

Introductory Lecture 3:

Renewables in Want of Materials and Processes

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A non-comprehensive list of materials and processes, currently considered of importance for renewable energy research and development, is given. In addition, the search for characteristic features, common to potentially important processes, is encouraged. Some speculative examples are given and their discussion shows that the existence of such common features is plausible and that they might be useful to screen candidate processes and materials.

1. General Remarks

I am not a materials specialist nor do I know much more than average on processes in the field of renewable energy technology. The fact that – all the same – I give this introductory lecture, has two reasons: (i) other people that I asked were not available and (ii) for the purpose of this introduction it is – according to my opinion – not absolutely necessary to be a specialist. Thus, the following goes back mainly to three sources:

- collected opinions which reflect today's general discussion on the subject (on the average about every fourth edition of «Scientific American» contains – in a broad sense – relevant information);
- discussions held in preparation of this workshop, including in particular the USA pre-meeting in June and the meeting of the organizing committee;
- some personal, somewhat speculative thoughts.

This should be enough to kick on the discussions in our workshop. And this – and nothing more – is the purpose of my presentation.

2. Materials

Fields in materials R&D, which are important for renewable energy technology, are inter alia:

- *ceramics* (e.g. high-temperature applications, superconductors, electrodes, carriers for catalysts etc.);

- *plastics* (e.g. electrical conductors, packaging of solar cells, daylighting);
- *materials designed for special applications*, e.g.: composites (for instance fiber-reinforced materials), materials with a very high reflectivity over a large part of the solar spectrum, photovoltaics, facades of buildings etc.;
- *application of modern tools* (e.g. mathematics: new concepts, advanced numerical methods) to improve physical models for the design of new materials.

3. Processes

Processes that are, or potentially may become important for renewable energy technology are inter alia:

- processes involving *active solar energy* technology, such as high-flux and high-temperature applications of solar energy, photoactivation of thermal processes, photochemistry and photoelectrochemistry (new idea: proton pumping by long-wavelength part of solar spectrum (*El-Sayed, Bolton*)), conversion of sunlight to coherent light (by solar pumped lasers), control of energy transmission through «skins» of buildings;
- *passive solar energy* technologies: daylighting, energy management in buildings;
- *storage*, in particular chemical storage of energy;
- *biomass* processes on three levels: basic understanding of photosynthesis for «molecular and submolecular engineering», genetic engineering (e.g. modification of



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bacteria for enzyme production etc.), breeding of plants, suitable for energy purposes;

- *ambient- and geothermal-energy* processes: advanced heat pumps, geothermal district heating, processes under the extreme conditions of deep geothermal wells (high temperature, high pressure);
- processes *improving the rational use of energy*.

Obviously this list is not comprehensive and topics not included are by no means excluded from the discussion in the workshop – provided at least two participants show an active interest to do so.

4. Some Speculative Remarks

Common Features of Potentially Important Processes

I personally believe that processes which offer long-range opportunities for renewable energy systems, will have characteris-

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tic features in common. Of course, it would be helpful to know them in advance. They would provide very valuable selection criteria in an exercise of the type, we are aiming at right now. In the following, three principles are presented, which – when applied – would lead to properties that might represent a subset of these characteristic common features:

1. Minimize the amount of material and energy used in the process.
2. Control the flow of matter in the process from the beginning to the end.
3. Go to extreme values for appropriate process parameters (one characteristic aspect of so-called «high tech» processes).

In support of this speculative assumptions we give examples derived from solar energy technology.

Promise and Problems of Solar Energy

The promise of solar energy is the high «quality» of the solar radiation spectrum, corresponding to the 6000 K of the solar surface. (Thus, *Bethe* is wrong when he compares solar power to mice, which could never be trained to accelerate and keep running a train at reasonable speed – even when being available in large quantities. See *Neue Zürcher Zeitung*, 31.08.88, review of the book «Prophet der Energie: Hans Bethe», by *Jeremy Bernstein*, German Translation, Hirzel-Verlag, Stuttgart 1988, ISBN 3-7776-0442-9).

The main problems are:

- solar radiation has – technically speaking – a low power density;
- it is a kinetic form of energy, which is difficult to store;
- it is of stochastic nature.

Impact on Solar Technology

Principle 1: «Minimize material and energy used»

The low power density entails the danger of high specific material requirements (kg of material used to gain 1 kWh/a), leading inevitably to both, high energy cost and long energy pay back times. In order to overcome this difficulty, principle 1 is mandatory. The question is, whether the natural physical limits are such that there is a chance to reach low enough values for practical purposes. Fortunately, the odds are not too bad, as two crucial examples show:

a) A p-n-junction of a photocell consists of a very small amount of highly sophisticated organized matter. Thus, the material used for today's cells consists almost completely of the envelope, necessary to get reasonable optical properties and lifetimes. Hence, it is the amount of material necessary for packaging and mounting the cells that has to be mini-

mized and we certainly are only at the beginning of this process.

b) A second path to circumvent the low power density is to concentrate solar radiation to densities comparable to «conventional fuels» such as, e.g., fossil flames or nuclear reactors. This is physically possible by using basically a very small amount of matter, namely in the limit some grams of aluminum per square meter of mirror surface. The question again is how much additional material is required to protect the reflecting surface from wind and weather and to orient it properly with respect to the sun.

The heliostat development of the last decade brought weights down by a factor of about 6, and cost by a factor of 10 and more, resulting in specific cost of concentrated radiation of a few cents per kilowatt-hour. And again, this process is far from being near its end. The two examples clearly illustrate the importance of principle 1.

Principle 2: «Control flow of matter»

In an infinite world, the best way to get rid of waste is to dilute it until its negative consequences vanish. This is easy and cheap and has been practiced throughout our technical civilization by far more than a century. Only recently we have painfully recognized that the dustbin called «environment» is – although large – definitely finite. The only possible remedy – besides reducing waste drastically – is to switch from diluting to its contrary, namely to confine the pollutants, i.e. to control the flow of matter until to the end of the process. Even better, of course, is to close the cycle (recycling). What does this mean for solar energy? Its diluteness means that distribution of matter over large areas cannot be avoided. Thus, those systems will be superior in the long run which

- do facilitate recollection and recycling of materials when decommissioning the plant;
- do not release noxious substances during accidents, i.e. in this respect Si-cells are basically preferable to e.g. GaAs- or CdS-cells, even if the amounts of As or Cd per square meter are small;
- have production processes which minimize the risk of release of noxious substances (the current production of semiconductor-grade silicon e.g. could be characterized by the term «hard chemistry»).

These examples illustrate the importance of principle 2.

Principle 3: «Extreme values of process parameters»

The history of advancement of technology is also the history of how man learned to create and master artificial environments, deviating more and more from his «natural environment». This path is characterized by changing the parameters,

defining this natural environment, to more and more extreme values. Examples:

- Parameter: length, mechanical precision. The technology of the wooden plough (1 cm) was followed by the steam engine and motors (0.1 to 0.01 mm). We have arrived now at the technology of the micrometer (micromechanics, chips, Nobel prize for the microscope of *Rohrer* and *Binnig*).
- Parameter: pressure. The technology of the heat engine developed from low to high pressure. Solar low-temperature collectors began at ambient pressure; advanced types use vacuum isolation. Amorphous solar thin film cells cannot be imagined without mastering the technology of very low pressures.
- Parameter: temperature. Mastering the fire (i.e. high-temperature technology) was one of the first technical achievements of mankind, generating very low temperatures one of its last. Both did advance technical progress decisively (iron age, metallurgy; refrigerators, superconductors).

These examples show that principle 3 seems to be characteristic for advanced, powerful technologies.

Conclusions concerning Solar Technology

Considering what has been said until now, we might speculate which will be the solar technologies that will concur best with the three principles. Such a list might include the following (certainly not comprehensive) entries:

- Minimum amount of material: photovoltaic systems, high concentration by low-mass mirrors, direct conversion/absorption of solar radiation, high energy content fuels and chemicals, in particular for storage, passive solar systems.
- Controlled flow of matter: solar detoxification of waste, solar systems which are easy to dismantle and recycle.
- Extreme values of parameters: high flux, high flux density, high temperature, surface effects, catalysis in solar chemistry, high purity materials.

Speculative considerations like these have brought me several years ago to become one of the promoters of a basic solar fuels and chemicals R&D program within the IEA. My favorites are direct absorption and conversion processes at high temperature and high flux density, including in particular high-temperature photochemistry.