Energy and Sustainability

UCC501 Sustainable Energy, Fall 2014

Instructor: Dr. Alejandro Rios G.

Masdar INSTITUTE

Lecture 2 – Thursday, September 4, 2014

Contents

- Different forms of energy
- Energy sources
- Energy needs
- Sustainable development
- Energy & Sustainability

Sustainable energy 1/4

- Energy is an essential need
- There are great disparities in the levels of energy use
  - e.g. The US has about 5% of the world's population, but consumes approximately 25% of the world's energy production
  - The average UAE citizen uses 100 times more energy than the average person in Bangladesh

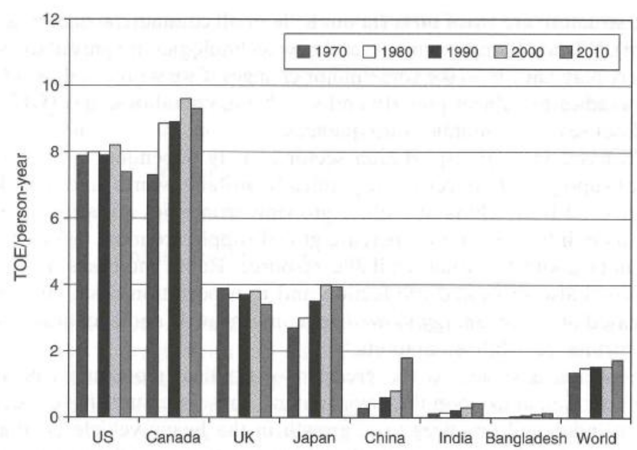


Figure 1.1
Per capita average commercial energy use for selected countries, 1970 through 2010. Data sources: BP (2011) and New York Times (2011) (population data).

Sustainable energy 2/4

- World population is increasing…
  - ~ 7 billion today →9 or 10 billion in 2050?
- 85% of commercial energy is derived from fossil fuels
  - Emissions
  - Climate change
- Sustainable energy future
  - Increased efficiency of production and use
  - Policy options
- Sustainability
  - Subjective
  - Tradeoffs

Meeting energy needs

- Electricity
  - Currently fossil, fission, hydro, wind, some solar and biomass
- Heat
  - Provided currently by fossil, fission, biomass
- Transportation
  - Provided currently by petroleum, electricity
- The case for Hydrogen?
  - Problems in production, transportation, storage
- Since we meet our needs, what is the problem?

Sustainable energy 3/4

- Economic consequences of human activities
  - Externalities
  - Internalizing the costs of energy

- It's difficult to estimate different costs and risks
  - Environmental risk
  - Length and time scales

- Uncertainties
  - Many processes are not well understood

- Energy – Prosperity – Environmental dilemma
  - Fairness
  - Equitable treatment of all stakeholders

How will we move forward?

- Core set of guiding principles
- Ongoing dialogue
- Participation of diverse stakeholders and perspectives

How does energy use impact sustainability?

- Some Benefits
  - Energy is critical to human survival and development
  - Fossil fuels are plentiful and convenient to use
  - Energy is key to industrialization and transportation
  - Energy facilitates economic growth and globalization

- Some Problems
  - Rapid growth in fossil fuel use raises concerns about:
    - Security of supply (over-dependence?)
    - Environmental impacts
    - Societal conflicts over inequitable distribution of resources
    - Depletion of critical resources

What are the problems with present energy use?

- Global Energy consumption is growing because:
  - Population is growing
  - Energy use per capita is growing – especially in developing countries
- Growing megacities need concentrated energy sources
- Transportation systems depend largely on petroleum fuels
- Major fossil energy sources have problems
  - Security of supply/price stability (esp. petroleum)
  - Depletion
  - Climate impacts from greenhouse gas emissions
- Energy access is unequally distributed
- Global economy is significantly dependent on present fossil energy prices and availability – changes to include "externality" costs may slow economic growth (or at least cause major short-term disruptions in the economy)

Intragenerational principles

- Reduce gross inequities between the poorest and wealthiest both nationally and globally
  - Meet the basic needs of the poorest with food, shelter, health care, clean water, access to electricity, education, opportunity for work, etc.
  - Avoid exploitation of poorer country/region resources and labor to create even greater wealth for the richest
- Provide ways to protect the common good (social, environmental, economic) locally and globally through national and international governance/cooperation
  - Preserve natural ecosystems against unconstrained development
  - Avoid interference with natural balances in the atmosphere, the oceans, and the arctic regions
  - Maintain stable institutions that protect human rights, adjudicate conflicts, and allow responsible trade and market economy activities

What are our obligations to future generations?

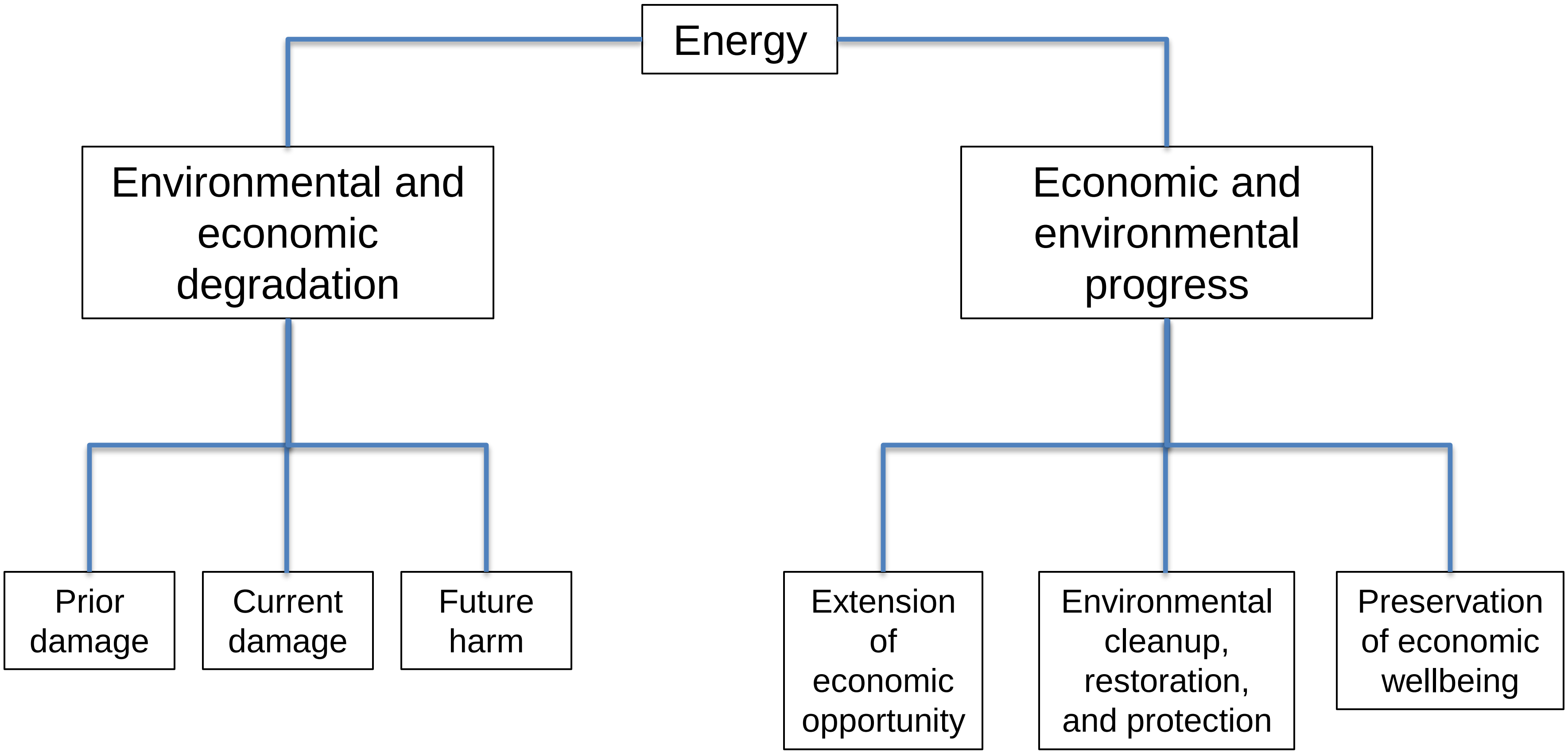
- Trustee: Every generation has an obligation to protect the interests of future generations
- Chain of obligation: Primary obligation is to provide for the needs of the living and succeeding generations. Near term concrete hazards have priority over long term hypothetical hazards
- Precautionary Principle: Do not pursue actions that pose a realistic threat of irreversible harm or catastrophic consequences unless there is some compelling or countervailing need to benefit either current or future generations

Are there limits to growth?

- Malthus – 1798* – Population grows exponentially; food production grows linearly. Population growth ceases when incremental person doesn't have resources to survive
- Hardin – 1968 – Tragedy of the Commons
- Ehrlich – 1968 – Overpopulation is the problem, depleting soils and disrupting natural life support ecosystems
- Forrester – 1972 – Limits to Growth – potential for disaster within 100 years
- Meadows – 1992 – Beyond the Limits – overshoot but human ingenuity could prevent collapse
- Cohen – 1995 – How many people can Earth support? (maybe a trillion, more likely around 16 billion)

*Full references are given in Text

Sustainable energy 4/4



What do investors care for?

- Money

- To navigate to a sustainable future we need to account for the economic effects of technology policy:
  - How to compare investing between different technologies?
  - How to account for total lifecycle energy flows?

Thank you.

Key definitions

- Energy:
  Capacity of a system to do work (“cause external action”)

- Power:
  Rate at which work is performed or energy is transmitted

Energy units

Fundamental scientific unit:

$$Joule = N \times m = \frac{kg \times m}{s^2} m = W \times s$$

1.0 J is defined as the work done when a force of 1.0 newton moves an object 1.0 meter in the direction of the force.

Power: W = J/s

kWh = 1000W x 3600 s = 3.6 MJ
Exajoule (EJ): 1 EJ = 10^{18} J
Quadrillion Btu(quad): 1 quad = 10^{15} Btu = 1.055 EJ
Terawatt-year (TWyr): 1 TWyr = 8.76 x 10^{12} kWh = 31.54 EJ = 29.89 quad

World Primary Energy Consumption: ~16TWyr or 475Quad

A person having a mass of 100 kilograms who climbs a 3-meter-high ladder in 5 seconds is doing work at a rate of about 600 watts.

Mass times acceleration due to gravity times height divided by the time it takes to lift the object to the given height gives the *rate of doing work* or *power*.

Source: Wikipedia

Energy sources

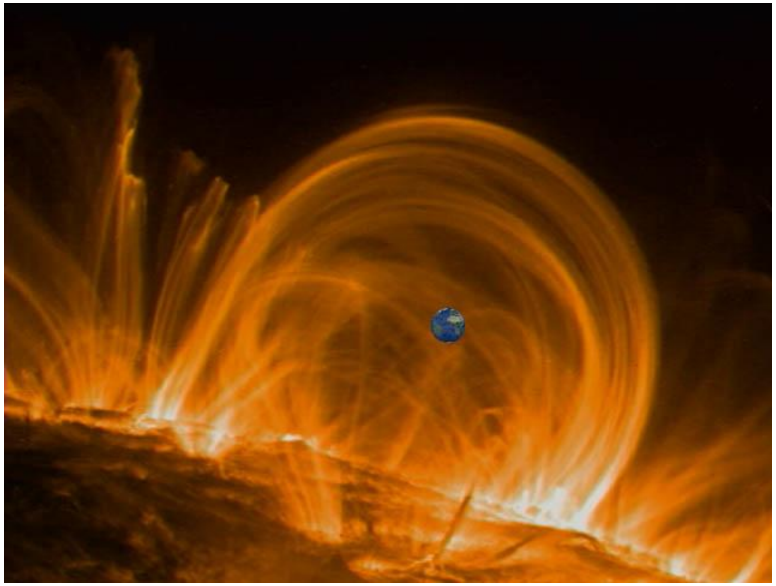
Is all energy solar (Y/N?)
YES (with one exception)

Fossil fuels = old biomass = solar

Nuclear = old solar

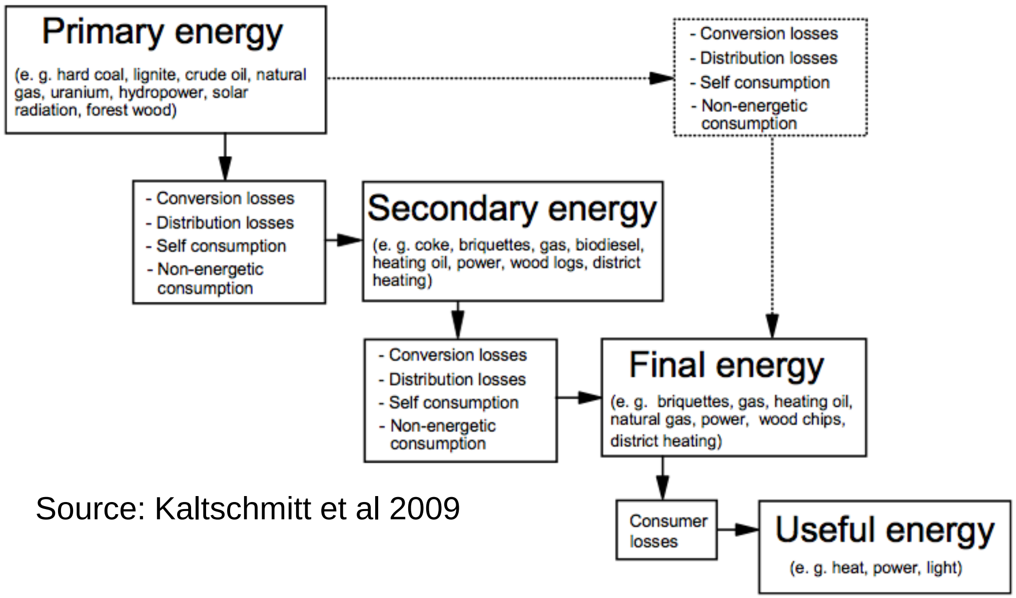
Renewables

- Solar (PV, thermal) = solar
- Wind, hydro = thermal circulation patterns = solar
- Wave = wind = solar
- Geothermal = nuclear decay = old solar
- Biomass = photosynthesis = solar
- Tidal = gravitation = Exception



Source: NASA

Energy source categorization



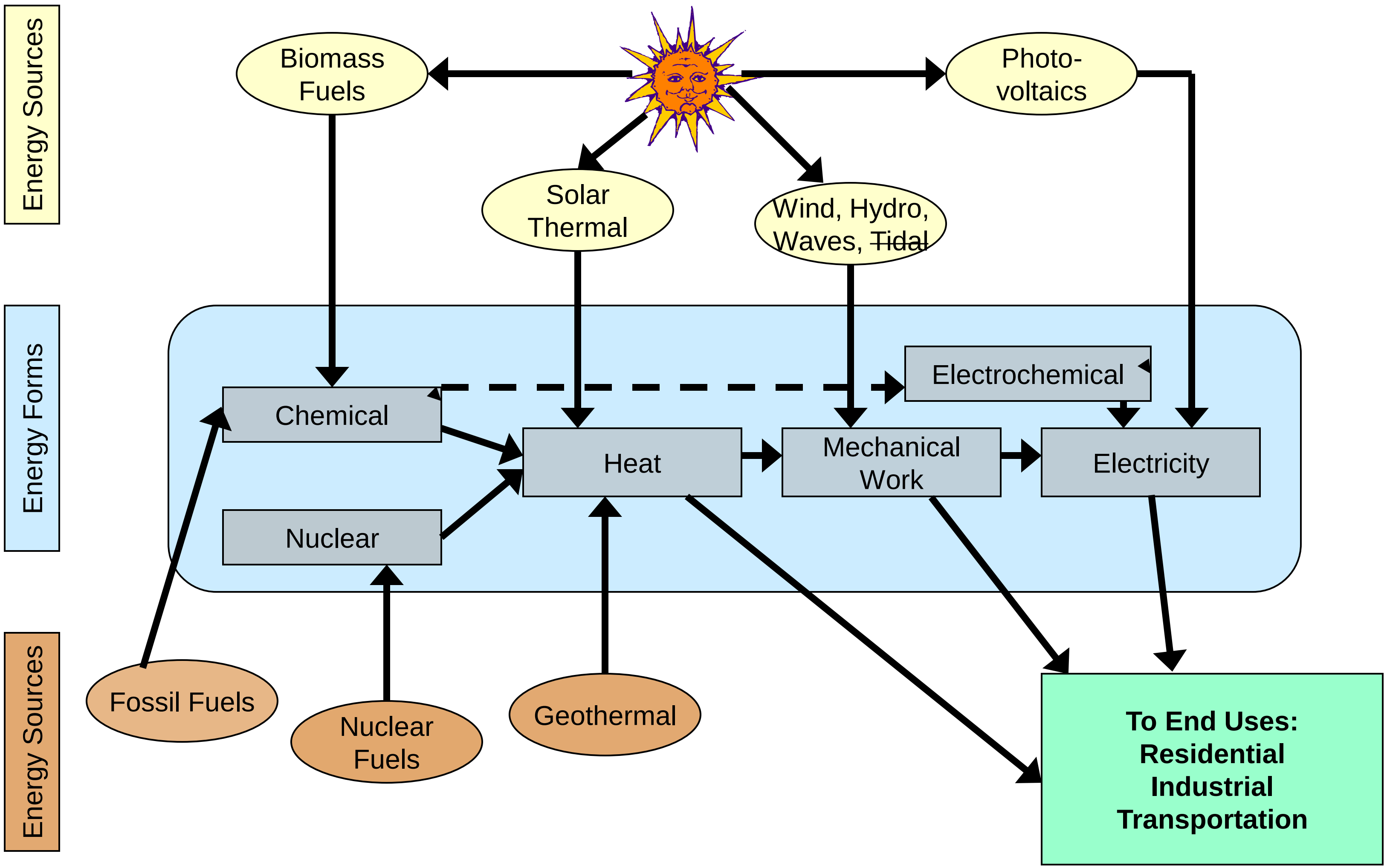
Source: Kaltschmitt et al 2009

- **Primary Energy**: Energy content without technical transformation either renewable (e.g. wind, solar, biomass) or non-renewable (e.g. coal, crude oil, natural gas)
  - Note that in some databases (e.g. BP) the transformed resource (e.g. electricity from wind) is quoted as primary
- **Secondary Energy**: Energy content of an energy carrier after transformation available for use
- **Final Energy**: Energy available to users from secondary or primary sources after final transformation into usable form

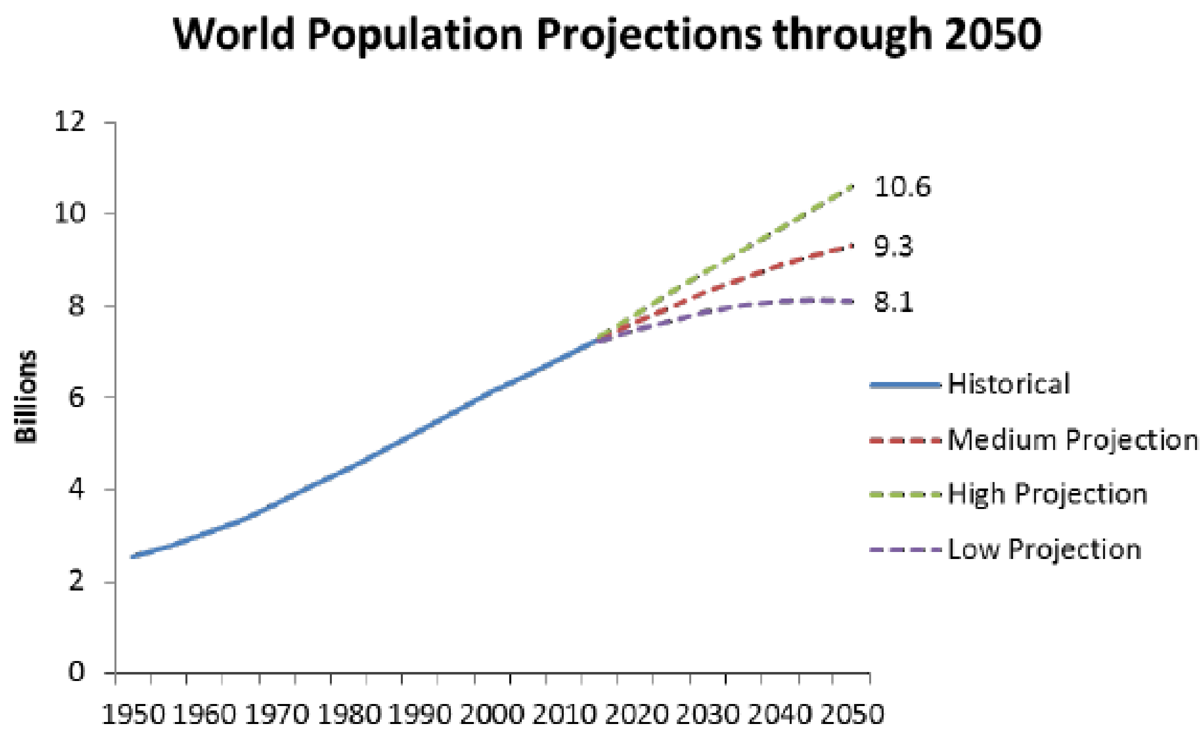
Technology options

- GHG Emitting ↔ Reduced CO_2 Emissions
  - Natural gas
  - Clean? coal
  - CO_2 Sequestration
- Renewable Technologies
  - Biomass
  - Solar thermal & photovoltaic
  - Wind
- Nuclear (fission and fusion)
  - Fission reaction or Breeding reaction
  - Fuel efficiency increase by factor of 70
  - Proliferation risk

Energy sources & conversion

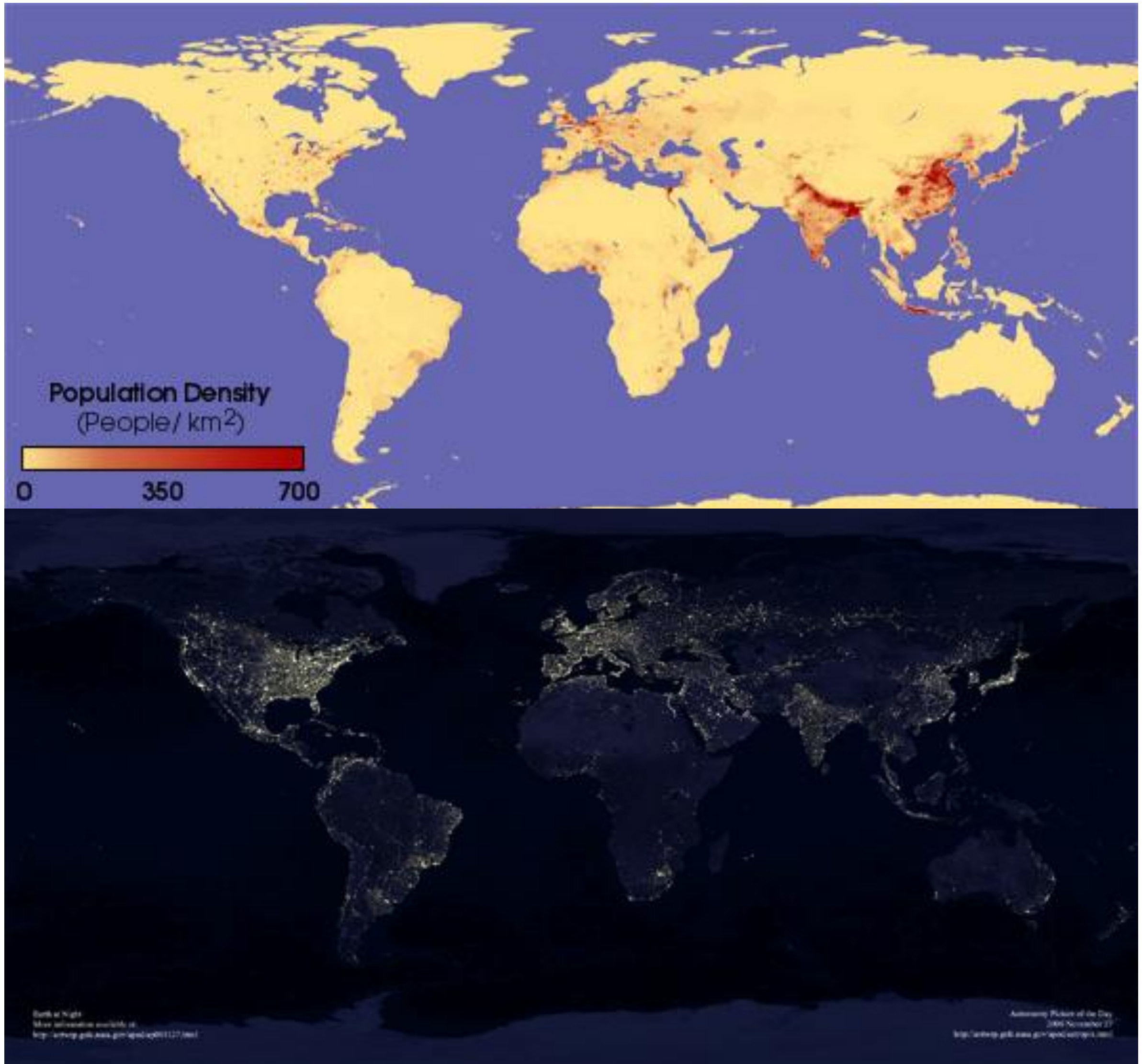


Demographic Trend

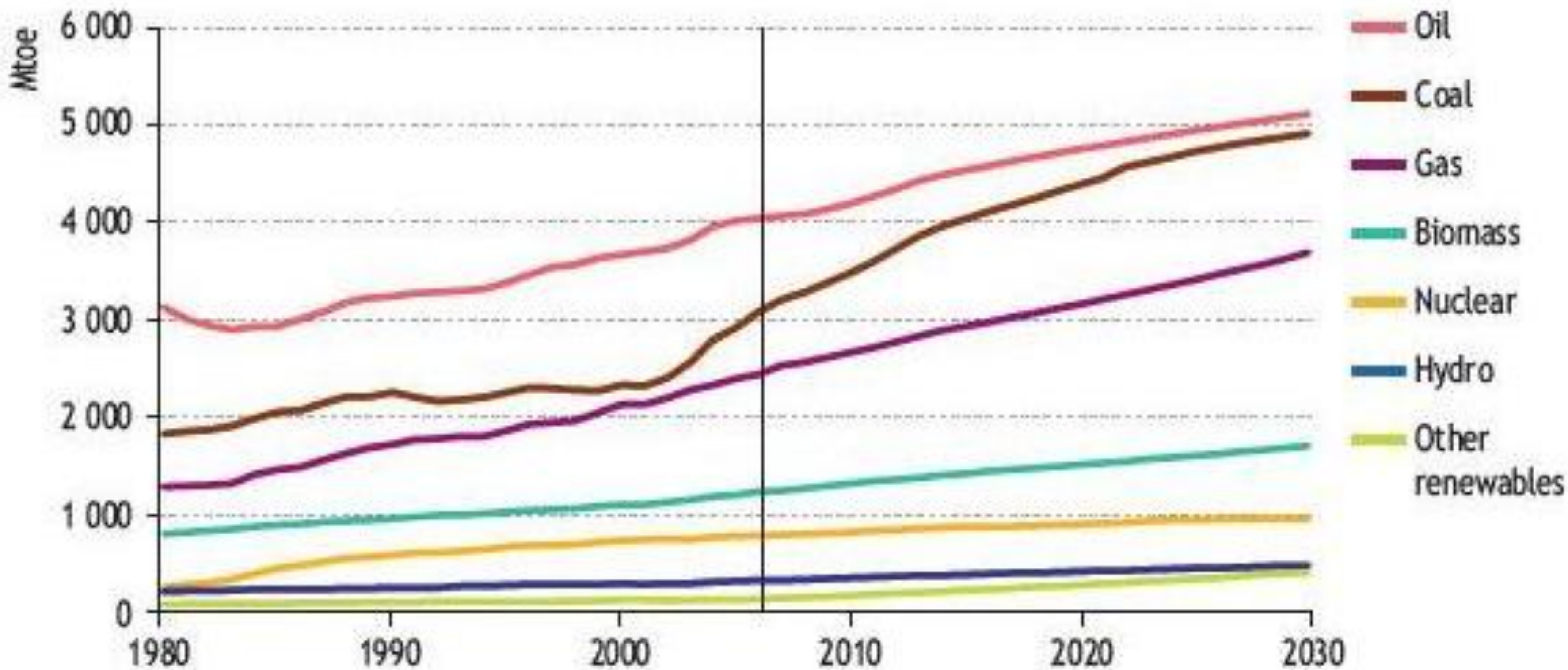


Source: UN Population Division

Global Population & Energy Density Distribution

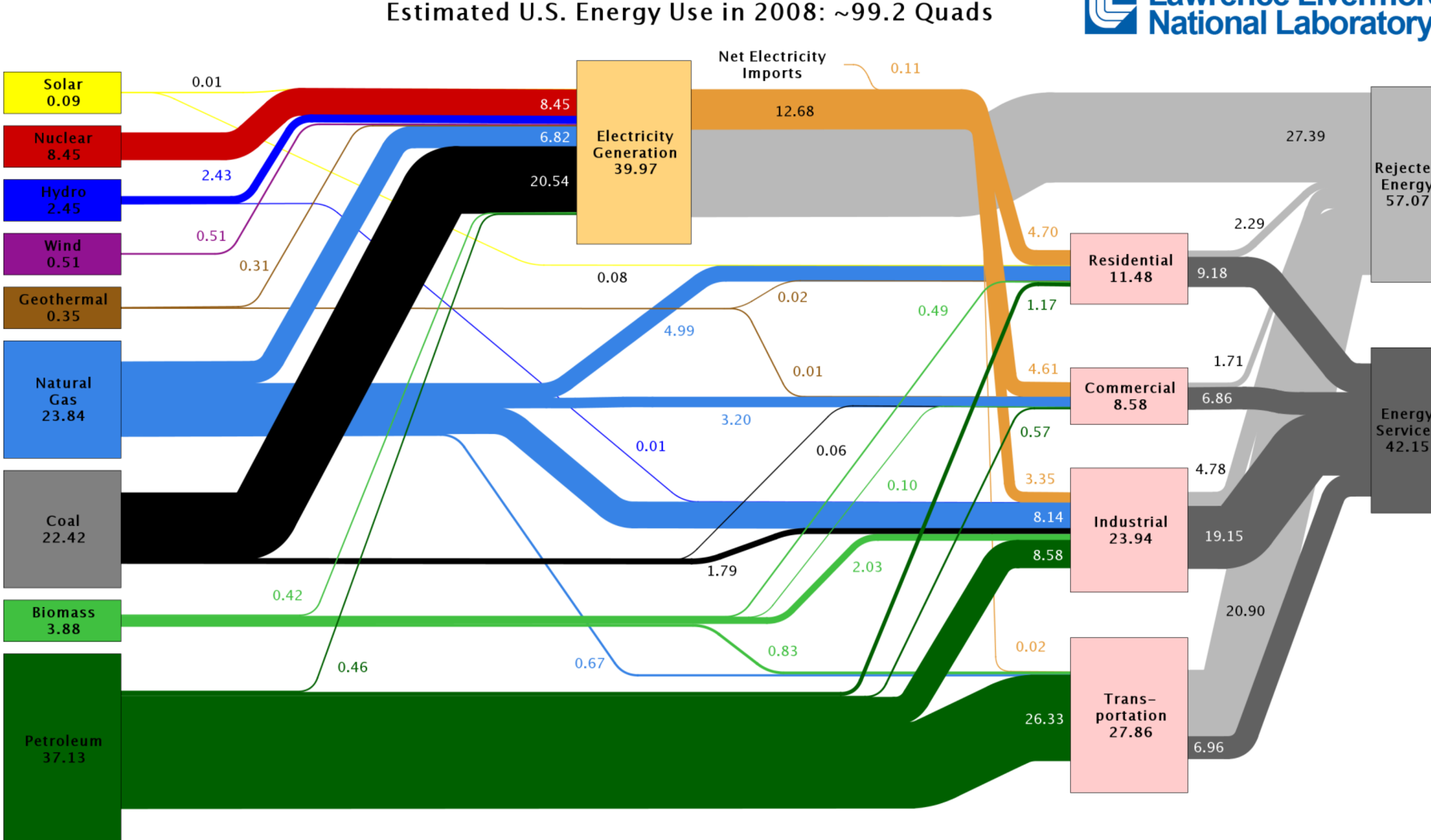


Global primary energy



Source: IEA WEO 2008

Energy flows (USA – 2009)



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

What drives the growth of energy needs?

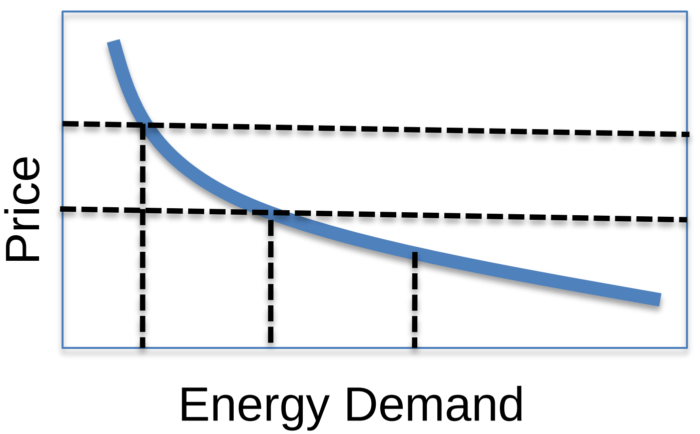
- Energy Equation:

Energy Consumption = Population x Service Demand per Capita x Service Energy Intensity

- Efficiency improvements?

- *Jevons Paradox*

  The growth in efficiency in the utilization of a resource tends to increase its extraction rate



Sustainability Definitions

- The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. [Bruntland, 1987]*

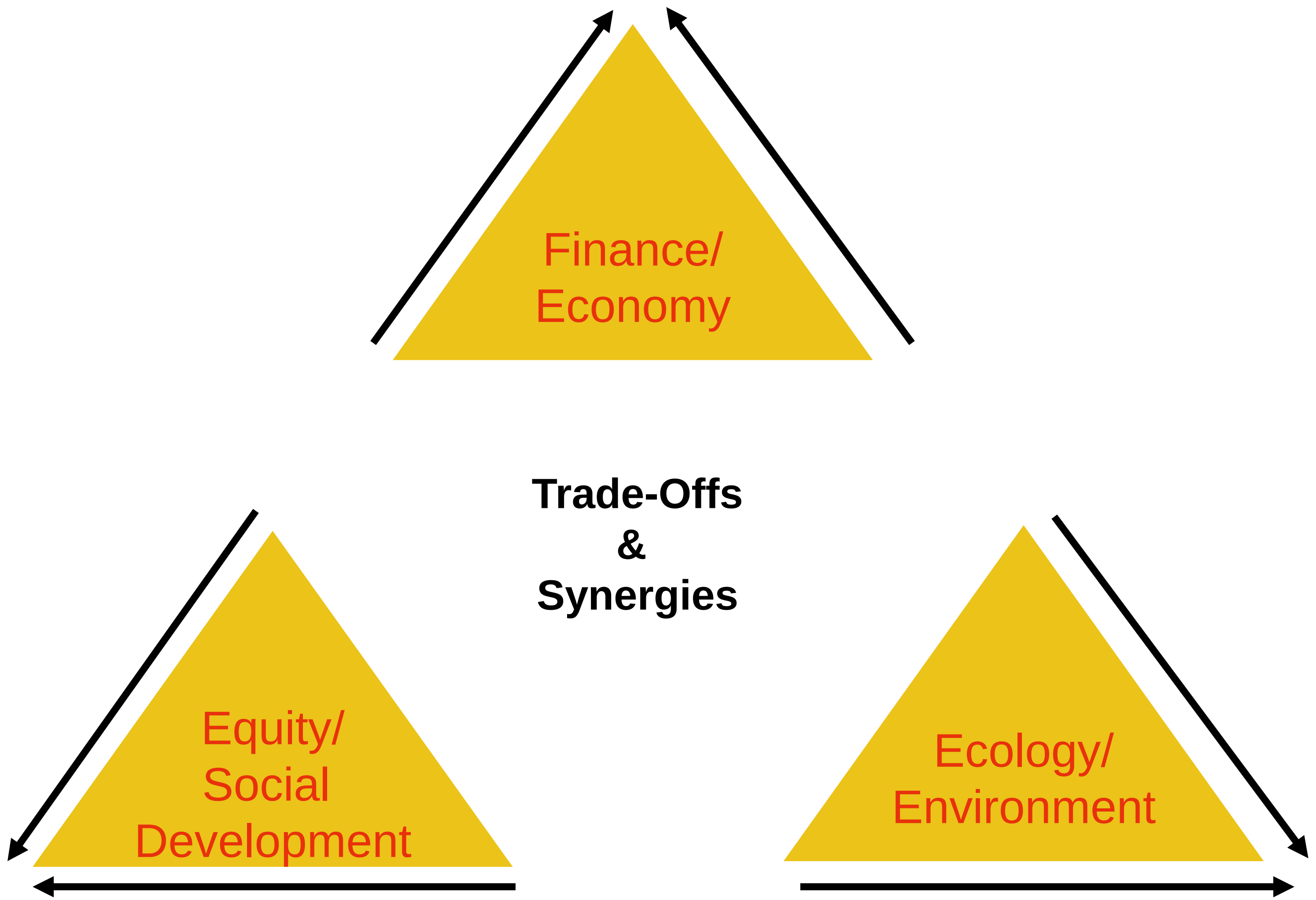
- Preservation of productive capacity for the foreseeable future. [Solow, 1992]

- Biophysical sustainability means maintaining or improving the integrity of the life support system of earth. [Fuwa, 1995]

- A dynamic harmony between the equitable availability of energy-intensive goods and services to all people and the preservation of the earth for future generations [Tester, et al. 2005]

*Full references are given in Textbook

The Three Dimensions of Sustainability



Derived from World Bank (1996)

Masdar INSTITUTE

What is Sustainable Development?

- *"The environment does not exist as a sphere separate from human actions, ambitions, and needs, and attempts to defend it in isolation from human concerns have given the very word "environment" a connotation of naivety in some political circles. The word "development" has also been narrowed by some into a very limited focus, along the lines of "what poor nations should do to become richer," and thus again is automatically dismissed by many in the international arena as being a concern of specialists, of those involved in questions of "development assistance."* ***But the "environment" is where we live; and "development" is what we all do in attempting to improve our lot within that abode. The two are inseparable.****"*

- ***"The concept of sustainable development does imply limits****—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. "*

What is Sustainable Development?

WHAT IS TO BE SUSTAINED:	FOR HOW LONG? 25 years "Now and in the future" Forever	WHAT IS TO BE DEVELOPED:
NATURE Earth Biodiversity Ecosystems		**PEOPLE** Child Survival Life Expectancy Education Equity Equal Opportunity
LIFE SUPPORT Ecosystem Services Resources Environment	**LINKED BY** *Only* *Mostly* *But* *And* *Or*	**ECONOMY** Wealth Productive Sectors Consumption
COMMUNITY Cultures Groups Places		**SOCIETY** Institutions Social Capital States Regions

Source: Our Common Journey: A Transition Toward Sustainability

Fuel resource time scales

The World Runs on Fossil Fuels

- Petroleum and natural gas
  - US (10-50 yr)
  - World (100-200 yr)
- Coal
  - US (250 →? yr)
  - World (350 →? yr)
- Other Fossil (> 350 yr ?)
  - Oil shale & tar sands // CAREFUL of Energy Returned on Energy Invested (EROEI)

Sequestration – work is embryonic & geologic timescale is needed

Solar (inexhaustible, but difficult to harvest, 400 W/m^2 = typical energy flux)

- Agri-business in industrialized countries
- Biotech might help

Nuclear

- Fission
  - Burners (100-200 yr, depending upon scale of use →demand curve)
  - Breeders (> 10 times greater)

The problem(s)

- Dual Carbon Constraints:
  - Fossil fuels are finite (availability)
  - Fossil fuel burning contributes to climate change and pollution (environment)

- Energy usage is not equitably distributed (equity)