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Workshop on Materials Science and Physics of Non-Conventional Energy Sources

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"Environmental and Health Effects of Different Energy Systems"

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

Environmental and health effects of different energy systems

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Role of energy systems on anthropogenic environmental and health effects of some important activities.

Impact	sector						
				energy systems*			
	industry	civil work	railway highway	electricity	transportation	space heating	industry
requirements of natural resources:							
-land	+	+	+	+			
-water	+			+			
air pollution*	+			+	+	+	+
water pollution	+			+			
noise	+			+	+		
global effects (climate, acid rains)	+			+	+	+	+
waste heat	+			+	+		+

* almost all anthropogenic air pollutants (CO_2 , CO, SO_2, NO_x) are produced by energy systems

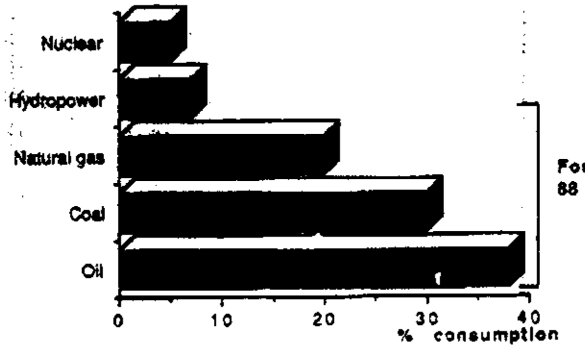


Fig.1. Primary energy sources used to satisfy the world demand

- The most common way to obtain energy is to burn a fuel, usually a fossil fuel, obtaining as a final result heat, motion or electricity.

- Energy sources used to satisfy the demand are quite few: as shown in Fig.1 more than 85% of the world demand is covered by fossil fuels (coal, oil and natural gas).

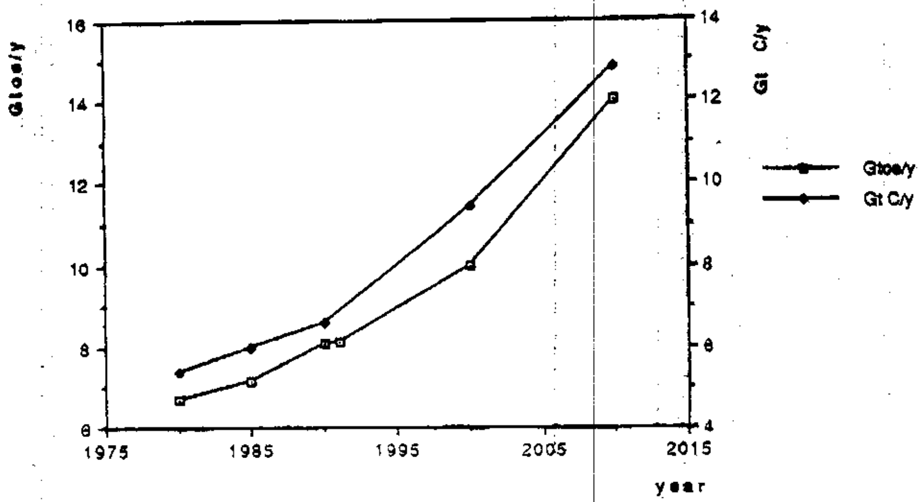


Fig.2. World energy consumption and carbon dioxide emission

- Health effects and environmental impact of energy systems and energy consumption have followed parallel pathways.

- The increase of the CO_2 concentration in the atmosphere in the last 20 years follows with good approximation the curve representing the world energy consumption in the same period.

- CO2 concentration has increased since the beginning of the industrial revolution (by the end of the18th century) from 280 to 350 ppm

Energy systems	Fixed systems			Mobile systems
	Power stations	Space heating	Industry and other uses	Transport
Primary energy %	34	18	26	22

Table 1.The most common energy systems and their contribution to primary energy consumption in Italy

- To the fixed systems belong the boilers used for space and industrial heating and the power stations producing electricity.

- The mobile systems include all types of transportation means such as cars, trucks, aeroplanes, ships and so on.

- The percentages of primary energy consumed in Italy by the systems is also referred in table 1.

Some important remarks on environmental and health impacts of energy systems

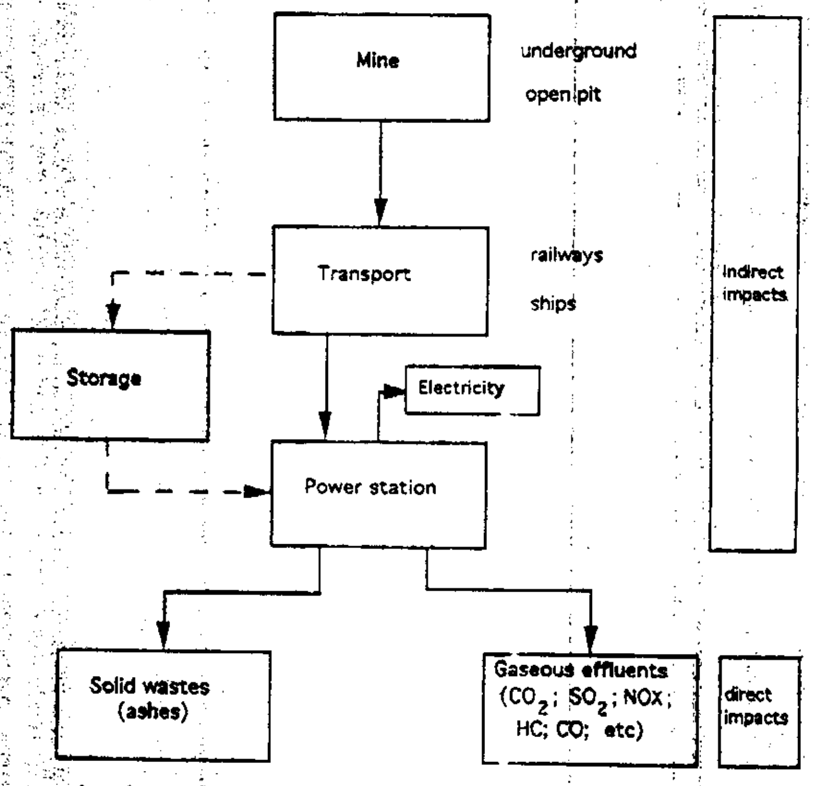
a. air pollution and thermal pollution are two relevant environmental and health effects of energy systems: this is related to the in fact a large fraction of energy is produced burning fossil fuels producing a huge amount of CO_2 and significant quantities of dangerous pollutants such as CO, SO: NO_X, hydrocarbons, etc.;

b. power stations, have a considerable size (typically some thousands of thermal megawatts); therefore the most part of environmental effects (especially pollution) is concentrated near the plant and this makes it easier the control of the environmental impact;

c. the control of the environmental impact is more difficult for systems of small size: this condition is particularly true for space heating systems used for houses and apartments and becomes very difficult in the case of automobiles which are characterised also by a variable regime;

d. the systems producing mechanical energy from heat (nuclea power stations, systems burning fossil fuels, home and industrial boilers, motor vehicles) discharge a considerable amount (50 - 70%) of the heat into the environment under t: form of hot exhaust gas into the atmosphere or as warm wate discharged into natural water bodies.

Fig.3 Schematic diagram of coal fuel cycle



a. the direct impacts of include all the effects that the energy system (e.g. a boiler, a power station; a car, a nuclear power plant, etc.); produces directly on the different environmental components, such as soil, air, water, etc.; examples of direct impacts are: occupation of land; air and water pollution; thermal and noise pollution; damages deriving to the environment and to the health owing to a severe accident occurring to the system;

b. the indirect impacts include all the ffects deriving not only from the building of the energy producing plants but also from all the operations of the fuel cycle such as the extraction, transportation and storage of the fuel; a schematic diagram of the fuel cycle of coal is shown in fig. 3; global effects such as climate changing and acid rains are also examples of indirect effects.

Approach to the evaluation of risk in energy production.

- The assessment of environmental impacts of energy systems is based on the evaluation of the risks, i.e. the expected effects, by using statistic data when possible or probabilistic analysis when data are not available.

- Many scientific approaches have been developed in order to provide decision makers with suitable tools to make choices among different solutions. One of the first attempt to apply these methods was done with the safety analysis of nuclear reactors.

- These approaches are very helpful, but they are not sufficient to convince the public, since the acceptance is strongly affected by a psychological attitude not always based on rational considerations.

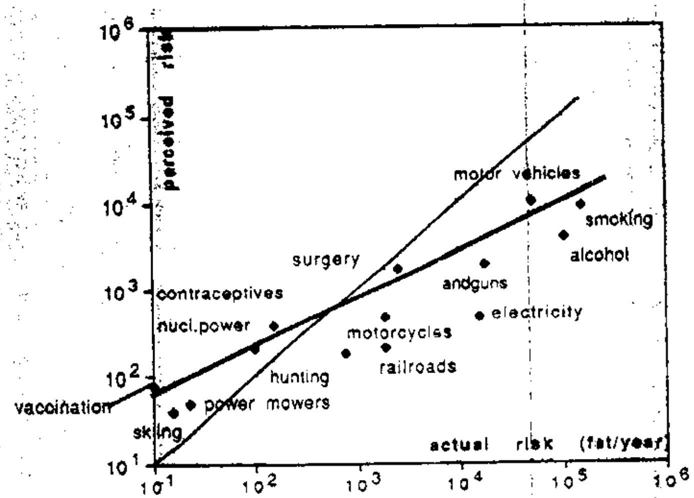


Fig.4. Perceived vs. actual risks for different activities and technologies

- In Fig.4. are shown the perceived risks versus the actual risks for different activities or technologies: some risks are perceived in a right way (e.g. car accidents), others are overestimated (e.g. nuclear energy) and others are underestimated (e.g. cigarette smoking).

- To take into account this psychological attitude the decision process follows a pathway that includes not only technical evaluations, but also a direct involvement of citizens and social organisations.

Basic considerations for a correct approach to risk evaluation of ener.y systems

- The availability of energy produces an improvement in the standard of life: the lack of energy below the 2000 kcal/person x day means that the people don't have even enough food; to reach an acceptable standard of life a certain level of energy availability is necessary;

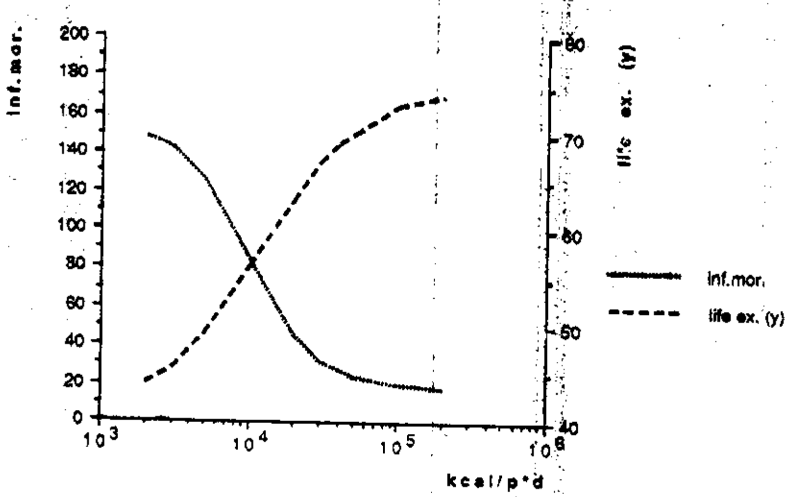


Fig.6. Life expectancy an infant mortality vs. energy availability

- risk analysis requires a risk unit, usually defined as the number of adverse effects (e.g. fatalities) referred to the unit time;

- the environmental risks, such as changes in local or global climate, damages to the vegetation, etc., are difficult to quantify,but they are taken into account in the decision process;

- the selection of a solution (type of energy system, its siting, etc.) should be the result of a risk-benefit analysis that involves big problems connected to the difficulty to evaluate risks and benefits quantitatively by expressing both of them by the same unit.

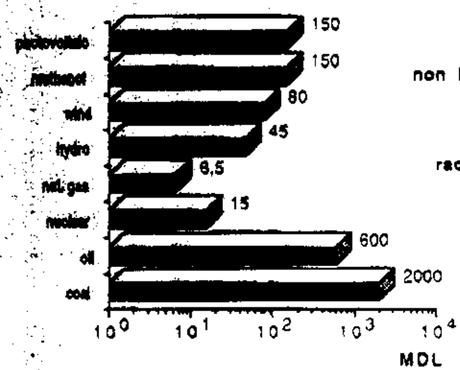
Basic assumptions of the Inhaber analysis

- all risks, occupational and public, are estimated for all the fuel cycle stages;

- risks are expressed only in terms of health adverse effects referred to the generation of an energy unit (thermal MWy): in this way the comparison among different energy systems becomes significant because it is referred to the same amount of benefit obtained;

- as a risk unit the number of fatalities/MWy is used; in order to take into account other adverse effects such as non-lethal diseases and injuries a more general unit is introduced: the "man day lost" (MDL); in this way, establishing a correspondence between the different adverse effects (fatality, disease, injury) and MDL it is possible to obtain the total risk as the sum of different types of risks and finally compare this total figure of an energy system with those of other systems.

Fig.7. Results obtained by Inhaber for different energy systems



non lethal accident	1 MDL
injury	30
disease	300
fatality	6000
radiat. disease	6000

- Coal results to be the most risky energy source: the highest risks are in the stage of extraction from the mines (occupational) and in the stage of energy generation (public) because of the large amount of dangerous pollutants emitted into the atmosphere.

- For oil a similar level of risk is estimated especially in the generation stage (public) because its combustion is also a source of dangerous pollutants.

- Natural gas and nuclear energy are characterised by the lowest level of risk: this is due for natural gas to the very low emission of pollutants; for the nuclear energy the main reason is related to the high energy intensity of the fuel that reduces the risks for unit energy generated; a further favourable aspect is the almost absolute absence of radioactivity release during normal operation.
- The surprising results regard the renewable energy sources: the relatively high level of risk of hydropower is due mainly to the rather frequent accidents occurring to the dams; for solar, wind and biomass energy systems the considerable levels of risk are related to the construction of the plants which require a large amount of material and manpower to produce the energy

Main limits of the Inhaber analysis

- It represents an interesting reference from the methodological point of view, but it is affected by several limits.

- It is affected by uncertainties on the risk data: some of them are deriving from statistics: this reduces greatly the significance of the final figure.

- The assumption of a coal fired station as a back-up systemin case of failure of the reference system penalises the systems characterised by low pollution and by a low plant factor, such as solar and wind energy sources.

- An important consideration lacking in the Inhaber analysis is the evaluation of environmental risk, such as problems connected to the CO_2 production,the acid rains,the use of natural resources (occupation of land, use of water, damages to vegetation, etc.).

- For these reasons the results of the Inhaber analysis cannot be taken as an exclusive element for the choice of an energy system, but only as a very helpful indication from a methodological point of view.

Recent results on environmental and health effects of energy systems producing electricity.

Basic assumption:

- calculation of health risks is done for the entire fuel cycle and is related to the unit of electricity produced for different energy systems;
- environmental effects are taken into appropriate consideration;
- any attempt to express all the risks with a single indicator is misleading: environmental and health effects are evaluated separately as well as risks from routine operations and severe accidents;
- the better known risk indicator is the acute fatality (mortality); there is therefore a tendency to make an exaggerated use of this indicator; some other indicators are usually more important such as the delayed lethal diseases (due to radiation or to pollutants) or the non-lethal diseases and injuries;
- environmental risks are difficult to quantify: an important role in the efficiency of the effect is played by the time and the space characterising the extension and the duration of the effect;
- the levels of health and environmental risks from electricity generation depend on environmental conditions, safety measures and degree of pollution control;

Table 2. Fatality rates (fatalities/GWe x a) for the four main energy sources used to produce electricity.

source	occupational		public	
	immediate	delayed	immediate	delayed
coal	0,4-3,2* 0,16-1,7°	0,13-1,1* 0,02-0,15°	0,1-1,0	2,6-6,0
oil	0,20-0,85** 0,22-1,35°°		0,001-0,1	2,6-6,0
gas	0,10-0,5** 0,17-1,0°°		0,2	0,004-0,2
nuclear	0,09-0,5* 0,07-0,4°	0,13-0,37* 0,07-0,33°	0,001-0,01	0,005-0,2

Note: Risk figures are related to the entire fuel cycle (operation included); risks from severe accidents are excluded.

*underground mining
°surface mining
**land extraction
°°offshore extraction

- Risk data of table 2 are all referred to the unit energy produced (1 GW_e a) and are expressed in terms of fatalities.
- Risks are divided into occupational and public and for both of them immediate (or acute) and delayed risks are considered; risk figures refer to the entire fuel cycle.
- Acute risks refer to routine accidents, but consequences due to severe accidents are excluded. Delayed risks refer to diseases leading to death with a certain period of time (e.g. cancer).
- The summary of the fatalities rates shown in table 2 refers only to the four main energy sources used to produce electricity.
- Risk figures for these four energy sources are founded on data deriving from appropriate statistics. They are relatively reliable, but it is necessary a great caution in their interpretation because of the uncertainty affecting especially the delayed risks.

Considerations on data of table 2

- The energy source with highest risks, both occupational and public, appears to be coal;
- occupational risks for coal and nuclear are due mainly to the extraction stage: underground mining involves higher risks (both immediate and delayed) than surface mining;
- occupational risks for oil and gas are also due mainly to the extraction stage: land extraction results less dangerous than off-shore extraction; no delayed risks are referred;
- immediate public risks are due mainly to transportation accidents; these assume high values for coal because of the large material transport requirements and for gas because of large leaks and explosions occuring to the pipelines or to the tankers; for oil and gas risks are much lower; for nuclear they are extremely low because the amount of material to be transported is about 10^4 - 10^5 times less than in the case of fossil fuels;
- delayed public risks are mainly due to the pollutants emitted during plant operation, except for the nuclear energy that involves late risks due to the exposition to radiation in the different stages of the fuel cycle; late risks of coal and oil are some orders of magnitude higher than those of gas.

Table 3. Nature of potential severe accidents from different energy sources.

Energy source	Accident description
coal	explosions and fires in underground mines; collapse of roof or walls in underground or surface mines; tailing dam collapse; haulage; vehicolar accidents.
oil/gas	offshore rig accidents; fires or explosions from leaks or process plant failures; well blowouts, causing leaks; transportation accidents, resulting in fires and explosions, loss of content in storage farms, resulting in fires or explosions.
nuclear	loss of coolant water and reactor meltdown; accidents during shipment of high level radioactive waste.
hydropower	rupture or overtopping of dam.
geothermal	well blowdown,resulting in the release of toxic gas.
solar thermal	release of toxic working fluids.

- severe accidents have a certain probability to occur for all electricity systems: accidents occur in the coal, oil and gas fuel cycle, particularly in the stages of extraction and of transportation; in the nuclear fuel cycle the worst accident occurred in Chernobyl where 31 person were killed, a large area of land was contaminated and a large number of people was evacuated and the risk of delayed fatalities has been also estimated;
- the renewable energy sources includes hydropower, solar and wind systems; hydropower has very low risks during normal operation but is characterised by very high accident risks due mainly to dam failures; wind and solar systems have relatively high health risks in the plant construction stage;

Table 4. Immediate fatalities from severe accidents occurred to energy systems and their fuel cycle in the period 1969-1986

energy option	n. events	immediate fatalities (fat/event)	total immediate fatalities	energy produced (GW x a)	normalized immediate fatalities (fat/GWe x a)
coal					
mine disaster	62	10-434	3600	10000	0,34
oil					
capsizing	6	6-123	NA	21000	-
refinery fire	15	5-145	450		0,02
during transport	42	5-500	1620		0,08
natural gas fire/explosion	24	6-452	1440	8600	0,17
hydropower	8	11-2500	3839	2700	1,41
nuclear	1	31	31	1100	0,03

NA = not available

Note: delayed fatalities, particularly relevant for Chernobyl accident, are not included.

- Immediate risk figures for severe accidents show that the most risky energy source is hydropower followed by coal and natural gas.
- The significance of the risk figures of table 4 are limited because delayed effects on the health and environment are not considered; also economic consequences are not taken into account.

Disposal of solid wastes produced by energy systems

- a serious problem encountered in the fuel cycle of some energy systems is the disposal of solid wastes; the two energy sources more interested are coal and nuclear energy;
- coal fired stations produce a huge amount of ashes, about 200.000 t/y for a 1.000 MWe plant; coal ashes contain toxic components which can be leached and therefore potentially contaminate the underground waters;
- nuclear reactors produce highly radioactive wastes: their amount is very little (few cubic meter per year for a 1.000 MWe power station), but their toxicity is so high that they require to be very carefully conditioned in order to absolutely avoid, during their management and storage, their release into the biosphere; conditioning and disposal of nuclear wastes have been studied extensively by many national and international scientific organisations and the problem appears technically solvable, but the attitude of the public to accept these technical solutions is still generally not favourable,

Environmental effects of energy systems

- Environmental effects of energy systems are manifold and their comparative evaluation appears very difficult; the most important considerations are related to the change in global climate, acid rains, land and water requirements.
- The problem of acid rains is trictly connected to the emission of sulphur and nitrogen oxides produced in the combustion of fossil fuels; this problem is under the attention of all energy producers: solutions to reduce emissions are being studied and appear feasible.
- One of the most important limiting factor in energy generation is the production of CO_2; non fossil alternatives for electricity generation have the potential to reduce considerably the total anthropogenic emission of CO_2.

Fig.7. The role of different electricity systems in producing carbon d

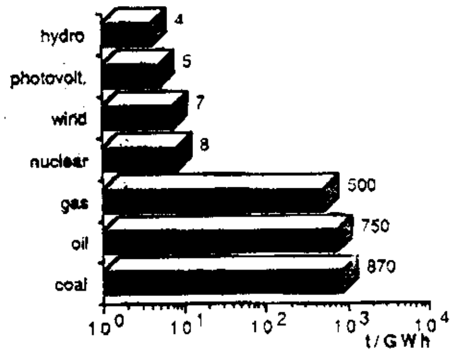
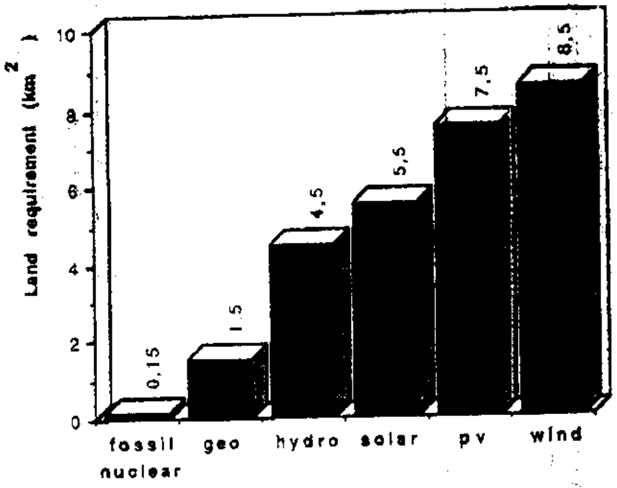


Fig.8.Land requirement (1000 MWe power station) - indicative values

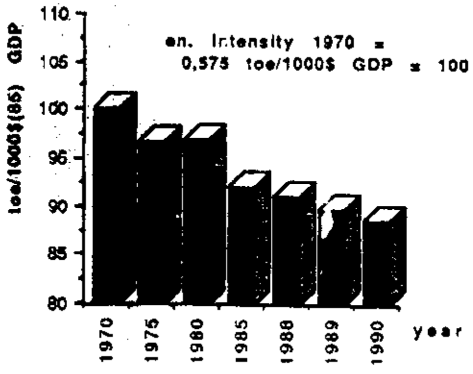


- An important consideration to be taken into account especially for the densely populated countries is the land requirement necessary to install a 1000 Mw_e power station for different energy systems.
- The fossil fuel fired plants require surfaces of the order of 0,1 km^2, hydropower of some km^2 and renewable sources (solar and wind) of many km^2.

Remedial actions

The easiest way to reduce the impact of energy sources is energy conservation.by improving the energy efficiency; in the last 20 years as a result of the oil crises and of a change in the type of production the energy intensity has lowered considerably, in the developed countries.

Fig.9. Evolution of energy intensity in the last 20 years



- The extensive use of electricity plays an important role in energy conservation: many measures of energy conservation are still possible in the phases of production, transmission and final use.
- For the fossil fuels some advantages can be reached going from coal to oil and from oil to natural gas; the first important result regards the CO_2 production, but benefits can be obtained also for other pollutants.
- In the field of transportation it becomes always more important to reduce the use of the private cars in the downtown areas, to make increasing recourse to electric cars and to introduce efficient abatement systems for pollutants.
- As far as nuclear energy is concerned, efforts must be devoted to improve their safety and to give satisfactory answers to the problem of waste disposal. These efforts to be effective must be accompanied by a parallel educational campaign aimed to reduce the gap between perceived and actual risks.

Conclusions.

- All energy systems produce impacts; some of them appear already today to have reached unacceptable levels.
- For energy planning it is necessary to take into account the following three fundamental aspects: economy, environmental and health impacts and public acceptance.
- The attitude of the public toward energy sources is essential in choosing energy systems to be adopted to satisfy social needs.
- Energy demand is growing all over the world but especially in the developing countries.
- Energy sources available for mankind needs are few; the most part of the energy demand is covered by fossil fuels.
- For traffic and space heating (about 40% of the total primary energy consumption) there are in the short and medium term no practical alternatives to oil derivatives.
- Fossil fuels are the most easy energy sources to be exploited; therefore they represent the short term target for developing countries to improve their degree of development.
- The status of the environment requires a considerable reduction in the impact due to energy sources especially as far as global effects are concerned.
- Electricity is the most important form of energy for the industrial development; in all countries the electricity penetration is increasing.
- Nuclear energy is the only source available in the short term able to reduce in a significant way the emission of CO_2 and of other pollutants; however the big problems of its public acceptance have not been yet solved.
- Hydropower has still a considerable potential in some developing countries: its extensive exploitation requires big investments and an improvement of the safety against the severe accidents deriving from dam failures.
- Renewable sources, such as sun, wind and biomass, appears to be extremely interesting for the future; their costs and also the risks connected with the construction of the plants are still to high to allow an extensive penetration in the energy market.
- The big problem to provide enough energy to the mankind, without damaging health and environment in an unacceptable way is one of the most important and urgent challenge of today; its solution appears feasible, but the conditions to reach this objective requires that a large part of resources of the mankind be conveyed in this direction.