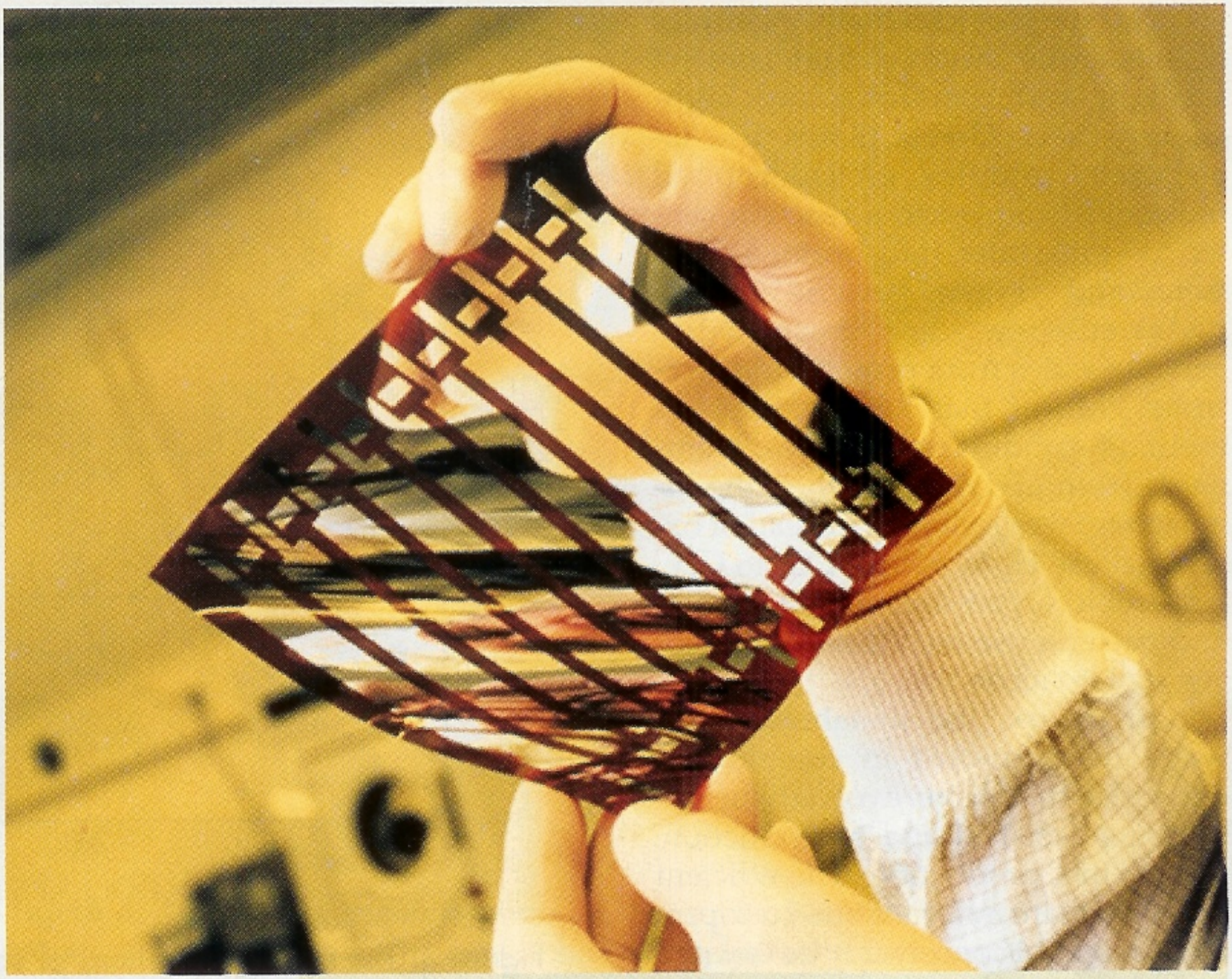

Figure 2. Novel conducting polymers enable solar cells that are flexible, inexpensive, and versatile. The new materials can be coated or printed onto flexible or rigid surfaces. (Image courtesy of Konarka Technologies.)

Photovoltaic conversion efficiencies

	Laboratory best*	Thermodynamic limit
Single junction		31%
Silicon (crystalline)	25%	
Silicon (nanocrystalline)	10%	
Gallium arsenide	25%	
Dye sensitized	10%	
Organic	3%	
Multijunction	32%	66%
Concentrated sunlight (single junction)	28%	41%
Carrier multiplication		42%

*As verified by the National Renewable Energy Laboratory. Organic cell efficiencies of up to 5% have been reported in the literature.

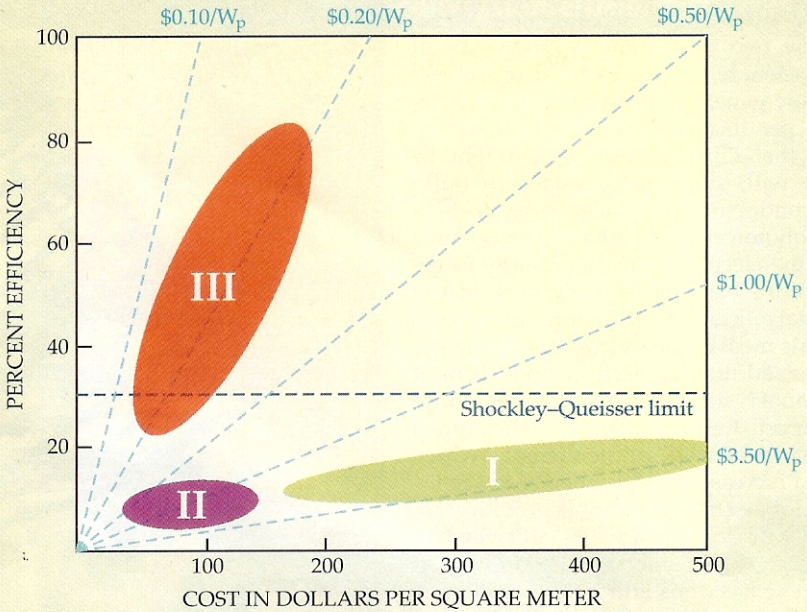

Figure 3. The three generations of solar cells. First-generation cells are based on expensive silicon wafers and make up 85% of the current commercial market. Second-generation cells are based on thin films of materials such as amorphous silicon, nanocrystalline silicon, cadmium telluride, or copper indium selenide. The materials are less expensive, but research is needed to raise the cells' efficiency to the levels shown if the cost of delivered power is to be reduced. Third-generation cells are the research goal: a dramatic increase in efficiency that maintains the cost advantage of second-generation materials. Their design may make use of carrier multiplication, hot electron extraction, multiple junctions, sunlight concentration, or new materials. The horizontal axis represents the cost of the solar module only; it must be approximately doubled to include the costs of packaging and mounting. Dotted lines indicate the cost per watt of peak power (W_p). (Adapted from ref. 2, Green.)

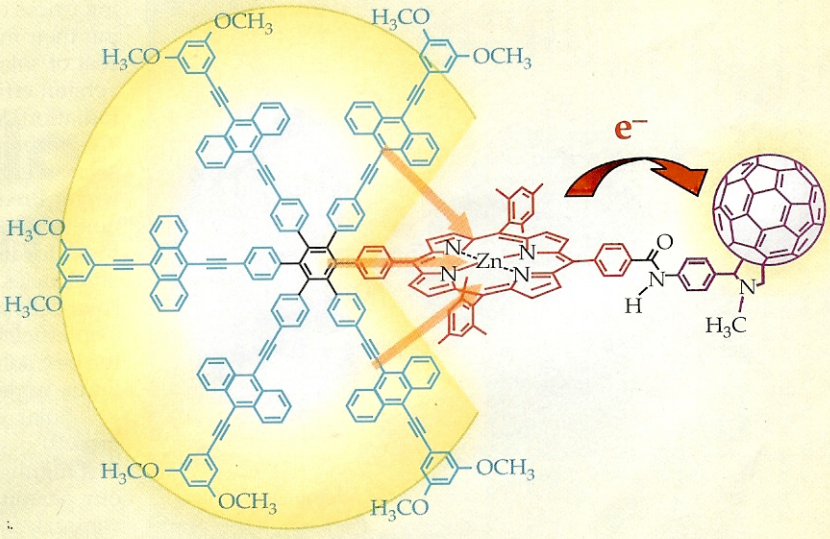

Figure 4. An artificial antenna–reaction-center complex that mimics the early stages of photosynthesis. The central hexaphenylbenzene core provides structure and rigidity for the surrounding wheel of five bis(phenylethynyl)anthracene antennas that gather light at 430–475 nanometers. The energy is transferred to a porphyrin complex in 1–10 picoseconds (orange arrows), where it excites an electron that is transferred to the fullerene acceptor in 80 ps; the resulting charge-separated state has a lifetime of 15 nanoseconds. Complexes such as the one shown provide the first steps in artificial photosynthesis. They have the potential to drive further chemical reactions, such as the oxidation of water to produce H_2 or the reduction of CO_2 to CH_4, alcohol, or other fuel. (Adapted from ref. 16.)

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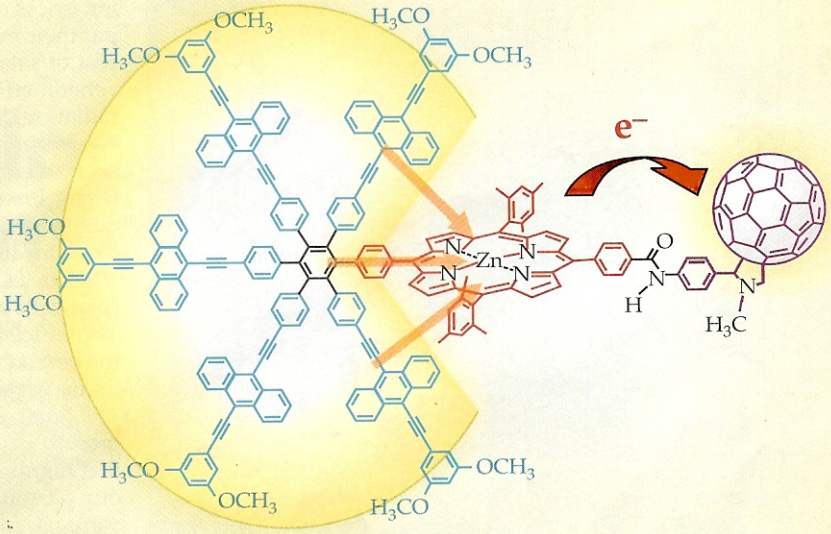
strength of the effect is measured by the thermopower, the ratio of the voltage produced to the applied temperature difference. Although the thermoelectric effect has been known for nearly 200 years, materials that can potentially convert heat to electricity efficiently enough for widespread use have emerged only since the 1990s.[13] Efficient conversion depends on minimizing the thermal conductivity of a material, so as not to short-circuit the thermal gradient, while maximizing the material's electrical conductivity and thermopower. Achieving such a combination of opposites requires the separate tuning of several material properties: the bandgap, the electronic density of states, and the electron and phonon lifetimes. The most promising materials are nanostructured composites. Quantum-dot or nanowire substructures introduce spikes in the density of states to tune the thermopower (which depends on the derivative of the density of states), and interfaces between the composite materials block thermal transport but allow electrical transport, as discussed by Lyndon Hicks and Mildred Dresselhaus in 1993.[14] Proof of concept for interface control of thermal and electrical conductivity was achieved by 2001 with thin-film superlattices of Bi_2Te_3/Sb_2Te_3 and PbTe/PbSe, which performed twice as well as bulk-alloy thermoelectrics of the same materials. The next challenges are to achieve the same performance in nanostructured bulk materials that can handle large amounts of power and to use nanodot or nanowire inclusions to control the thermopower. Figure 5 shows encouraging progress: structurally distinct nanodots in a bulk matrix of the thermoelectric material $Ag_{0.86}Pb_{18}SbTe_{20}$. Controlling the size, density, and distribution of such nanodot inclusions during bulk synthesis could significantly enhance thermoelectric performance.[15]



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