Is Solar Power More Dangerous Than Nuclear?

by Herbert Inhaber

Consider a massive nuclear power plant, closely guarded and surrounded by barbed wire. Compare this with an innocuous solar panel perched on a roof, cheerfully and silently gathering sunlight. Is there any question in your mind which of the two energy systems is more dangerous to human health and safety? If the answer were a resounding "No", the matter could end there, and the editors would be left with a rather unsightly blank space in their journal. But research has shown that the answer should be a less dramatic but perhaps more accurate "maybe".

How can this be? Consider another example. In the driveway we have two vehicles. One is a massive lorry, and the other a tiny Mini. Which of the two is more efficient? No, not larger – more efficient. Their relative size is easy to judge, but efficiency involves the amount of petrol used, the distance travelled, as well as the weight carried.

The moral? You can't judge the relative risk of an energy system merely by its size or fearsome appearance. You must find the risk per unit energy – that is, its total risk to human health divided by the net energy it produces. This is the only fair way of comparing energy systems.

In addition, we must consider the *total* energy cycle, not one isolated component. If you calculate the risk of only part of a system and compare it with the corresponding part of another, by judiciously choosing the component you could prove that any energy system is riskier (or safer) than any other system. You would obviously be proving precisely nothing.

You may wonder why the Atomic Energy Control Board (AECB), the main regulatory agency for nuclear power in Canada, is concerned with this question. We do our best to minimize nuclear risk, but we are not in the business of regulating other energy forms. The answer is simple: the AECB has been studying the risk of nuclear power, but the results will have more meaning if they are put into context. That is, finding that nuclear power produces a certain number of man-days lost per megawatt-year has only a limited meaning to non-specialists. Knowing that this value is twice (or half) that of other energy systems means a lot more.

We can calculate the net energy output easily enough. But what is the total risk? The new field of risk accounting addresses this question.

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By now, most people working on energy questions have heard of energy accounting This extension of the accountant's art adds up all the energy required for components of a system in order to determine the overall energy requirement. For example, a coal-burning electricity plant needs X kilowatt-hours of energy to mine each tonne of coal, Y to lay each kilometre of track to transport it, Z to construct each turbine, and so on By summing the required energy inputs, we can compare the result to the output

Risk accounting is based on the same principles. All sources of risk are evaluated in terms of the deaths, injuries or diseases they cause. This implies that we evaluate not only the final stage of energy production, but the initial and intermediate stages. For example, in the two cases mentioned in the first paragraph, we would evaluate the risk in mining the sand, copper, iron, coal, uranium and other raw materials that are required, as well as the risk due to fabricating them into glass, copper tubing, fuel rods, steel and all other necessary components. To this would be added the risk associated with transporting material, manufacturing components, and the more obvious risk of constructing and operating the nuclear-powered station or solar panel

Risk accounting has been around a long time, in various guises. For example, nuclear power, coal, oil and natural gas were compared in terms of risk per unit energy by C.L Comar and L A. Sagan in a landmark article in the 1976 *Annual Review of Energy.* They found that, when all the major sources of risk for each technology were summed nuclear power had a substantially lower risk than coal- or oil-burning stations. Other studies both before and after have confirmed this.

But those who are uneasy about nuclear power, or who even denounce it, rarely advocate a return to coal and the smoky cities we all faced a few decades ago Rather, they usually propose the use of "alternative", "soft" or "non-conventional" technologies such as solar, wind, ocean thermal, methanol, geothermal and a panoply of others. The question then is, what is the risk of each of these technologies compared with conventional systems like coal, oil and nuclear?

Results of our risk accounting are surprising, to say the least. They indicate that when all the sources of risk are accounted for, most non-conventional technologies fare rather badly in comparison with conventional ones. Figure 1 shows our results. The vertical axis refers to the total man-days lost by both workers and members of the public due to deaths, injuries or disease per unit net energy output for each system. To combine fatalities with less serious disabilities, an arbitrary number of man-days lost (6000) was assigned to each death.

Electricity produced from natural gas has the lowest risk of the 11 technologies (five conventional, six non-conventional) It is a factor of about two lower than the next highest, nuclear power Third is a non-conventional system, ocean thermal, which can convert the temperature differences of ocean layers into electricity. Most other non-conventional systems have far higher risk. However, the highest of all are coal and oil, with risk about 400 times that of natural gas.

Materials add risks

What are the reasons for these surprising rankings? The details are contained in a recent report* The main reason why non-conventional systems have relatively high risk is the large

* *Risk of Energy Production* 1978, No AECB-1119 Atomic Energy Control Board, PO Box 1046, Ottawa, Canada, K1P 5S9.

amount of materials and labour they require per unit energy output. Why should solar need more materials than coal or oil? It's because of the diffuse nature of the incoming energy solar and wind energy are weak, and require large collection and storage systems to amass an appreciable quantity of energy Coal, oil and nuclear systems deal with concentrated forms of energy and so require less apparatus This argument is simplistic and glosses over many lesser considerations, but is generally found to be true. Figure 2 shows the results of these calculations.

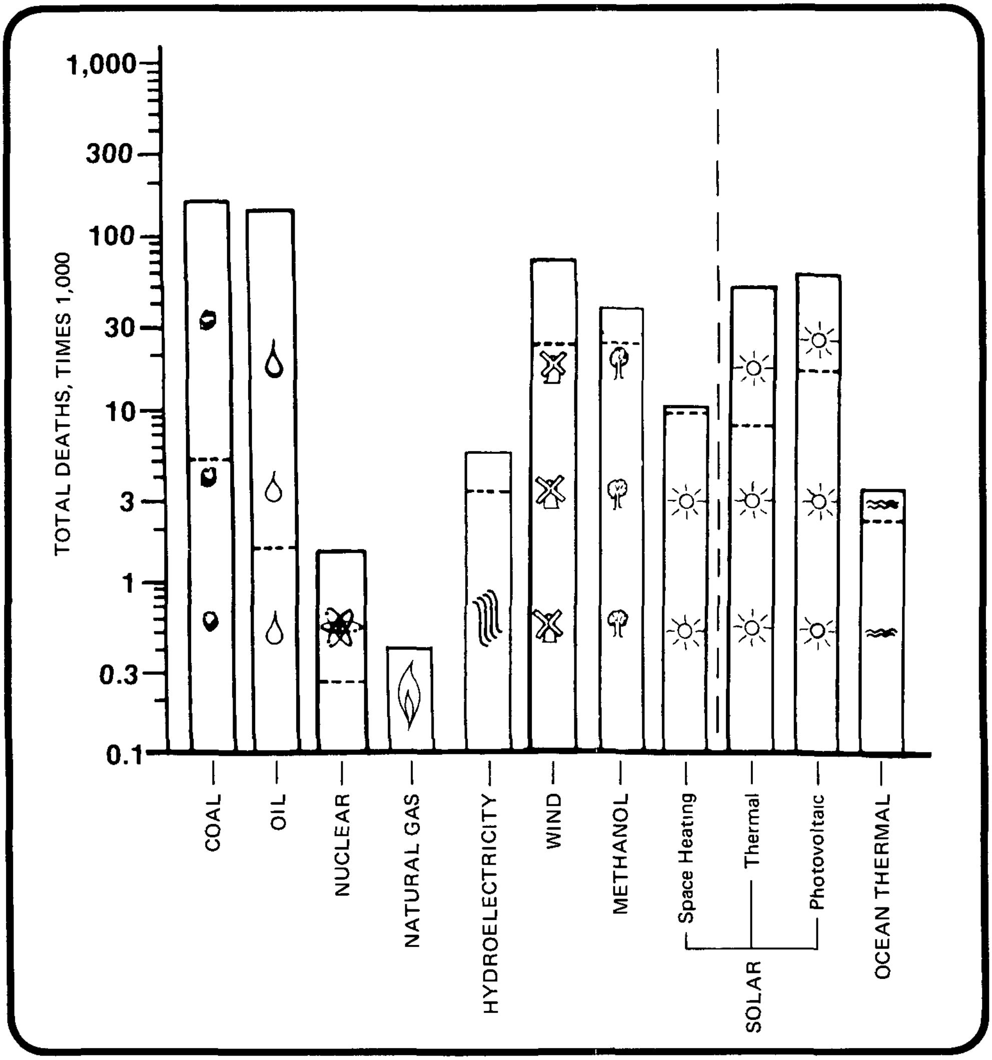

Figure 1. Total risk per unit energy output (one megawatt-year) for 11 energy systems. Each system has a range of values The maxima are the tops of the bars, the minima are the horizontal dotted lines. Natural gas has a very small range. Bars to the right of the vertical dotted line indicate those systems which are not likely to be used in Canada in the near future. Note the logarithmic scale.

The large quantity of materials required for unconventional systems implies huge industrial efforts in mining, refining, fabricating, and constructing the collectors, storage systems and all related apparatus. Every form of industrial activity has an associated risk, which can be

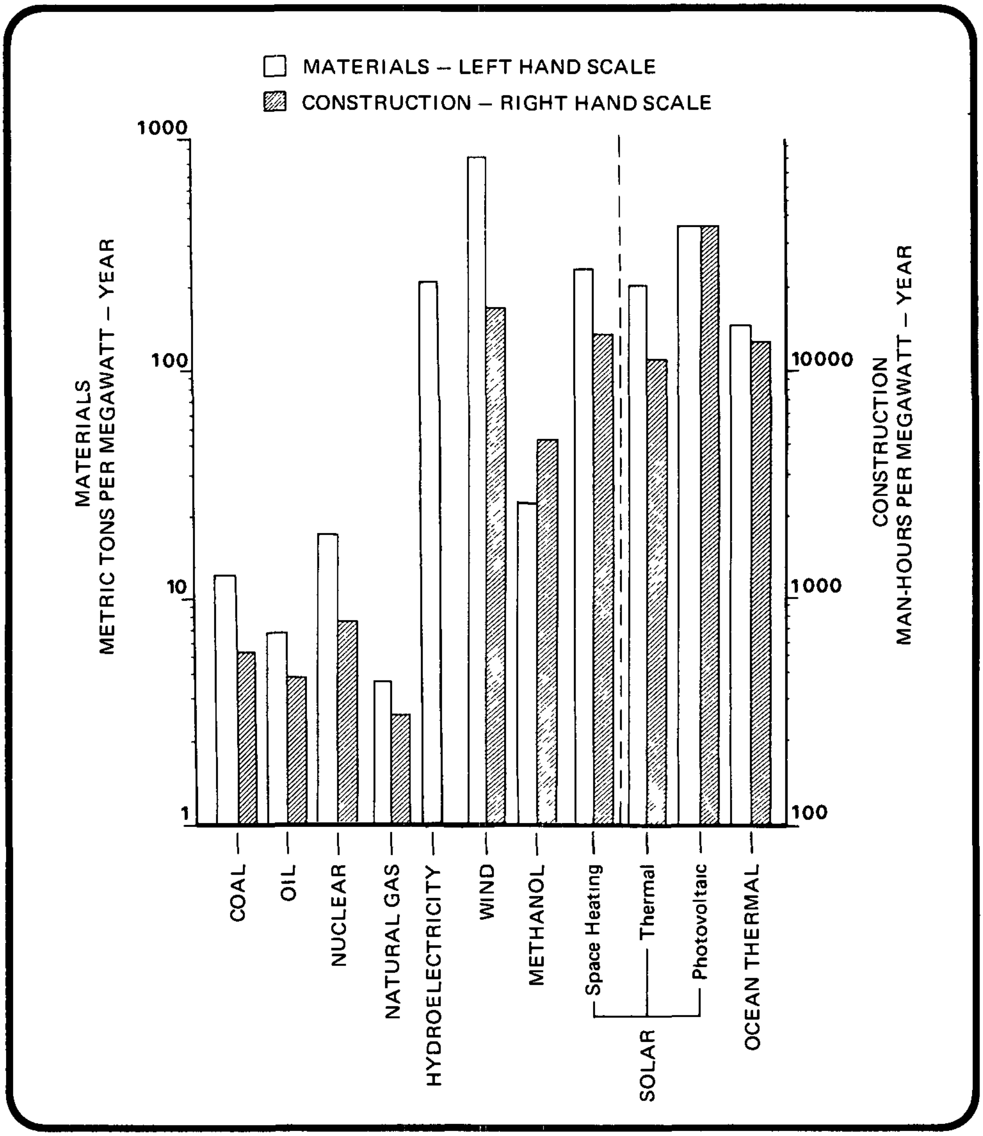

Figure 2. Material and construction time requirements are greater for non-conventional as compared with conventional systems (the first five on the left). Natural gas has the lowest requirements of both types. Windpower has the highest material requirements, and solar photovoltaic the highest construction times. The ratio between the highest and lowest values in each category is between 100 and 200. Energy systems to the right of the dotted lines probably will not be used in Canada for the foreseeable future because of the country's climate.

found through accident statistics compiled by national organizations. When all the multiplications and additions are done, we find that the risk from unconventional energy systems can be substantial.

This raises an interesting point. Although these systems are labelled unconventional, their risk comes, in the main, from highly conventional sources. In other words, the risk from windmills doesn't come primarily from a blade flying off and hitting you on the head, and the risk from solar space heating doesn't arise from falling off the roof as you make that last little adjustment. Rather, it comes from the more mundane tasks of mining the coal iron and other raw materials and fabricating them into steel, copper and glass.

The overall risk, as shown in Figure 1, may be divided into two categories: occupational and public risk. Occupational risk is incurred by those connected to the process of producing and operating an energy system: public risk is incurred by everyone else Because of the different mixes of materials and labour in each energy system the rankings within each of the two risk categories are not necessarily the same as for the overall risk. Results for each of the two categories are given in Table 1.

In terms of occupational risk, natural gas used to produce electricity ranks lowest, followed closely by nuclear. This occupational risk includes, for example, that incurred in drilling, building pipelines, constructing distribution networks, and so on. Coal risk is much higher. While the risk per hour spent in the mine is not strongly dissimilar for coal and uranium miners, the latter worker produces far more energy per unit time worked. As a result, his occupational risk per unit energy is much lower.

The remarkably high occupational risk for methanol is primarily due to one factor — logging. In Canada (and elsewhere in the world), this is a job with quite high accident rates. Plans for methanol plants have implied that large volumes of wood would be gathered, so the risk would be commensurately large.

However, in terms of public risk methanol ranks second lowest, behind natural gas used to make electricity. As far as is known, the combustion of methanol produces little or no air pollution, so the risk to the public is close to zero. On the other hand, most of the large public risk from coal and oil combustion is derived from air pollution.

How can unconventional technologies like wind or solar thermal (the "power tower" concept) have substantial public risk? The answer is simple. The production of the metals needed in many unconventional technologies requires that coal is burned, and this coal will produce air pollution, which in turn causes public health effects. In addition, public risk is produced by the necessary back-up system, required for when the sun doesn't shine and the wind doesn't blow.

It may well be contended that the first of these two sources takes the analysis too far back, that the coal, iron ore and other raw materials are too removed from the final production of energy to play a part in risk accounting However, the role of basic materials in the analysis is important. If energy is needed, the nuclear plants or solar panels must be built. To produce the plants or panels, we need to mine, refine, fabricate, and install the raw and intermediate materials, the components and finished products We cannot avoid risk by ignoring it just because it happens to somebody else.

The energy system with by far the greatest amount of controversy about its risk is undoubtedly nuclear power. In a study of this type, we could not review all the claims and

Table 1. Risk in man-days lost per unit energy output

	Occupational	Public
Coal	73	2010
Oil	18	1920
Nuclear	8.7	1.4
Natural Gas	5 9	–
Ocean Thermal	30	1.4
Wind	282	539
Solar:		
Space Heating	103	9.5
Thermal Electric	101	510
Photovoltaic	188	511
Methanol	1270	0.4

counter-claims about nuclear risk which have been made, especially with respect to reports such as the 4000-odd pages of the Rasmussen study on nuclear reactor safety (WASH-1400). Instead, a survey was taken of the major papers in the scientific literature which had estimated aspects of nuclear risk, including a monograph written by a well-known nuclear critic, John Holdren of the University of California at Berkeley For each component of risk, the highest value from the group of scientific sources was used This procedure, not followed for any other energy system, was chosen as a way of removing suspicion of pro-nuclear bias which often clouds energy debate

Accounting for hazards

There isn't room here for a full discussion of the methodology – the full AECB report contains further details of its features. However, because material acquisition and construction produce large risk for some energy systems, a brief review may be useful Suppose mining X tonnes of coal or any other material to produce a unit output of net energy requires Y man-years If the number of man-days lost per year of work is Z, then the number of man-days lost per unit of energy output is YZ/X. A similar calculation is made for the number of man-hours per unit energy output and the risk associated with various required occupational categories such as engineering, construction, operation and maintenance, and so on We find the risk associated with each part of the system in the same way, and add them to determine the total The calculations require no advanced mathematics or abstruse models, merely the ability to multiply and add.

This type of calculation implies that certain data are available. the time required per unit of production, rates of industrial accidents, disease and death, construction times, and, raw material requirements for industrial processes While none of these data is known absolutely, they are known adequately for purposes of a general study such as this Because the same methodology was applied to all the systems, wherever possible, potential inadvertent bias was reduced to a low level Different methodologies were used for such risk sources as transportation, air pollution and waste disposal Every effort was made to ensure that all energy systems considered were treated as uniformly as possible.

Contrary to the intuition of many people, the risk to human health (and its resulting consequences) per unit energy from unconventional energy sources such as solar and wind are apparently higher than those of conventional sources such as electricity produced from natural gas and nuclear power. There are at least two reasons why intuition fails: first, we tend to ignore all parts of the energy cycle except the last, most visible aspect, and secondly, we forget that risk must be compared in terms of unit energy output.

The above conclusions have implications beyond that of energy Many people have advocated the use of decentralized energy systems as part of a political and economic process Due to the risk they entail, material requirements alone may preclude this option. Neither I nor the Atomic Energy Control Board propose the use or non-use of any particular energy system. However, all of us must have knowledge of the risks involved in order to make reasoned judgements on the technical acceptability of a particular system