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SMR 1585 - 8

WORKSHOP ON DESIGNING SUSTAINABLE ENERGY SYSTEMS
18 October - 5 November 2004

DESIGNING SUSTAINABLE ENERGY SYSTEMS:

MAJOR ISSUES

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These are preliminary lecture notes, intended only for distribution to participants.

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DESIGNING SUSTAINABLE ENERGY SYSTEMS – MAJOR ISSUES

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Planning and Economic Studies Section

International Atomic Energy Agency

Content

- Energy for Sustainable Development – Defining the Concepts
- Current Status
- Main Features of a Sustainable Energy System
- Designing Sustainable Energy System

The Concepts

Sustainable Development

- Sustainable development is development that meets the needs of the present without compromising the ability of the future generations to meet their own needs
  - (What are the needs ?)
    - ➔ Basic needs: food, shelter, mobility, health care, education
    - ➔ Luxury needs: entertainment, personal satisfaction and development, etc.

- Strategy for Sustainable development aims to promote the harmony among human beings and between humanity and nature

Source: WCED 1987, Our Common Future

Sustainable Development

- Three pillars:
  - Economic development
  - Social development
  - Environment Protection
- At all levels:
  - Local
  - National
  - Regional
  - Global
- Add to that equity, equality

Source: Report of the World Summit on Sustainable Development. Johannesburg 26 Aug - 4 Sep 2002

The Challenges

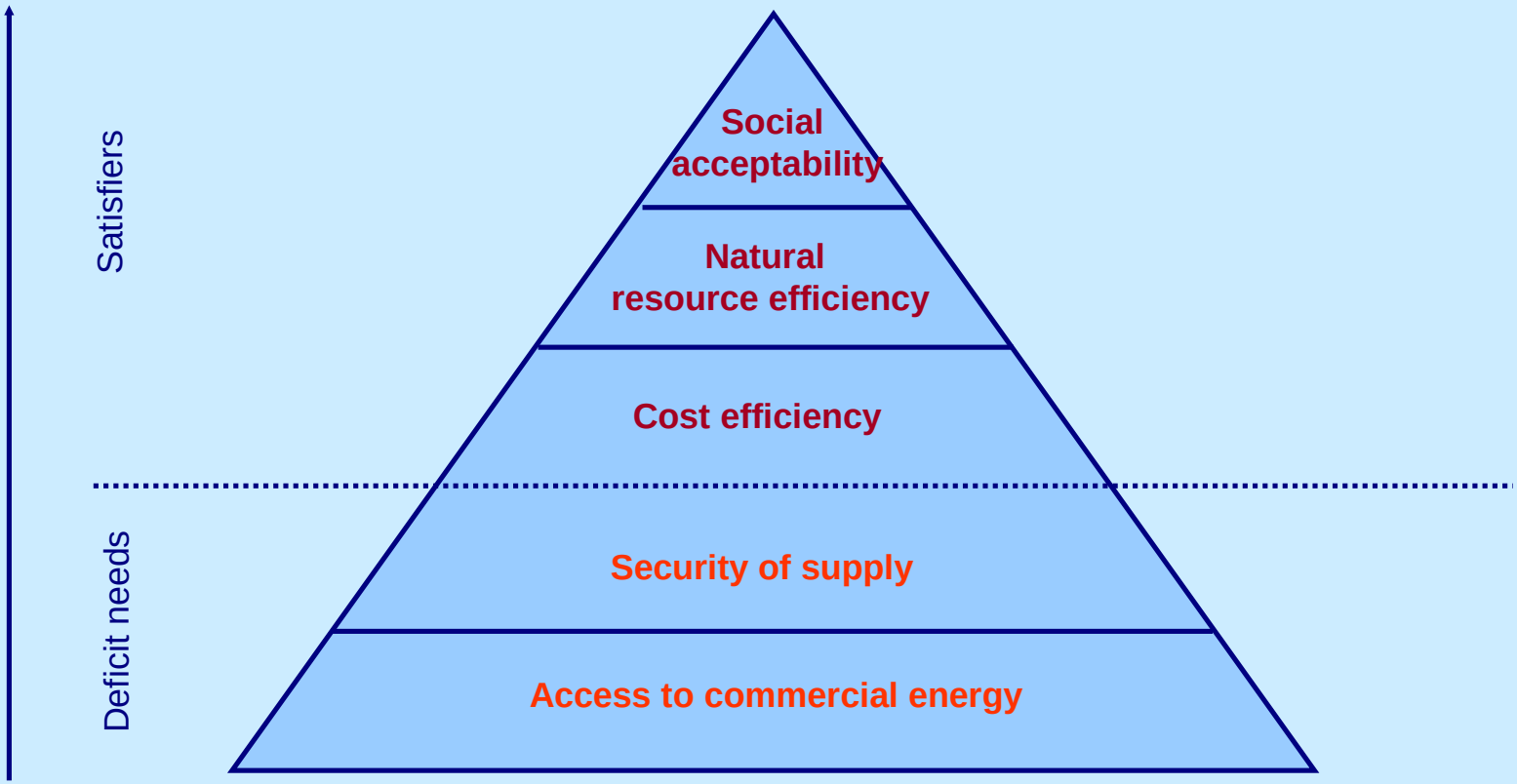
- Deep fault line that divides human society between the rich and the poor
- Ever increasing gaps between developed and developing worlds
- Environment degradation

- Poverty eradication
- Changing the production and consumption pattern
- Managing the natural resource base for socio-economic development

Sustainable Energy

- Energy produced and used in ways that **support** human development over the long-term in all its **social, economic and environmental** dimensions is what is meant by sustainable energy:
  - Energy as source of prosperity - adequate services for satisfying human needs, improving social welfare, achieving economic development
    - ➔ Accessible, affordable, reliable energy services
  - Should not endanger quality of life of current and future generations and should not exceed the carrying capacity of the ecosystem

The Energy Need Pyramid



Source: C.W. Frei, Energy Policy 32 (2004)

Three Components of Sustainable Energy

- Economic
  - Energy is essential to economic and social development and improved quality of life (Agenda 21, chapter 9.9)
- Social
  - To develop for all poverty-stricken areas integrated strategies and programmes of sound and sustainable management of the environment, resource mobilization, poverty eradication and alleviation, employment and income generation (Agenda 21, chapter 3.4)
- Environment (health)
  - All energy sources will need to be used in ways that respect the atmosphere, human health and the environment as a whole (Agenda 21, chapter 9.9)

Source: Agenda 21, Chapter 3.4 and 9.9

Current Situation

Four Main Divides

- The lifestyle divide: excesses of consumption by one-fifth of the world population (90% of total personal consumption) vs. 1.2 bill people living with less a dollar per day
- The vulnerability gap: the gap is widening between countries, regions. The disadvantaged at more risk to environmental change and disasters
- The environmental divide: stable, improved environment in developed vs. degraded environment in developing countries
- The policy divide: strength in both policy development and implementation vs. difficulties and struggling in both

Source: UNEP 2002, GEO3

Uneven Economic Growth

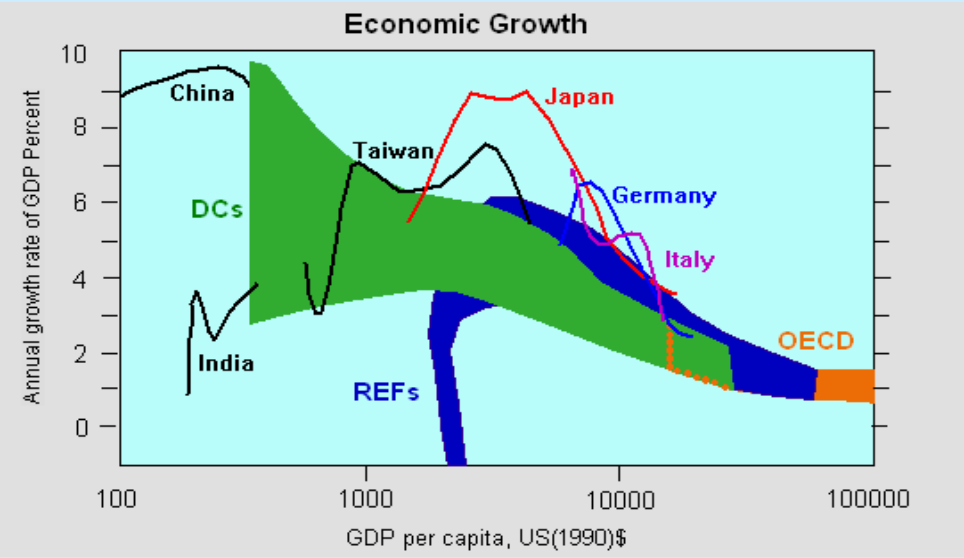
Economic Growth Rates

Region	Historical (percent per year) mer Since 1850	mer Since 1950	ppp Since 1950
NAM	3.5	3.3	2.1
WEU	2.4	3.7	2.2
PAO	3.9	6.2	3.6
EEU	2.1	3.9	2.4
FSU	3.5	5.2	3.5
CPA	2.9	6.1	4.3
SAS	2.0	4.5	3.1
PAS	n.a.	9.8	6.8
MEA	n.a.	4.6	3.1
AFR	n.a.	2.7	2.0
LAM	3.7	4.2	2.9
World	n.a.	4.0	2.8

Two observations can be made from historical experience:

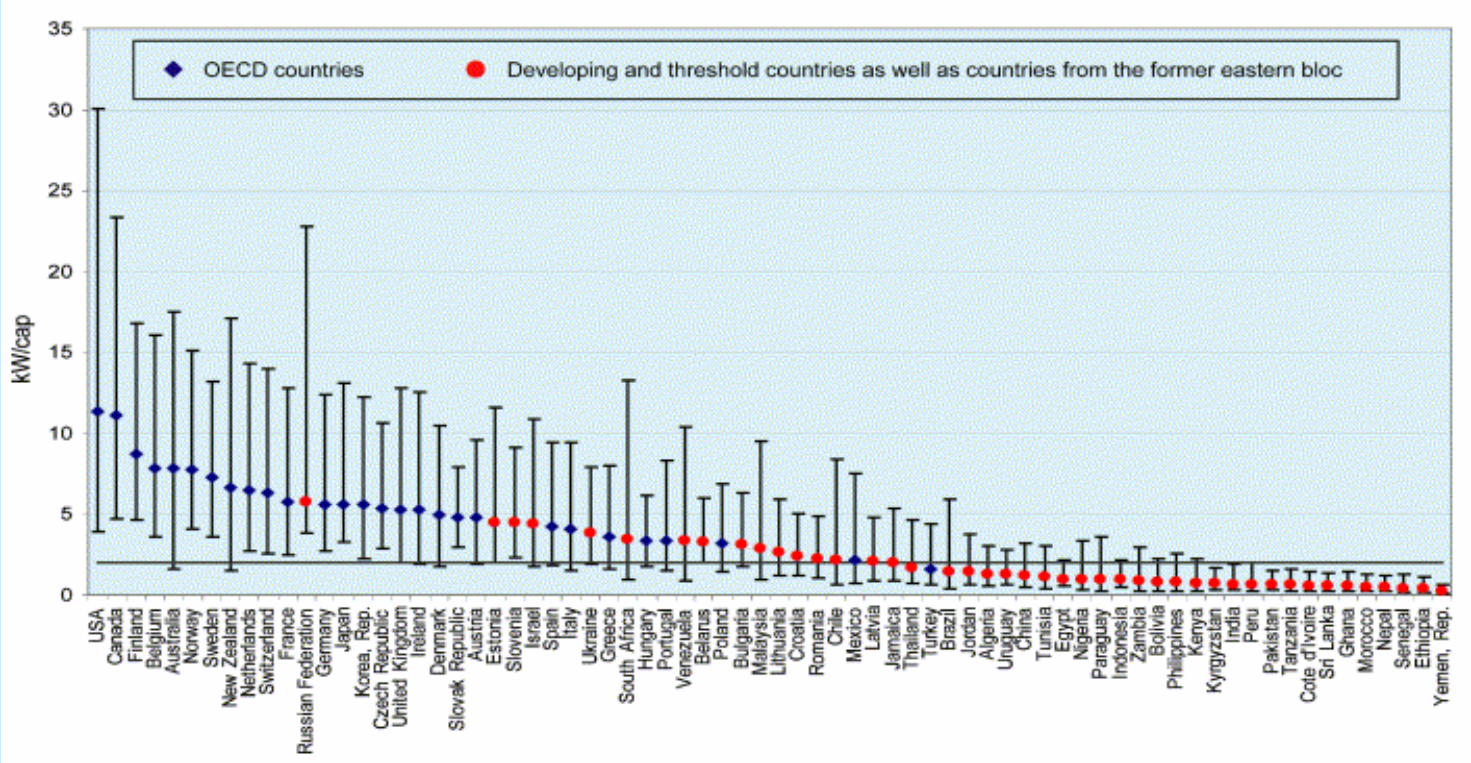
First, economic growth is uneven, across countries and over time.

Second, there is conditional convergence over time as developing countries "catch up" with the industrialized economies.



Source: IIASA 1998 Global Energy Outlook

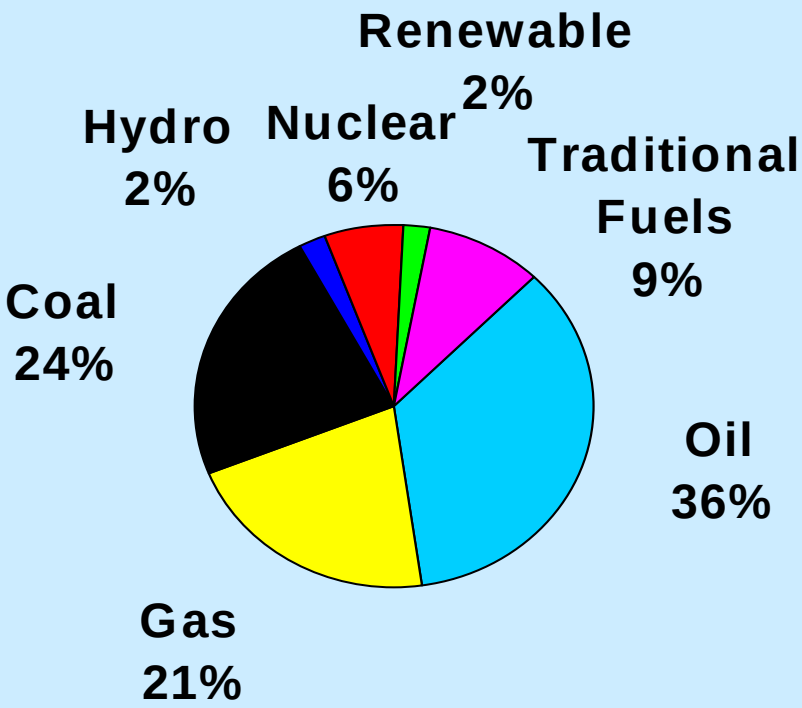
Energy Consumption Inequality



Points represent average consumption, in KW/cap (1 KW/cap = 8760 KWh/a)
Bars represent highest and lowest deciles of users

Source: D. Spreng, Energy Policy (article in press)

World Energy Consumption



Biomass consumption

OECD	3,4	12,5
Africa	58	22,6
Asia excluding China	42	35
China	27	21,6
Latin America	20	7,1
Former USSR	1	0,7
Non OECD Europe	7,4	0,5

Number are in %: of the total consumption (1st col.) and of total biomass consumption (2nd col.) in 2001

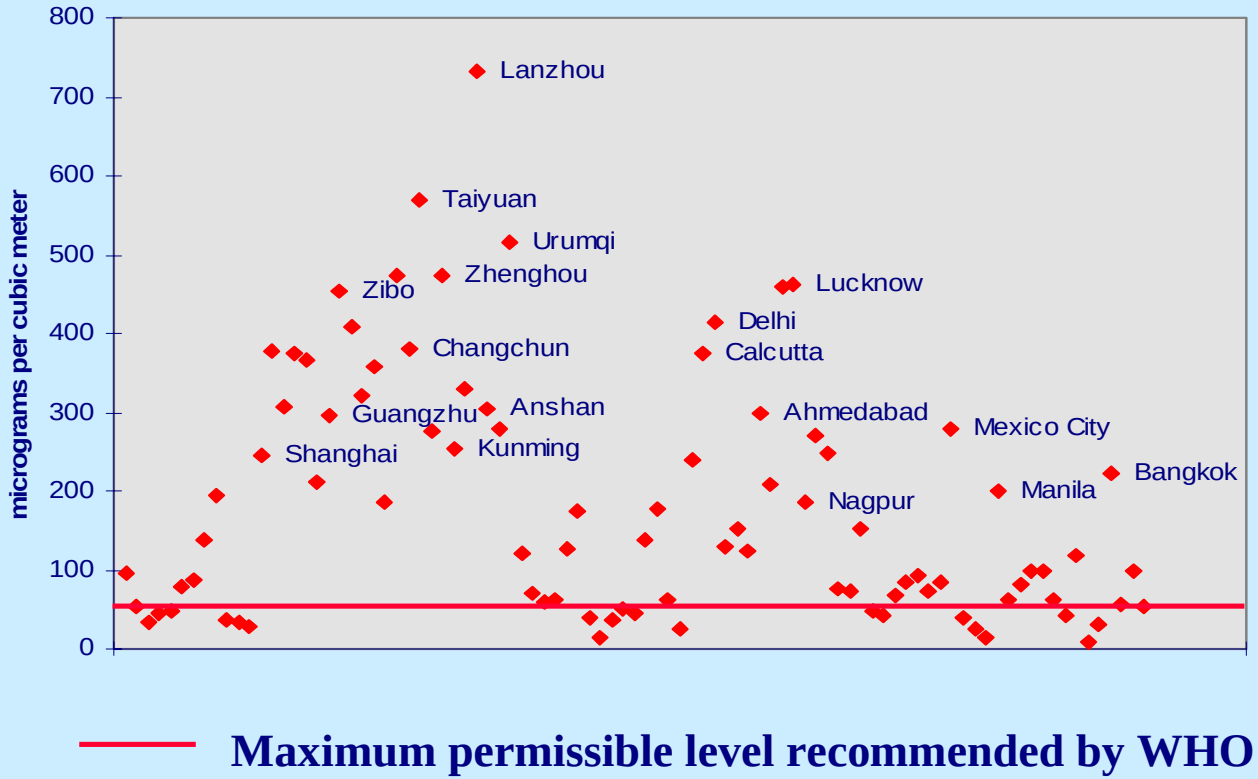
Source: IAE Energy Balances 2003 ed.

Global Atmospheric Emissions from Fossil Fuel Consumption

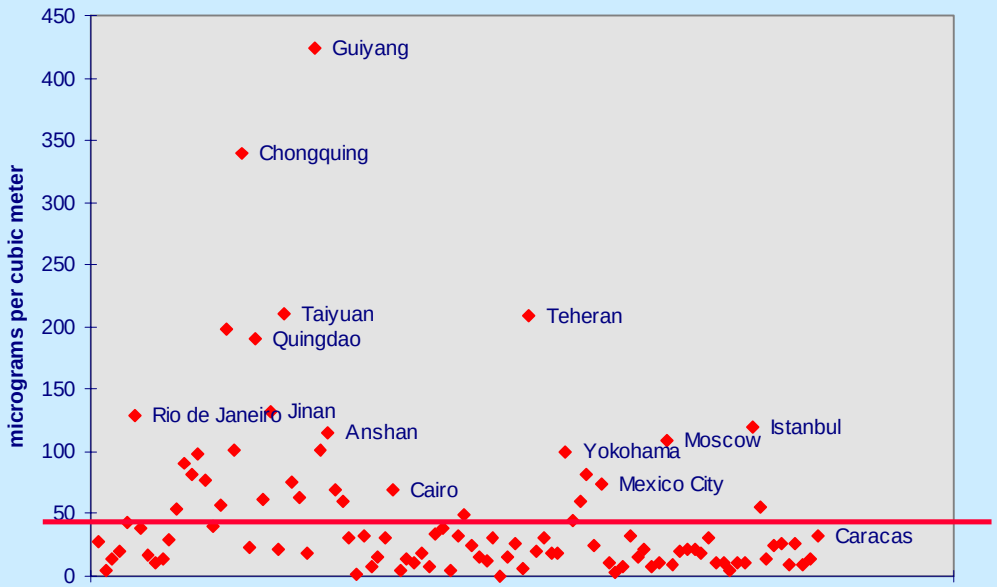
CO_2	5.8 billion tons C
CH_4	84.6 million tons
SO_2	71.6 million tons
NO_x	63.0 million tons
HC-	42.0 million tons
PM	130.2 million tons
Hg	735 tons
Cd	880 thousand tons
Pb	88.5 thousand tons

- World Energy Assessment, UNDP/UNDESA/WEC, 2000

Concentration of Particulates in Urban Areas

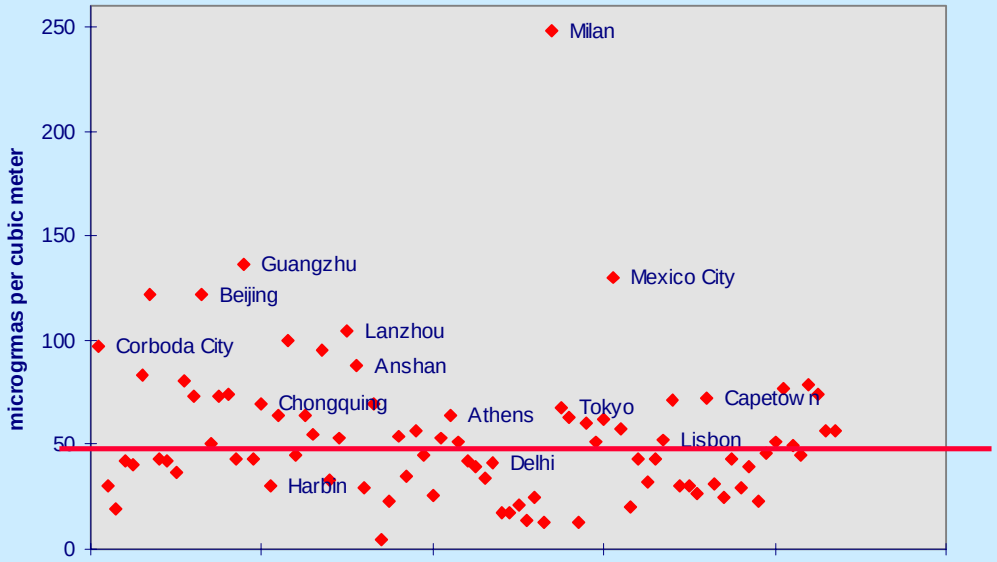


Concentration of SO2 in Urban Areas



Maximum permissible level recommended by WHO

Concentration of NOx in Urban Areas

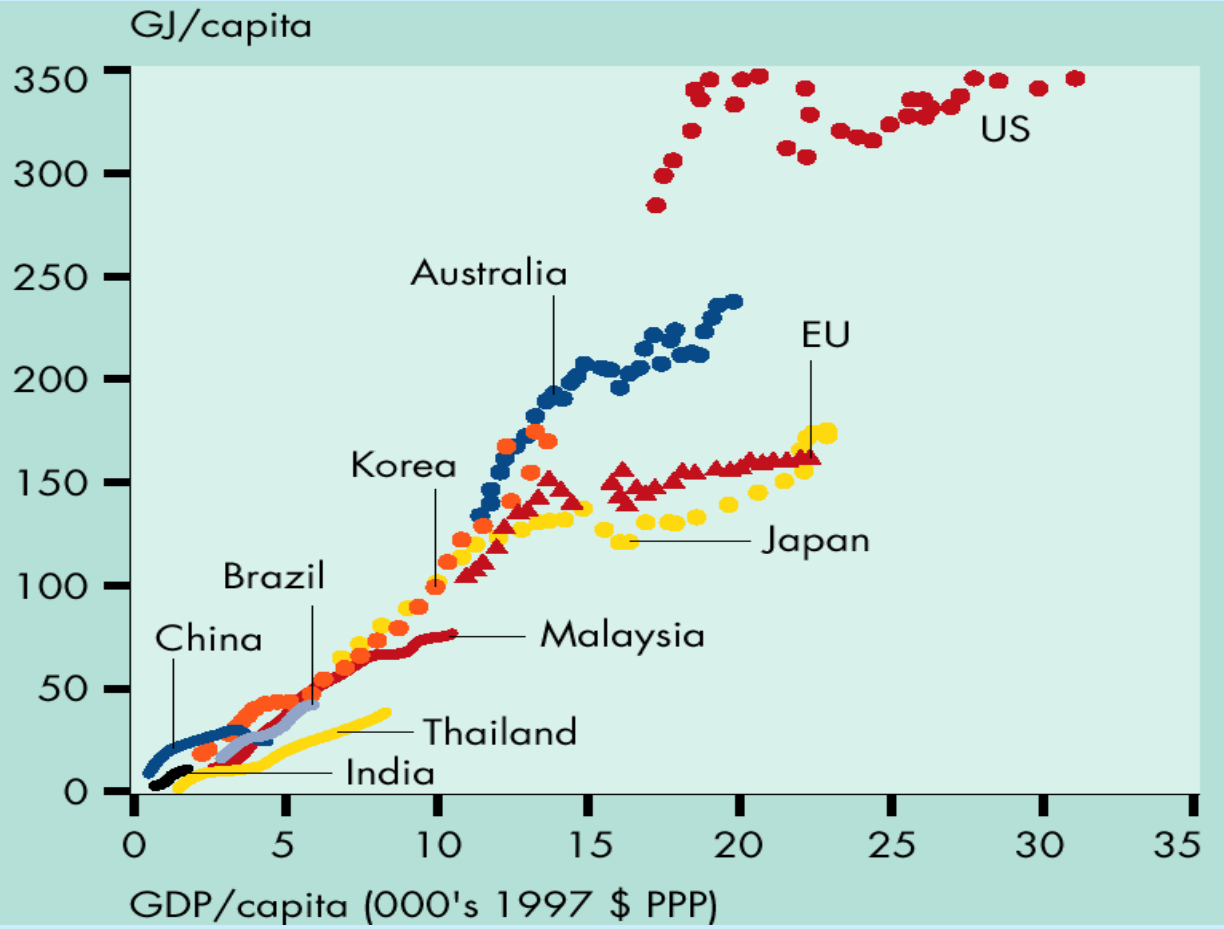


Maximum permissible level recommended by WHO

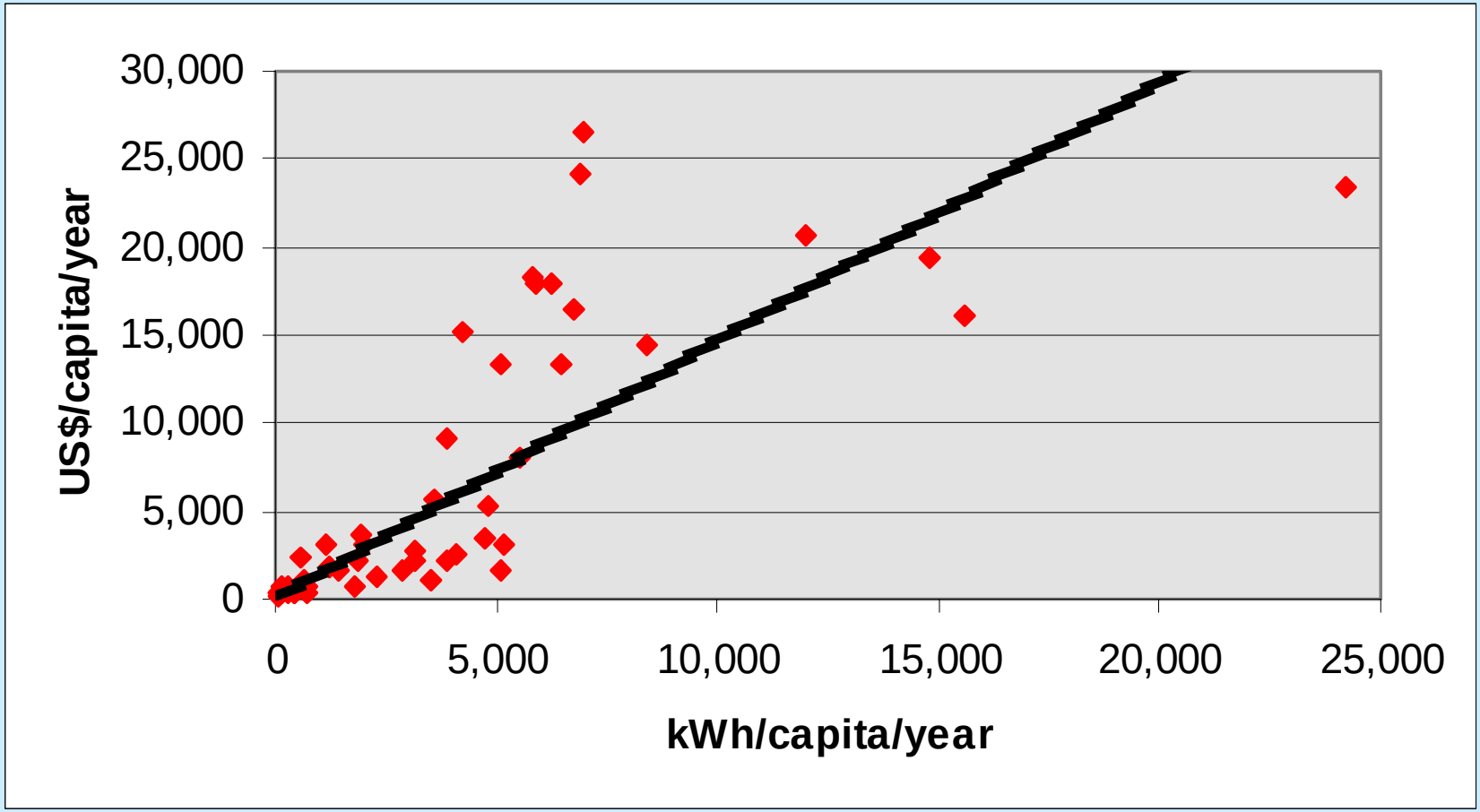
The Energy Ladder

- $1,000 – substitution of commercial for traditional fuels sets in
- $3,000 – industrialization and personal mobility accelerate demand
- $10,000 - demand slows down as main spurt of industrialization is completed
- $15,000 - demand grows slower than income (basic energy service requirements are met)
- $30,000 - economic growth requires little additional energy

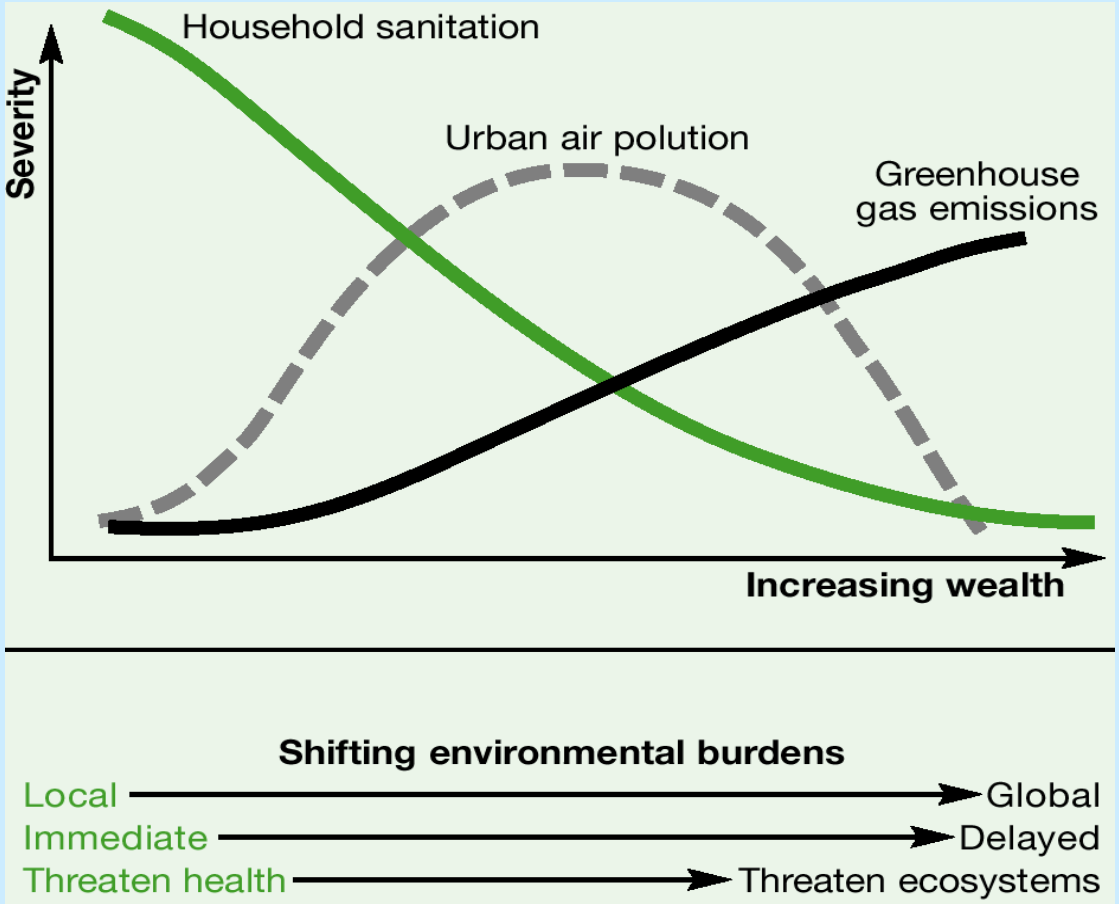
Climbing the Energy Ladder



GDP per Capita versus Electricity Use per Capita

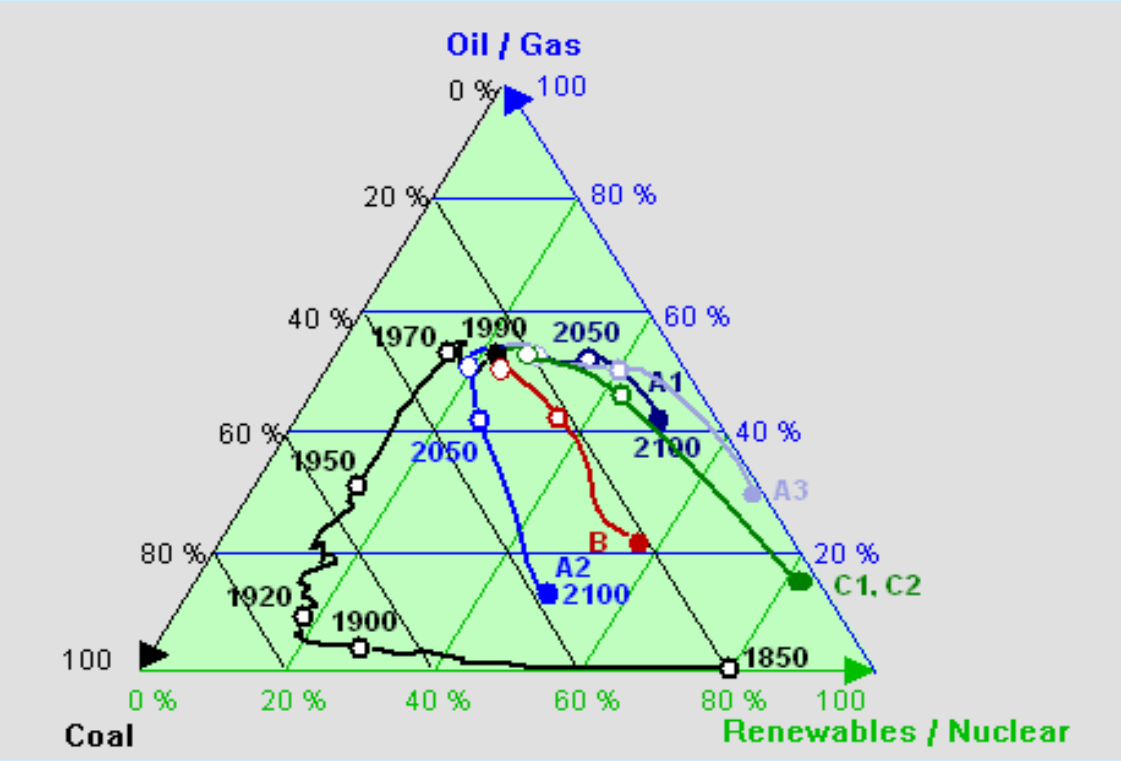


Environmental Impact Transition



Sources: McGranahan *et.al.* (2000); Smith and Sakbar (1999)

The Energy Route



What will be after another 100 years ?

The present energy system: Unsustainable?

- Modern energy services are not accessible to some 2 billion people.
- Non-commercial (traditional) energy use has led to deforestation, soil erosion and diminishing ground water levels.
- Human health is threatened by high levels of pollution resulting from its use at the household, community, and regional levels.
- Closing the fossil fuel cycle through the atmosphere generates a host of energy-linked emissions such as
  - suspended fine particles and precursors of acid deposition which contribute to poor local air quality and degradation of ecosystems.
  - anthropogenic greenhouse gases which are altering the atmosphere in ways that already has a discernible influence on the global climate system.

The present energy system: Unsustainable?

- Some energy chains create long-lived wastes that are not disposed of in an inter-generationally equitable manner.
- Current oil supplies originate from politically sensitive regions resulting in supply security concerns and potential geopolitical conflicts.
- Externalities are generally not internalized.
- Producers cannot recover costs.
- Some technologies such as nuclear or some renewables encounter socio-political acceptance problems.
- Fossil resources are finite – does the present generation create sufficient capital & knowledge to compensate future generations (“weak sustainability” criterion)?

The present energy system: Unsustainable?

- Agenda 21, Chapter 9.9:
- Much of the world's energy is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially

The Characteristics of Sustainable Energy System

Compatibility Criteria

- Based on three pillars of sustainable development – economic, social and environmental – the following seven compatibility criteria can be used to evaluate energy technologies and energy systems:
  - Economic compatibility
  - Environmental compatibility
  - Intergenerational compatibility
  - Socio-political compatibility (or public acceptance)
  - Geopolitical compatibility (security of supply/ import dependence)
  - Demand compatibility

Future Energy Technology Development

- Will depend on consumer preferences, producer profitability and government policies which together shape the energy system seen as most satisfactory in terms of:
  - Costs
  - Quality
  - Reliability
  - Security
  - Convenience
  - Environmental impacts
  - Social impacts

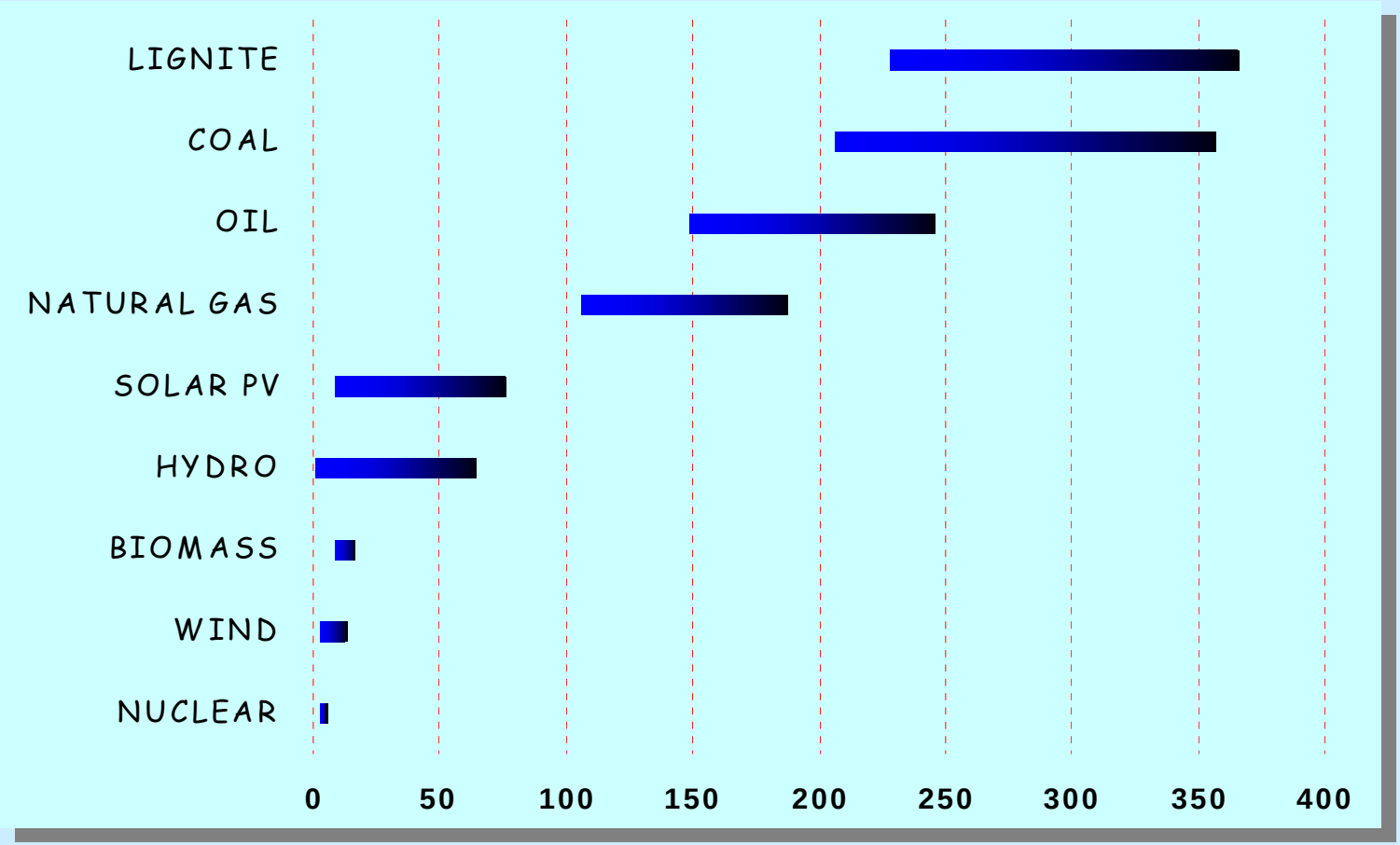
Economic Compatibility

- Sustainable energy services must be
  - Accessible
  - Affordable
  - The prices of energy services must cover the true social cost
- The contradictory objective here is: full social costs but affordable
- The solution is efficiency, effectiveness and competitiveness
- If the technology, or the system that is not competitive – it is NOT sustainable

Environmental Compatibility

- The inputs to and outputs from each link of the energy system chain must minimally intrude the nature's flows and equilibria, e.g., do not overload carrying capacity of the ecosystems
- Decommissioning of energy technologies, fuel cycles and infrastructure must be technically and economically feasible

GHG emissions (gCeq per KWh)



Intergenerational Compatibility

- Energy services must be based on inexhaustible energy sources or finite sources that lead to creation of energy substitutes
- Waste should not pose a risk to future generations

Availability of Fossil Fuels

life time of reserves (years)

	A	B
Oil	45	200
Gas	69	400
Coal	452	1500
Total	170	630

A: Conventional reserves only

B: Conventional and Unconventional reserves

- World Energy Assessment, UNDP/UNDESA/WEC, 2000

Two Alternative Strategies

ATMOSPHERE

Partial removal to solid waste

SO_2 NO_X CO_2 TOXIC

POLLUTANTS

SOLID WASTE

GROUND DISPOSAL
shallow

DISPERSION STRATEGY

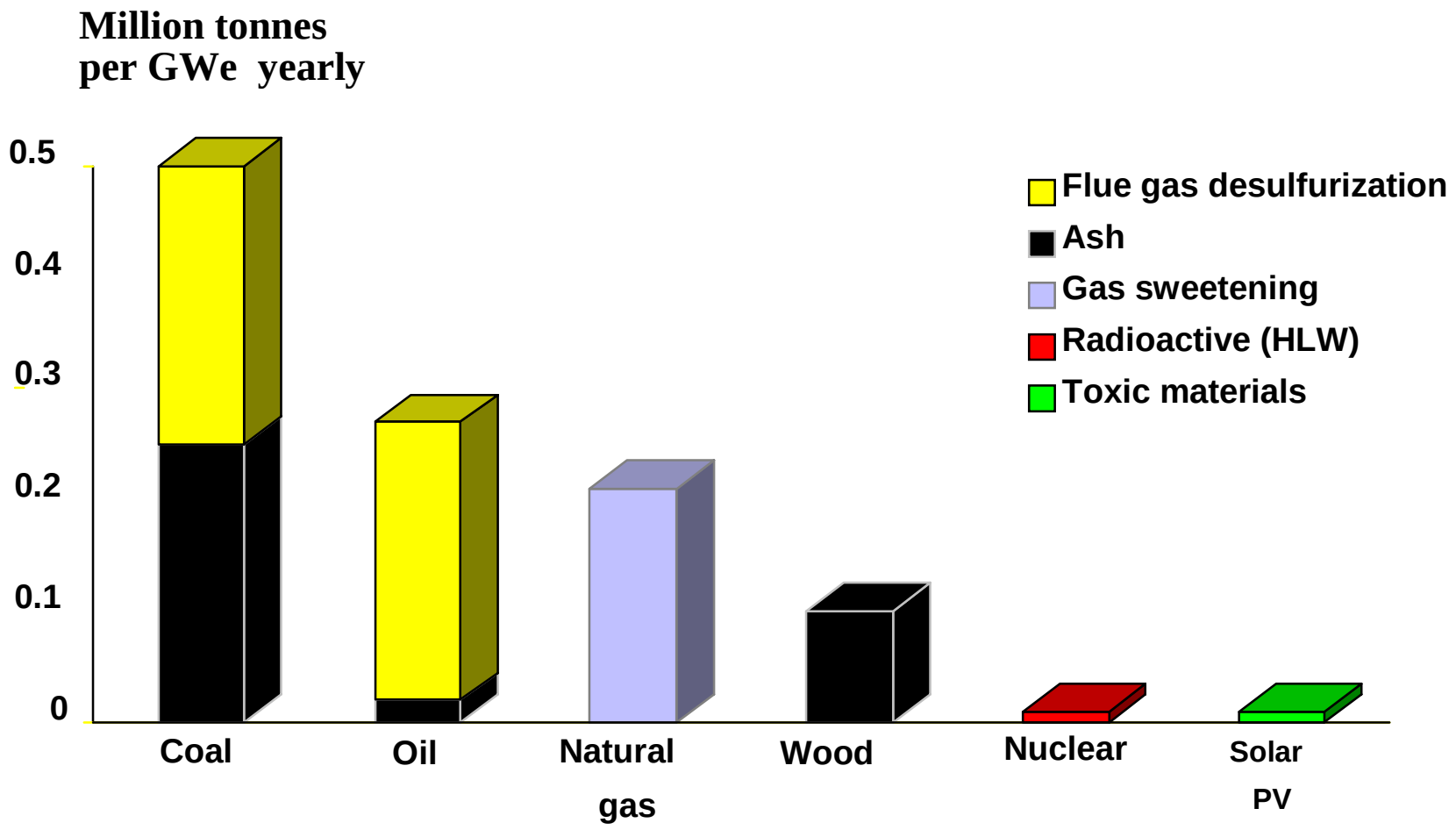
RADIOACTIVE WASTE

Volume reduction

GROUND DISPOSAL
shallow or deep

CONFINEMENT STRATEGY

Wastes in Fuel Preparation and Plant Operation



Source: IAEA, 1997

Public Acceptance

- The technology links of the energy systems must be tolerated by general public
- Public attitude and perceptions change and can be influenced by education campaign
- Issues such as:
  - Safe operation of nuclear energy
  - Long-term solution for radioactive waste disposal

Security of Supply

- Heavy dependence on imported fuels pose instability and risk disruption in supply
- Expose to price hike or crisis
- A good combination of sources ensure a more stable supply and higher security

Designing Sustainable Energy System

Future Sustainable Energy Possible ?

- Realising sustainable future requires a well-balanced combination of technological measures:
  - Higher energy efficiency (thus reducing demand for energy services)
  - Increased penetration of renewable energies
  - Use of advanced energy technologies
- And policy measures:
  - Continued market reform
  - Consistent regulations
  - Price incentive for higher efficiency, competitiveness as well as development and diffusion of sustainable energy technologies
  - Getting the prices right

A Framework for Designing SES

- Level of analysis:
  - Local (system)
  - Regional
  - Interregional
  - Global
- Emphasis on specificities
- Scenario approach: visions about the future

Steps in Designing SES

- Construct future social, economic and demographic background and future trends
- Translate these trends into physical indicators and values on the level of economic activities thus requirements for energy services
- Take inventory of the most important options and technologies that can play a role in future energy system. This inventory includes:
  - Energy efficiency options in the industrial, residential and commercial and transport sectors

Steps (continued)

- Inventory includes:
  - A wide variety of energy conversion technologies
    - ➔ Fossil fuel based
    - ➔ Renewables
    - ➔ Nuclear
- Technological options are related to the socio-economic context:
  - Availability
  - Social acceptance/preferences

Steps (continued)

- Quantitative analysis of scenarios with focus on sustainability objective (indicators):
  - Economic compatibility:
    - ➔ Cost of energy services
    - ➔ Accessibility and affordability
  - Environmental compatibility
    - ➔ Emissions (PM10, SO2, NOX, GHG)
    - ➔ Waste
  - Intergenerational compatibility
    - ➔ Use of resources
    - ➔ Waste

Steps (continued)

- Sensitivity analysis
- Interpretation of quantitative indicators, summary and recommendations

- Use computer tools.