Project Summary

Life Cycle Design of Building Integrated Photovoltaic Systems

National Science Foundation - Lucent Technologies Industrial Ecology Research Fellowship

Background
A very small percentage of U.S. electricity is currently generated from renewable, potentially sustainable sources (hydropower - 8.6%, wood - 1.1%, geothermal - 0.5%, wind - 0.1%, solar - 0.03%). Generating electricity from non-renewable coal, natural gas, fuel oil, and nuclear fuel is not a sustainable practice. Environmental impacts due to use of these unsustainable generating systems include release of greenhouse gases, acidification, smog and ground-level ozone formation, dispersal of air pollutants such as mercury, and generation of long-lived radioactive waste.

Photovoltaic (PV) devices convert sunlight directly into electricity and are an important renewable energy technology. PV systems are a method of distributed power generation that is capable of supplying a significant portion of the electricity production in the U.S. An elegant application of PV technology is in building integrated designs (BIPV), in which the PV system becomes an integral part of the building envelope. The BIPV concept has been applied to both roofing systems (shingles, standing seam metal) and facade elements (curtain walls, glazing). The BIPV system serves multiple functions: weather protection, structural, aesthetic, electricity generating. BIPV systems displace conventional building material requirements and do not require additional land area or support structures.

Industrial ecology focuses on the systematic analysis of global, regional, and local material and energy flows associated with a product system or economic sector and is the foundation of the proposed research. Based on an analysis of material and energy flows related to the BIPV product system, as well as life cycle design and economic principles, NPPC will develop a computer software tool (Photovoltaic-Building Integrated Design and Policy Assessment Tool, or PV-BIDPAT) to be used for BIPV design and planning.

Objectives
1. Development of a life cycle inventory (LCI) and life cycle cost (LCC) model for BIPV systems, as well as for the displaced conventional building materials and centralized electricity generating systems.
2. Determination of the salient performance, regulatory and policy factors influencing the inventory and cost models (environmental, energy, and economic performance of BIPV systems are directly dependent on these factors).
3. Construction of the BIPV design and planning tool PV-BIDPAT to measure:
   a. BIPV pollution prevention factors for air pollutant emissions (greenhouse gases, NOx, SO2, particulates, VOCs), water effluents (heavy metals, suspended and dissolved solids, COD, BOD, oils and greases, phosphate, ammonia), and solid waste.
   b. BIPV life cycle energy performance (energy payback time, electricity production efficiency).
   c. BIPV economic performance (life cycle costs, including social benefits and costs) and the implications of various policy scenarios (such as national and international policy on marketable permits for various air pollution emissions).
4. Evaluation and testing of PV-BIDPAT using three existing sites and application of the tool to two new proposed installations.
Methods
The research plan is organized into five tasks that address the objectives outlined above: Task 1 - life cycle inventory model development; Task 2 - policy analysis and life cycle cost model development; Task 3 - development of the BIPV software tool PV-BIDPAT based on the model equations and parameters from Tasks 1 and 2; Task 4 - data collection and measurement of model parameters for amorphous silicon BIPV technology and appropriate conventional building materials; Task 5 - application of PV-BIDPAT to both existing and new sites.

The life cycle inventory component of PV-BIDPAT consists of a set of modules characterizing a variety of BIPV technologies (amorphous, crystalline, and polycrystalline silicon, CdTe thin film, for example) and another set of modules for the displaced building materials (fiberglass asphalt shingles, galvanized metal roofing, curtain wall panels, glazing components). The inventory model is coupled to a life cycle cost model comprising economic and policy modules that account for Public Utilities Regulatory Policies Act (PURPA), current Federal Energy Regulatory Commission (FERC) rules, and existing and proposed emissions allowance trading systems. The cost model assigns monetary value to social costs of pollutants and environmental damage due to electricity generation. PV-BIDPAT computes the following metrics: pollution prevention factors for air pollutant emissions, water effluents solid waste; energy payback time and electricity production efficiency; life cycle cost. In this phase of the project, inventories are being conducted for amorphous silicon BIPV products using data collected at United Solar, for the displaced fiberglass asphalt shingles and standing seam metal roofing materials, and for balance of system components necessary for the BIPV installation (wiring, fuses, inverter). Inventories for other BIPV and conventional building products will be added in the future. PV-BIDPAT will be applied to three existing building sites (Southface Energy Institute, Atlanta, GA, NAHB 21st Century Townhouses, Bowie, MD, Art & Architecture Building, University of Michigan, Ann Arbor, MI) and designs for two proposed installations will also be evaluated.

The primary deliverable is the BIPV life cycle design and planning tool PV-BIDPAT, although the conceptual framework underlying the tool is also an important product of this research. PV-BIDPAT will be made available to the PV, architecture, and building industries, as well as other interested stakeholders, and will be capable of being used to inform policy makers and the public about the benefits of BIPV.

Research Team
The development and application of the BIPV design and planning tool PV-BIDPAT is being accomplished by an interdisciplinary team that combines expertise in life cycle design and assessment, PV technology, architecture, environmental economics, and energy policy. The research team (listed below) brings together investigators from the National Pollution Prevention Center (NPPC), the School of Natural Resources and Environment (SNRE), and the College of Architecture and Urban Planning (CAUP) at the University of Michigan, and the Research and Technology Division of United Solar, a leading manufacturer of amorphous silicon PV products.

Team members:
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