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# Economics of Solar Energy Conversion Using a Product-Value Analysis

**James R. Bolton***

## 1. A Proposal

The power output of the Sun is prodigious ($3.8 \cdot 10^{26}$ W); even the power input to the Earth is enormous ($1.7 \cdot 10^{17}$ W); yet the power density at the Earth's surface is quite diffuse, varying from a maximum irradiance of about 1000 W/m$^2$ in bright sunlight to of course zero at night. The average irradiance on a horizontal surface (averaged over 24 hours and 365 days of the year) varies from about 100 W/m$^2$ in the polar regions to about 300 W/m$^2$ in the desert regions.

In considering the economics of solar energy conversion, we should first ask how much product will be produced per square meter of collector per year. Then, estimating the value of the product, we can place some limits on the justifiable capital cost. For purposes of illustration, an average annual irradiance of about 200 W/m$^2$ on a collector will be assumed. The product yield will scale almost linearly with the average annual irradiance and the efficiency assumed. Table III 1 lists the product yields for three systems as well as the product value (at current market prices).

System I would be characteristic of a space-heating or water-heating solar system. These are the simplest and most developed type of solar collectors and come closest to meeting the economic criteria. Nevertheless, current collector costs are $1000 or more per m$^2$ and will have to come down significantly before solar heating can stand alone without economic incentives.

System II could be applied either to a photovoltaic array or a solar-thermal concentrator system. In the latter case the collector area should be taken as the field area occupied by the mirrors. Current capital costs are about 10 times higher than the criteria listed in Table 1 but costs are dropping rapidly. In remote areas where electricity costs are very much higher, solar-cell systems are often the system of choice. The capital cost of $175 per m$^2$ can be converted to the usual dollars per peak watt by noting that a 1 m$^2$ solar-cell array will generate 100 W at peak power at 10% conversion efficiency; thus the capital cost would then be $1.75/Wp for a 10% assumed return on investment. This is similar to the often quoted $1/Wp target for break-even with grid-connected electricity.

*James R. Bolton: Born 1937 in Saskatchewan, Canada. Received his Ph. D. in physical chemistry 1963 from the University of Cambridge. He studied with Prof. Fraenkel at Columbia University 1963–1964 and was on the faculty of the University of Minnesota 1964–1970. Since 1970 he has been Professor of Chemistry in the Photochemistry Unit, The University of Western Ontario. His research focuses on the photochemical conversion and storage of solar energy involving organic donor-acceptor dye molecules designed to mimic the primary processes of photosynthesis.*

The hydrogen-generation solar system (System III) is the least developed of the three examples. It is clear that candidate systems for hydrogen generation from water will have to use relatively cheap components and materials to meet the stringent capital cost criteria.

Table III 1. Product-value analysis.

| System | Product | Efficiency [%] (assumed) | Product Yield[a]) per m$^2$ per year | Product Price (assumed) | Product Value | Maximum Capital Cost[b]) per m$^2$ |
|---|---|---|---|---|---|---|
| I | heat | 50 | 3.15 GJ | $10/GJ | $31.50 | $315 |
| II | electricity | 10 | 175 kWh | $0.10/kWh | $17.50 | $175 |
| III | hydrogen | 10 | 66 m$^3$ | $0.25/m$^3$ | $16.50 | $165 |

[a]) At 200 W/m$^2$ average annual irradiance.
[b]) At 10% return on investment.

* For correspondence address, see List of Participants, p. 242.

The product values listed in Table 1 are correct only for the set of assumptions made and will alter linearly with changes in the assumptions. For example, no estimate of «external costs» such as environmental effects has been included. Consideration of these factors would raise the price of competing energy technologies and would raise the capital cost limits for solar systems.

The product-value analysis procedure described here is simple and can be applied to any local set of conditions. It is important to note that the analysis assumes zero operating costs and so the estimates of capital costs represent upper limits for the assumptions made. The utility of this procedure is that it provides a simple method for estimating approximate upper limits for capital costs of a given solar system being considered.

## 2. Discussion

***Comment of Carl-Jochen Winter****

Usually conventional (fossil or nuclear) systems consist of three consecutive system parts:
(1) the energy raw materials;
(2) the conversion components;
(3) the residues.
In solar systems (except biomass systems) parts (1) and (3) are non-existent, since solar energy systems consist only of (2), the conversion part.

External, not fully internalized, ecological costs of conventional systems are involved in all three parts of the conventional chain (1)–(3). But external costs of solar systems are relevant only, if at all, to part (2), the conversion part of the chain.

It can well be expected that conventional systems imply large amounts of largely fuel-related external costs, whereas, although trivial to say, these must be close to zero for solar systems.

Internalizing external costs of conventional systems «helps» solar technologies because the cost gap between conventional and solar systems becomes smaller.

Whilst conventional systems contribute to the quantitative growth of a national economy (GNP) – even with ecological costs! – the solar system does not. The solar system only contributes to the qualitative growth (net welfare), because it is a non-fuel system.

The solar system adds to the GNP (almost) without raising the ecological costs. The solar system contributes to the autonomous qualitative growth without contributing to the fictitious growth, which is the difference between quantitative and qualitative growth.

Worldwide, in the Western World, the «official» economic doctrine is the quantitative growth of economies (1987 Nobel Prize to *R. M. Solow*). Seeing this, solar is not in line with the official doctrine. What is needed is a net welfare accounting of relative economics, in order to promote solar.

***Comment of Jorgen Loevseth****

The heating of houses typically requires of the order of 25% of the national energy budget. Replacing this by a renewable source will therefore have a large impact on the energy budget.

Considering solar heating of a house by a dedicated system, the values of Table 1 need some qualification. Unless yearly storage is included, only part of the annual production can be used. Even with weekly storage to even out weather variations, the summer production will, in most places, not be useful.

Depending on where the house is located, and the fraction of the heating demand to be produced by the solar system, product values in the range of \$5–15 per annum may therefore be more realistic. With 10% return on investment, the total capital cost can be no more than \$50–150 per $m^2$ of collector. This price must include storage, distribution, and back-up system (if needed). Integration of the solar heating system into the house construction seems necessary to realize such a low capital cost, i.e., panels mut become part of the walls or roof; the distribution system must also be used by the back-up system.

The solution to this economic problem will require interdisciplinary R&D (solar specialists, civil engineers, architects, etc.) focusing on system yield and system construction.

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*Carl-Jochen Winter: Born 1934 in Berlin. Received his Dr.-Ing. 1968 in mechanical engineering from the Technische Hochschule Darmstadt, where he worked in the Institute for Thermal Turbomachinery. After various positions in industry he joined the German Aerospace Research Establishment (DLR) in 1976, and currently heads its Research Centers in Stuttgart and Lampoldshausen, and its Departments of Energetics and Materials/Structures. He is the author of numerous articles and lectures on the subjects of solar energy utilization and hydrogen as a secondary energy carrier.*