4. Upgrades

This section describes the consideration of life-cycle environmental factors when introducing incremental and routine improvements in the performance of existing products, systems, processes, or facilities[3].

4.1 Products and Systems

Product and system upgrades are often introduced when an item currently being sold or already placed in service is not performing at a desired level or when it is felt that a greater market share may be achievable with a better performing product. Customer feedback through the maintenance, technical support, marketing, or customer service channels may trigger a need to modify components, to re-engineer certain assemblies for better service or replacement access, or a myriad of other performance considerations. A desire to improve the manufacturability of a product or system may also create an opportunity for upgrades. Under most circumstances the environmental performance of the product or system will not be the primary reason for undertaking an engineering effort to upgrade. Nevertheless, life cycle engineering offers the potential for consideration of possible improvements in the environmental aspects of a product or system at the same time that performance- or cost-drivers are creating a need to improve its technical or cost envelope.

4.2 Processes and Facilities

Process and facility upgrades may be either consequential to a product or system upgrade or independent. Oftentimes, changing requirements for production of the components or assemblies comprising a product will initiate an assessment of the operational efficiency, throughput rates, or manufacturing quality procedures. In turn, once the evaluation team has a charter to modify the process or facility, life cycle engineering can be employed to ensure that environmental aspects are considered along with productivity and cost. More than this, the LCE framework encourages the team to select processes and facility upgrade elements that avoid the transfer of impacts to supplier organizations.

Even in the absence of product-driven initiatives to upgrade, process and facility improvements can be justified on the basis of improved life cycle costs for the operations, improved quality of products, debottlenecking of production, or other non-environmental considerations. However, with regard to processes and facilities upgrades, environmental factors can be an important driver apart from production costs. Life cycle engineering offers the capability for an evaluation team to simultaneously consider process changes that reduce environmental compliance costs, reduce overall facility environmental burdens, and beneficially impact productivity and profitability.

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[3] When upgrading is non-routine and significant, rather than incremental, the decision falls in the “New” type.

4.3 LCE Case Study: Photovoltaic Module Development

Photovoltaic modules (PV) are devices that convert solar energy into electricity. The UPM-880 tandem junction power generation module, a PV produced by United Solar, uses thin film amorphous silicon as the photovoltaic material and contains two identical semiconductor junctions. The UPM-880 is 119.4X34.3X3.8 centimeters in size and weighs 3.6 kilograms.

4.3.1 Targeting the Evaluation

Establishing the Function being Provided

The function of the UPM –880 is to convert sunlight to energy. It has a rated output power of 22 watts, which represents a stabilized conversion efficiency of 5%. The UPM-880 has a 10-year warranty.

Naming an Evaluation Team

The evaluation team for this effort consisted of management and technical functions. Members of the team included:

- National Pollution Prevention Center staff who are experts in Life Cycle Design,
- A Vice President of Research and Technology at United Solar, and
- A Senior Research Scientist at United Solar.

These groups interacted on a number of occasions. The Research scientist was responsible for data collection and analysis of energy module manufacturing. The Vice President of Research and Technology helped to initiate and define the scope of the project.

Developing Requirements and Goals

The requirement of the design activity was to guide the next generation design of the UPM-880 by improving upon four metrics:

- **Energy payback time-** the length of time required for a module to generate energy equal to the amount required to produce it from raw materials.
- **Electricity production efficiency-** the ratio of the total energy produced by a generating system over its lifetime to the sum of energy inputs required for the system's manufacture, operation and maintenance (including fuel), and end-of-life management to the amount of radiant energy as sunlight incident on the generating system over its lifetime. The metric can be used to compare all types of renewable fossil fuel-based generating technologies.
- **Life cycle conversion efficiency** – the ratio of the energy produced over a generating system's lifetime minus energy inputs required for the system's manufacture, operation and maintenance (including fuel), and end-of-life management to the amount of radiant energy as sunlight incident on the generating system over its lifetime. This metric is most useful for comparing solar-fueled generating systems to each other, as opposed to fossil fuel systems.
- **Life cycle cost** – the total acquisition, operation and maintenance, and retirement costs for a generating system divided by the total amount of energy generated over its lifetime. The metric can be used to compare all electricity generating systems.

Table 4.1 provides an assessment of requirements and goals based on these metrics. Production efficiency and life cycle cost were considered as requirements.

Table 4.1 UPM-880 Assessment Requirements and Goals

Category	Applicable Life Cycle Stage				Requirements and Goals	Requirement (R) or Goal (G)
	MP	MC	USM	D		
Performance						
Electrical	X	X	X	X	Decrease payback time.	G
Electrical					Increase production efficiency	R
Electrical		X	X	X	Increase life cycle conversion efficiency.	G
Cost						
Equipment, and installation		X	X		Reduce cost.	R
End-of-Life Management				X	Reduce life cycle cost	G

Proposing Engineering Technologies and Options

Design strategies were found to depend on many factors such as useful life of the module, opportunities for reusing modules in less demanding applications, and efficiencies associated with improved technology at the time of retirement. PV technology development focuses on increasing conversion efficiency and reducing costs. Electricity production efficiency, energy payback time, and life cycle cost add valuable new perspectives in guiding technology development. These metrics illuminate material and process choices, and help utility companies, policymakers, and the public make accurate comparisons between technologies.

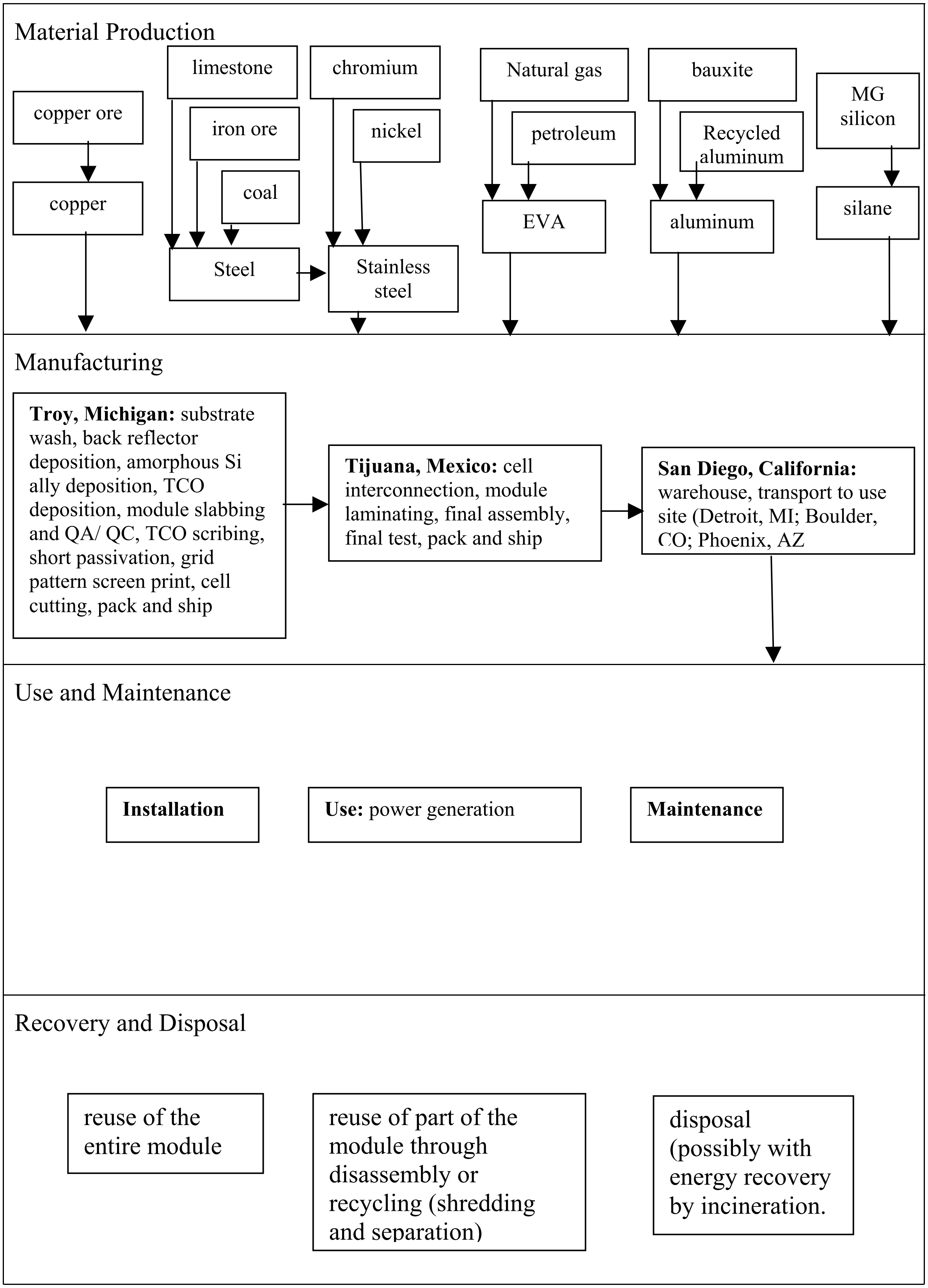
Design strategies for end-of-life management phase were explored. The analysis was conducted for standard and frameless versions of the UPM-880 module.

4.3.2 Preliminary Assessment

Defining the Technology Life Cycles

Over 26 materials are used in the production of the UPM-880, 20 of which are actually incorporated into the finished product. Several processes used for cleaning, etching, and short passivation are not incorporated into the module, although they were included in the analysis of embodied energy. Incorporated materials include gases, liquids, and solids, both metals and plastics. The consituents products were listed and sorted by mass to highlight their continued attension in the assessment. The highest contribution to the mass was the anodized aluminum extruded frame (38%), the EVA encapsulation (25%), the galvanized mild steel backing plate (25%), and the stainless steel substrate (11%).

Figure 4.1 Defining the Technology Life Cycle



The phases of the product investigated included material production, manufacturing, use, and end-of-life management. As shown in Figure 4.1, it was beyond the scope to examine raw material extraction and processing operations in depth for all materials used in the production of the UPM-880. The manufacturing phase is composed of a large number of components that are carried out in the United States and Mexico. The use phase of a UPM-880 module has installation, use (power generation), and maintenance. Because there are limited documented examples of what happens to PV modules at the end-of-life, the end-of-life management phase was addressed in terms of three possible scenarios: (1) reuse of the entire module, (2) reuse of part of the module through disassembly or recycling (shredding and separation), or (3) disposal (possibly with energy recovery by incineration.

Upon examination, the team found the aluminum frame an obvious candidate for reuse.

4.3.2 Preliminary and Detailed Assessments

The preliminary and detailed assessments were combined to include the quantification of the set of metrics linked to the requirements and goals. Material energy requirements were calculated for each of eight components of UPM-880. For each component a low case and a high case energy requirement were developed. The totals for the high and low cases were 831.4 MJ and 25.5 MJ, respectively. The energy requirements for the nine major steps of manufacturing were also calculated as equivalent primary energy. These data were collected by measuring electrical consumption of each machine for the amount of time necessary to process one module of UPM-880. The total energy requirement was 201.2 MJ.

Conversion efficiency metrics were calculated for three locations: Detroit, MI; Boulder, CO; and Phoenix, AZ. Energy payback time in years was calculated as module production energy (in kWh) divided by energy generated per year. These calculations were made for conversion efficiency factors ranging from 5% to 9%. The calculated payback periods for the three locations and five different conversion factors ranged from 1.3 to 13.4 years. Energy production efficiency was calculated summing the energy produced by a generating system over its life time, and dividing it by the sum of the energy inputs required to manufacture and transport, install, operate and maintain, and disposal or reclaiming of the system at the end of its life time. Conversion efficiency was defined and calculated as energy produced over a generating system's lifetime minus energy inputs required to manufacture and transport, install, operate and maintain, and dispose or reclaim that system divided by the amount of radiant energy as sunlight incident on the generating system over its lifetime. Electricity production efficiency and conversion efficiency metrics were calculated for 10, 15, 25, and 25 year assumed lifetime.

A life cycle cost analysis was conducted to estimate the total cost of electricity production from the UPM-880 module. Initial purchase price, installation, maintenance, and retirement costs were included in this analysis. The estimates were made for 10, 15, 20, and 25 year lifetimes for the same three geographic locations that were cited earlier. These estimates ranged from $0.24 per kWh to $1.23 per kWh.

4.3.4 Specification Development

Two components of the UPM-880 were illustrated as major opportunities for design improvement: the aluminum frame and the EVA encapsulant. The energy invested in the aluminum frame consists of material production energy and energy required to extrude and anodize the frame parts. Material production energy can be reduced by using a higher proportion of secondary material or by using a different, less energy intense material. Also, the aluminum frame is a good candidate for reuse.

The useful life was recognized as a primary design parameter. Early design failures illustrated that moisture intrusion is a sure cause of module failure. EVA encapsulant, which is not completely impermeable to moisture, has been a factor in the determination of useful life. EVA also requires high energy for lamination.