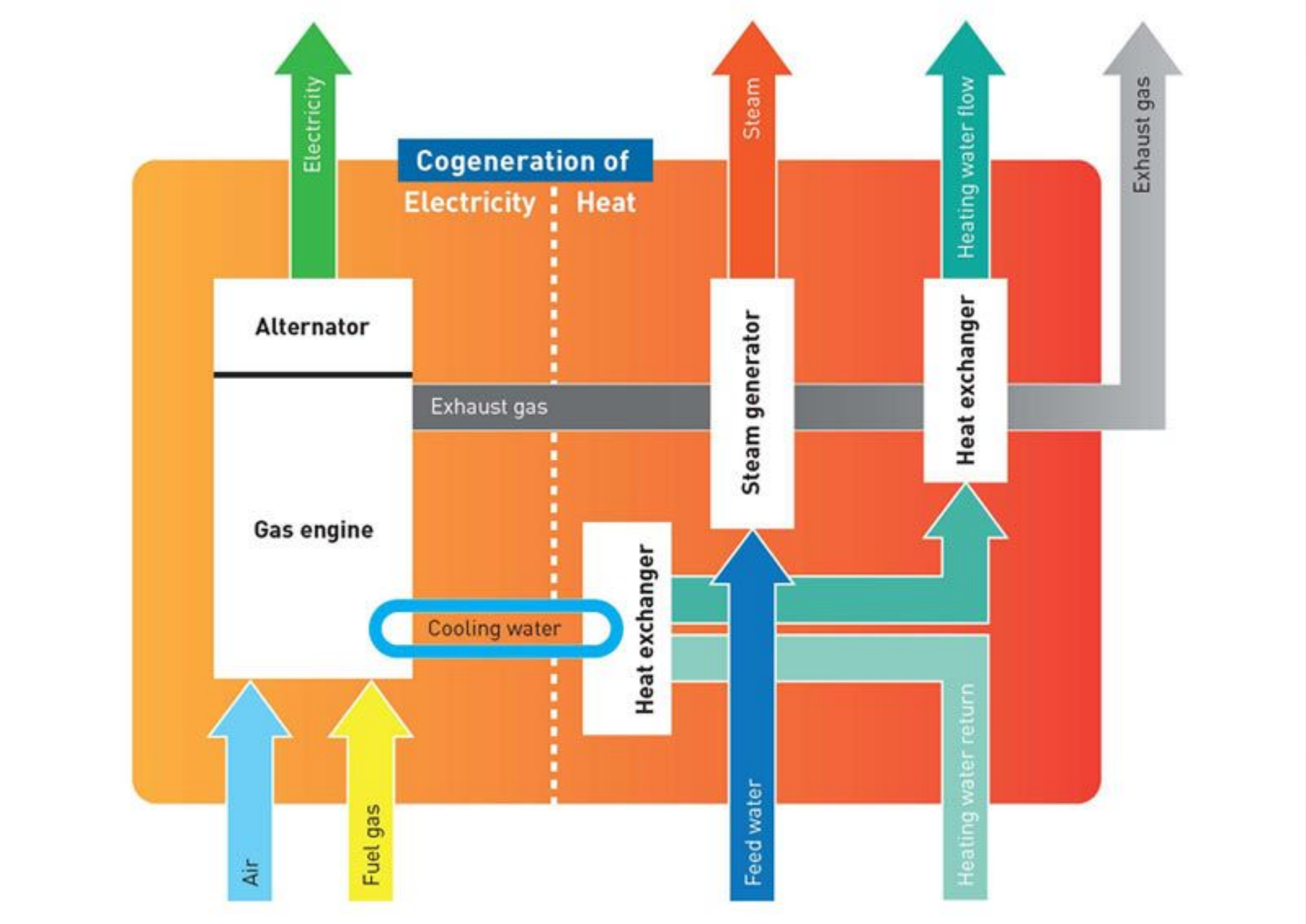
Conventional Generation
Combined Heat and Power
5 MW Natural Gas
Combustion Turbine
and Heat Recovery Boiler
Power Station Fuel
(U.S. Fossil Mix)
91 Units Fuel
Power Plant
Electricity
30 Units Electricity
Electricity
EFFICIENCY: 33%
147 Units Fuel
Combined Heat & Power (CHP)
100 Units Fuel
EFFICIENCY: 80%
56 Units Fuel
Boiler Fuel
Boiler
Heat
45 Units Steam
Heat
51%
...OVERALL EFFICIENCY...
75%

CHP

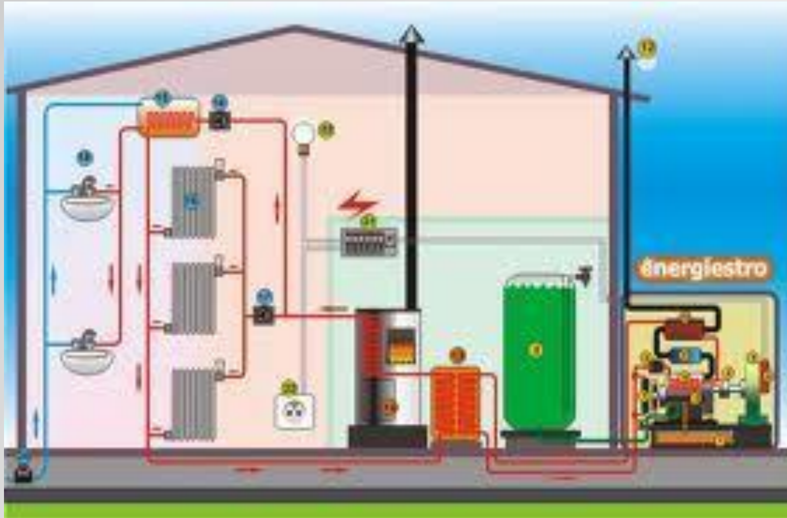


http://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/mwm-competencies/cogeneration-trigeneration-plants/

Working of CHP

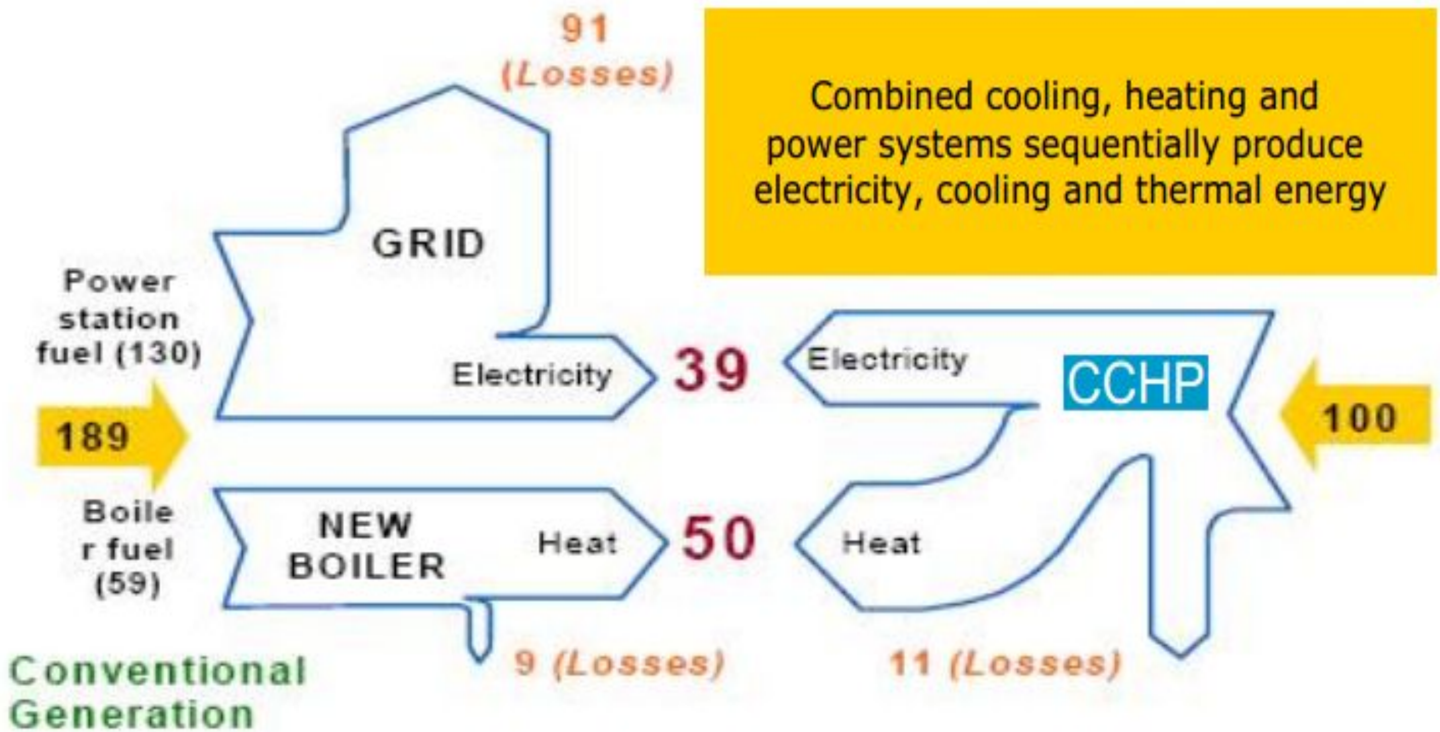


http://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/mwm-competencies/cogeneration-trigeneration-plants/



CCHP comparison

Combined cooling, heating and power systems sequentially produce electricity, cooling and thermal energy

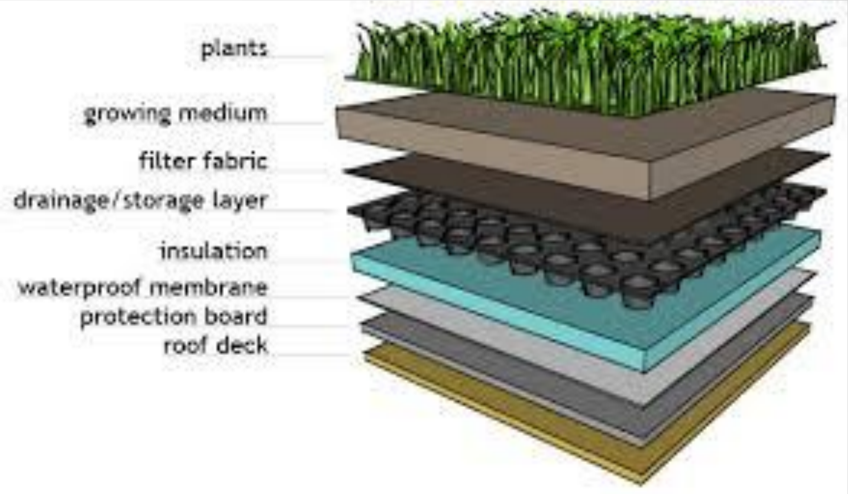


There are many ways to basically reduce our domestic energy use.

One such is green roofs:

- Reduced building heat gain.
- Evaporative cooling
- Food production
- Carbon absorption
- Possibilities for greywater recycling

Green Roofs



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Fnews%252Farchive%252F2012-01%252F04%252Fbeirut-wonder-forest%3B620%3B413

s%252F2014%252F02%252Fvilla-bio-spain-green-roof-home.jpg%3Bhttp%253A%252F%252Fwww.powerho
usegrowers.com%252Fgreen-roofs-101-what-is-a-green-roof-and-what-does-it-do%252F%3B750%3B514

Earthships 101 part I (5.21 min)
Earthships 101 part II (6.47min)

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What Can Chemical Engineers Do?

- Industrial Symbiosis
- Process Integration, Pinch Technology
- Cogeneration: CHP, CCHP
- Heat Integration, Waste Heat Recovery
- Pyrolysis: gasification, liquid fuel, biomass utilization, plastic waste-to-energy, etc.
- Biomethanation (biogas)
- Biofuels
- Green Chemistry
- Plastics recycling
- Natural polymers and composites
- Environmental remediation, Waste treatment

What Can Mechanical Engineers Do?

- Cogeneration: CHP, CCHP
- Heat Integration, Waste Heat Recovery
- Industrial Symbiosis Networks
- Automotive efficiency improvement
  - Use engine waste heat for air conditioner (absorption chiller)
  - Convert engine waste heat to electricity (thermoelectric devices) and change battery.

What Can Materials Scientists Do?

- Photovoltaics:
  - organic photovoltaics
  - semiconductors, quantum dots, etc.
  - Dyes, electrolytes,
- LEDs
- Nanostructured catalysts:
  - for degradation of toxics, gas-to-liquid,
- Ultracapacitors
- Sensors
- Fuel Cells: membranes, catalysts, etc.
- Batteries: economical, high energy and power density, low toxic, rechargeable/refurbishable?

What Can Consumers Do?

- Minimize the purchase of new appliances and gadgets, clothes, and products. Repair and reuse old ones.
- Avoid air conditioners. Prefer fans or desert coolers.
- Minimize waste of electricity by turning of lights (CFL/LED) , fans and appliances, (unplug when not in use)
- Keep computer in shutdown or hibernate modes when not in use.
- Build an ecohouse: green materials and architecture, daylighting, passive heating/cooling concepts, integrated energy systems, rainwater harvesting, water recycling, dry composting toilets, backyard/terrace/balcony food gardens

What Can Consumers Do?

- Walk or use bicycles for short distances and public transportation or two-wheelers for longer distances.
- Avoid air travel and purchasing private cars.
- Purchase essential products grown/produced in the 5, 50, 100 km radius. Low product miles and low embodied energy.
- Use cloth bags and old containers for shopping. Avoid disposable plastic bags.
- Use reusable plates, cups and silverware. Avoid paper/plastic
- Calculate your carbon and ecological footprint and try to minimize it.

What Can Consumers Do?

- Conserve LPG while cooking.
- Use solar heaters to heat water.
- Minimize the use of paper
- Adopt alternative medicines (e.g. homeopathy) for minor ailments (pharmaceutical industry consumes a lot of energy)
- Be vegetarian! Vegetarian food consumes far less water, energy and is better for your health!
- Avoid processed foods.