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Materials and Processes

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1. Introduction

Suggestions for long-range research topics in renewable energy materials and processes were solicited by a focused brainstorming method. Each of the three initial groups at the workshop (labeled G1, G2, G3) were queried, in turn, for suggestions. These were accumulated during the sessions by a scribe who wrote them on a viewgraph and checked for accuracy prior to the resumption of the general discussion.

This process led to eighty-four «raw» suggestions which were reduced in number by combining identical and closely related items and by discarding fourteen items which could not be cast into the form of a suggestion for materials or process research. These in turn were grouped into the general classifications indicated in section 2. The complete lists of combined, validated suggestions is given in section 2; the original «raw» list is reproduced in section 3.

2. Condensed Suggestions from Brainstorming

2.1. Materials

Photovoltaic
- Development of long-life, inexpensive, coatable, transparent, photochemically inert encapsulants.
- Study of materials suitable for use in the construction of photovoltaic systems optimized for the utilization of low-intensity light.
- Study direct photovoltaic effects in plants: breed plants to enhance this effect.

Passive Solar
- Development of external wall materials/coatings which trap incident photons.
- Design of materials whose performance improves on weathering/aging.
- Design of materials which degrade along a controlled trajectory (e.g., into biodegradable final products).
- Design of materials which self-correct for damage (e.g., reversibility of adverse intensity effects or window materials with thermally induced photochromic effects).
- Incorporation of solar/thermal elements into standard structure members of buildings (e.g., wall panels, selective absorptive/reflective windows) for systematic use in the design of energy-efficient buildings.
- Development of new insulating materials for speciality uses (e.g. pipes, windows, etc.).
- Development of light-weight structural materials for energy conservation.

Active Solar
- Development of high-temperature selective absorbers.
- Development of light-weight structural materials for energy conservation.

Storage (Energy)
- Utilization of two-phase systems for heat storage.
- Elimination of causes for low hydrogen concentration in hydrides (used for hydrogen storage).
- Develop low-enthalpy fluids to replace fluoro-chloro-carbons (e.g. freon) as working fluid in refrigerators, heat pumps, and heat engines.

Transport
- Develop new molecularly doped conducting polymers (e.g. polyaromatics).
- Develop new superionic conductors.
- Utilization of high-transition-temperature superconductors in the power grid.

Wind/Ocean
- Develop reliable, highly-stressed materials (e.g., for windmachine blades).
- Develop materials suitable for use under the sea (corrosion resistant, fouling resistant, scaling resistant).

Biomass
- Explore lignin chemistry to identify new applications.
- Develop novel biopolymers (polysaccharides, proteins) for use as structural, electronic materials.
- Utilize fibrous biomass to construct novel insulating and structural materials.
- Breed plants for energy generation and/or control of atmospheric CO_2.

Theoretical and Computer-Assisted Design
- Development of computer-assisted design systems for special classes of materials (e.g., structural composites).
- Development of data bases of materials properties suitable for use with computer-assisted design software.

Standards
- Promulgation of performance standards for materials used in renewable energy systems. Make these publicly available in standard formats.

2.2. Processes

Photoconversion
- Study of the influence of temperature, pressure, and photon flux as independent variables on photochemical conversion processes.
- Utilization of temperature gradients in

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photochemical cells to generate fluxes of other entities, especially protons.
- Construction of photoconversion systems using superlattices of appropriate chemical compositions to affect the efficient photogeneration of electrons and holes.
- Construction of hybrid organic/inorganic photoconversion systems.
- Construction of vapor-phase photoelectrochemical cells.
- Construction of supercritical-fluid photochemical systems.
- Study of the influence of strong electric fields on photoconversion processes.
- Develop solar-driven detoxification processes.
- Develop new photochemical decomposition catalysts for use in low-temperature photoconversion processes.

Environmental
- Development of models of environmental processes which enable forecasts of microclimates, local solar insolation.
- Acquisition and organization of data on the transport of chemicals via ocean-atmosphere interactions.
- Design of novel ventilation systems based on local wind pattern («passive wind» technologies).
- Study processes pertinent to the design of buildings which are both, pleasant to live in and energy efficient, e.g. by creating local climates within the buildings.
- Control atmospheric CO_2 concentration by CO_2 extraction and subsequent transport to deep oceans.
- Design self-assembling systems which organize themselves for power generation.

Materials Fabrication
- Development of real-time, in-situ process control for the quality control of fabricated materials.
- Utilization of optimization strategies for materials fabrication.
- Design of industrial and agricultural fabrication processes for optimal energy efficiency (e.g., utilize as much as possible of internally generated waste heat).
- Process materials in space, using solar power.
- Utilization of high-temperature, high-pressure, high photon flux photoelectrochemistry to make ceramics.

Energy Transport/Storage
- Invention of better methods of electrochemical energy storage.
- Development of solar energy pumped lasers.
- Development of «cold» storage systems.
- Invention of photon-storage systems utilizing non-linear optical materials and phenomena.

Linked Systems of Processes
- Development of computer models of relevant physical phenomena to enable the construction of design algorithms and data bases for the design of hybrid wind/solar/hydroelectric/biomass systems.
- Development of cradle-to-grave analysis methodologies for tracing the flow of matter in energy production/distribution/utilization systems.
- Development of optimal regional biomass production/treatment/conversion systems including long-term effects.

Magnetohydrodynamic
- Utilization of ocean water as the conducting working fluid for the generation of electric power.

Mechanical
- Harness the rotational energy of the earth to generate power.

3. Original List of Topics from Brainstorming

Group G1
- Use temperature gradients in photochemical cells for the generating of proton movements; use high fluxes generated by temperature to generate electricity more generally.
- Study the influence of temperature and photon flux as independent variables. Are there different scaling laws for electron and proton transfer?
- Design efficient *e-T* systems via multilayer systems (à la superlattice technology) of «appropriate» chemical composition.
- Build hybrid biological/inorganic photoconversion systems with inorganic photo-charge generator combined with enzymes for generation of chemical products.
- Build vapor-phase photoelectrochemical cells.
- Bulk photoconversion systems doing photochemical reactions in supercritical fluids.
- Build transport material with a high index of refraction and a low thermal conductivity; especially a composite material.
- Examine effect of strong electric fields on photoconversion especially in composite systems.
- New materials/processes for storage and transportation are required for «practical» PV systems. These should be identified.
- Superconductive devices (enabled by high T_c).
- Screen possibilities for chemical storage of solar energy.
- Screen chemical storage media for minimal production of CO_2 (e.g. Al).
- Design total solar recycling systems.
- Old idea (1837): Natural magnetohydrodynamics (using the ocean as the moving conductor) could couple with electrochemical generation of fuels.
- Study direct photovoltaic effects in plants. Can the phenomenon be enhanced by genetic engineering? (Potential gradient at the earth's surface is vertical, i.e. in the same direction as the plant's main direction of growth).
- Breed plants for energy generation and/or control of special chemicals in the atmosphere (scrub CO_2).
- CO_2 control via extraction from the atmosphere and placing in the sea (estimate cost of CO_2 removal).
- Stimulate acquisition of data on transport of chemicals through atmosphere-ocean interaction (CO_2 example).
- Design self-assembly systems which organize themselves for power generation via photoconversion, metabolic processes.
- Design global-scale thermoelectric generator system.
- Solar pumped lasers (especially 2nd harmonic).
- Investigate renewable systems in order to control the flow of matter (besides energy production).
- Investigate microsystems, in particular deviations from bulk classical laws of, e.g., optics for small systems.
- Photon storage via total internal reflection using phase-inversion mirrors.
- Materials whose performance improves with aging.
- Solar-powered material processing in space of materials already in space.
- New thermionic effect to generate $V(I)$ directly at high T.
- Gasification of coal and solar generated H_2 to generate a clean fuel/energy system.
- Harness rotational energy of the earth to generate power.

Group G2
- Design of materials whose performance improves upon aging.
- Design of materials which degrade on a controlled trajectory (e.g. biodegradable final products).
- Design of materials which self-correct for damage (e.g. photocromic effect), included intensity/temperature window «darkening».
- Stimulate the production of renewable energy sources by hampering the introduction of new power sources based upon conventional (fossil, nuclear) fuels.
- Change design algorithm for housing via use of solar thermal elements (e.g. panels, etc.) built into structural components (selective absorptive/reflective windows).
- ... same for industrial processes, e.g. design process to re-use its own waste best.
- ... same for agricultural processes (biomass).

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- Develop new insulation materials (reduce heat losses, e.g. on pipes).
- Develop «cold» storage systems (modern ice houses).
- Heat storage via two-phase systems.
- Use fibrous biomass to construct insulation and structural materials. Do via modifying structure of lignin or cellulose.
- Develop solar detoxification schemes – photothermal vs. thermal processes (especially dioxins need high T to decompose, «sterilization» of hospital waste); multistep schemes (combine sunlight treatment with, e.g., oxidation, bacterial decomposition).
- Develop new photochemical decomposition catalysts (e.g. TiO_2).
- Stabilize TiO_2 pigments to photochemical degradation.
- Design of novel ventilation systems based on local wind patterns («passive wind» technologies).
- Application of computer modelling of properties of compound/composite materials – screening of components.
- Application of computer modelling to predict effective local solar insolation (clouds, winds, etc.).
- Construct data base for material properties for «photo-x» applications.
- Data acquisition and design algorithms for hybrid wind/solar/hydroelectric systems – biomass production: special applications are well developed now.
- Solar refrigeration of high T_c superconducting devices.
- Develop new light-weight structural materials to save energy (heating, driving, etc.).
- Put more money into research. This will save money by developing options before conventional costs demand them (financing via non-renewable-energy tax).
- Role of energy in politics: Norwegian report.

Group G3

- Development of real-time process control for in-situ evaluation of materials quality.
- Promulgation of standards for materials packages.
- Data-base construction for classes of application (retrieval, validation, etc.). Standard format.
- Application of large-scale modelling to materials design. Development of publicly available software packages.
- Find better methods of electrochemical storage: key to all solar energy applications.
- Reliable, highly stressed materials – design and new materials.
- Use of optimization strategies for materials fabrication (optimize the fabrication process).
- Research on synthesis of biopolymers: polysaccharides, proteins.
- Lignin chemistry to find new applications.
- Research on polyaromatics for organic conductors.
- Research on H_2 storage by hydrides – how to eliminate small-concentration stabilizers.
- Research on high-temperature, high-pressure, high photon flux photoelectrochemistry to make «useful» materials (e.g. ceramics).
- Forecasts of microclimates for life modelling of wind, solar systems – for system planning.
- Data collection on operation of individual machines to access reliability of the machine population.
- Development of long-life, inexpensive, photochemically inert materials (encapsulants).
- Research on superionic conductors.
- Research on materials for thermal energy storage (including reversible phase transition materials).
- Research into materials stability under H_2S attack (goethermal, biogas, etc.).
- Research on photosensitive materials for use in low light levels, photogeneration efficiency including amplifiers and concentrators.
- Solar energy pumped lasers – to make «expensive» materials in particular.
- Develop freon replacement (heat pumps/refrigeration).
- Develop materials that are suitable for use under the sea (corrosion resistant, no scaling, barnacle resistance, biofilm preventions).
- Develop high temperature (1000 °C) selective absorbers.
- Research into ethanol product process (biomass-produced fuels) – optimize output, minimize waste.
- Optimize «engines» for burning of biomass-produced fuels.
- Develop an external wall material which traps incoming photons and home-generates heat in the house.
- Research into «intelligent buildings», especially homes, based on maximal use of renewable energy (livable *and* energy efficient); thermal underwear («local climate»).
- For each region identify plants which are optimal for biomass production.
- Make energy-efficient spirits (beer, wine, etc.).
- Develop insulating glass for building materials.
- Research into materials/processes to conserve use of energy (e.g., cheap, efficient heat exchangers).
- Develop low-enthalpy fluids for use in low-temperature gradients (replace chlorofluorocarbons).