DOE/CH/10571--T1

Final Technical Progress Report

Phase II

August 1995

Revised Sept. 1995

Subcontract Title: Rooftop PV System

Subcontract Number: DE-FC02-93CH1 0571

Subcontractor: Energy Conversion Devices, Inc.
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Team Members:

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Solar Design Associates (SDA)

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Introduction

Program Objectives and Background

Under this four-year PV:BONUS Program, ECD and United Solar are developing and demonstrating two new lightweight flexible building integrated Photovoltaic (BIPV) modules specifically designed as exact replacements for conventional asphalt shingles and standing seam metal roofing. These modules can be economically and aesthetically integrated into new residential and commercial buildings, and address the even larger roofing replacement market. The modules are designed to be installed by roofing contractors without special training which minimizes the installation and balance of system costs. The modules will be fabricated from high-efficiency, multiple-junction a-Si alloy solar cells developed by ECD and United Solar.

Under the Phase I Program, which ended in March 1994, we developed two different concept designs for rooftop PV modules: (1) the United Solar overlapping (asphalt shingle replacement) shingle-type modules and (2) the ECD metal roof-type modules. We also developed a plan for fabricating, testing and demonstrating these modules. Candidate demonstration sites for our rooftop PV modules were identified and preliminary engineering designs for these demonstrations were developed; a marketing study plan was also developed.

The major objectives of the Phase II Program, which started in June 1994 was (1) to develop, test, and qualify these new rooftop modules; (2) to develop mechanical and electrical engineering specifications for the demonstration projects; and (3) to develop a marketing/commercialization plan.

Two new products have been developed by United Solar and ECD: a 1 ft by 10 ft overlapping PV shingle-module, and a 1.3 ft by 19 ft metal roofing module. The United Solar shingle module design utilizes a mounting procedure similar to that used for conventional asphalt shingles, and the ECD metal roofing module utilizes a mounting procedure designed for metal roofing systems. Both types of rooftop PV modules are lightweight and flexible and can be installed directly over standard wood roof sheathing replacing ordinary shingles or metal roofing panels. The product design features and installation methods have been refined though discussions, reviews, and testing by ECD and United Solar, and by building industry experts including the National Association of Home Builders (NAHB) Research Center, Solar Design Associates, and Minoru Yamasaki Associates.

In Phase III of this project we shall scale up fabrication of these prototype roofing modules and begin field demonstration, performance monitoring, and in-field economic data analysis of the new arrays. The UniSolar shingle-module will be showcased on a home in the Olympic Village in Atlanta Georgia, and the ECD metal roofing module on a townhouse being built at the NAHB Research Park in Maryland outside Washington D.C. Other demonstration sites are also being investigated. During this phase we shall also form a business group for commercialization of these building integrated PV arrays, identify near-term niche markets, and begin initial product offerings to these markets.

Summary of Phase II Tasks

There were three principle Tasks in the Phase II Program: (1) Module Development; (2) Demonstration Program; and (3) Business Development. We briefly summarize these tasks here, and describe them in more detail in the following sections.

Module Development

Two new modules were developed: the United Solar 1 ft by 10 ft overlapping shingle module, and the ECD 1.3 ft by 19 ft metal roofing module. In order to fabricate these new modules, United Solar designed, fabricated, and commissioned a 4 ft by 12 ft lamination machine, and ECD a 4 ft by 24 ft lamination machine.

The United Solar shingle module was designed to emulate conventional asphalt shingles in form and function. The initial module design geometry was 11 ft long, with individual PV shingles about 2 ft wide by 1 ft tall, roughly twice the size of standard shingles. These modules were fabricated and installed on a test array system outside United Solar's Troy manufacturing facility for aesthetic evaluation, evaluation of installation procedure, and outdoor testing. This module design evolved in a number of significant ways, the principle changes being: (1) the shingles were reduced in size to exactly match the size of conventional shingles; (2) the "cuts" between individual shingles were replaced by an embossment; and (3) a new electroplated grid design was incorporated which allowed for a significant reduction in encapsulation materials and costs. Two new arrays were constructed using modules of this design: active modules were built to replace the previous generation modules on United Solar's outdoor test array, and dummy modules were made for installation and aesthetic evaluation at the NAHB research center. The modules were also qualified according to the SERI interim IQT specifications.

The ECD metal roofing module is designed to be an exact replacement for a commercially available standing seam metal roofing product produced by the ATAS Aluminum-n Corp. The initial design used tubular bypass diodes, and had the current busses bordering the cells for ease of assembly. This module evolved into one incorporating flat chip bypass diodes with the current buses underneath the cells. Both the encapsulation method and ATAS roll forming machine were modified for compatibility as a result of a series of roll-forming tests. ECD has built three test arrays. The first was sent to NREL as a deliverable, the second is being used for outdoor testing by ECD and as a display model by United Solar. The third array will also be sent to NREL as a deliverable. In each array the module encapsulation, forming technique, and connector placement and design were revised and optimized.

Demonstration Program

There are 3 demonstration projects: one of the projects, the Bluebird Bed and Breakfast Inn on Beaver Island, uses a currently available United Solar product. The system has been installed and is now being monitored. The two other sites have been chosen to demonstrate the new metal roofing and shingle replacement modules:

The ECD metal roofing module fabrication is now being scaled up and the modules will be installed on an "Energy Smart" townhouse being build by the NAHB Research Center. Besides accomplishing the goal of putting the PV modules on the townhouse, ECD also wishes to demonstrate that these modules can be installed by conventional roofing contractors and electricians. Consequently, ECD/NAHB shall develop instructions, connectors and junction boxes to "standardize" this operation. NAHB shall then contract with a local roofing company and electricians to install the PV system. ECD and NAHB shall observe and document the process and then modify the installation procedure and instructions based upon these observations.

The United Solar shingle module is being showcased on a home being built in the Olympic Village next to the Science and Technology Museum. In addition to a tandem same-bandgap 1.9 kW roof array, United Solar will fabricate a 300 W state of the art spectrum splitting array using cells produced in a research batch reactor.

Business Development

The BIPV systems developed in the PV:BONUS program will compete in the retail power market, where residential commercial power cost 5-130 (average 8.50) 3-170 per kW-hr, rather than in the wholesale market where power is produced for about 3-50/kW-hr. (Residential figures from 1993; commercial figures from April 1995). Consequently, the BIPV systems are the most economically favorable near- and medium-ten-n markets for PV in this country.

Arizona Public Service (APS) has performed a marketing study to estimate the size of the market for the BIPV product, project penetration of the product into the market and identify initial penetration opportunities. This study is included as Appendix C in this report; here we summarize a few highlights of the report.

The technically feasible market is tremendous: on the order of 15 billion ft2, corresponding to about 150,000 MW. The economically attainable market, based upon consumer acceptance at 2.3 $/W, although much smaller, is still very significant: @ 100 MW/yr. The sensitivity of this economically attainable market to cost is very strong (somewhat akin to the J-V curve of the cells themselves), especially in the commercial sector where a 30% change in cost would affect the market size by about a factor of 15! In other words, at 3$/W we would be on the very tail of the commercialization curve; consequently levels of insolation and DSM incentives are very important, and as a result, most of the initial market would probably be in the states of Arizona, California, Nevada and Hawaii. The commercial market is larger than the residential market and is much more sensitive to cost and DSM incentives; this market also has a much better coincidence between consumption and insolation.

These studies, together with our initial responses from consumers, builders, architects, etc. assure us that there exists a market well beyond our means to satisfy. Arthur D. Little Inc. estimates that the BIPV market could grow to as high as 2.6 B$ in the next decade.

The NAHB Research Center has also carried out a commercialization study to assess strategic options for the distribution of the BIPV shingle and metal roofing modules in the residential and commercial building markets. This reports outlines:

- existing and potential distribution channels, evaluating them for commercialization of the BIPV products;
- issues relating to marketing and packaging the systems together with BOS components, evaluating their potential impact on the distribution channels; and
- analyses of warranties of the present roofing materials and the implications of these warranties on the commercialization of the BIPV modules.

United Solar has developed a market introduction plan for the BIPV systems. They are conducting advanced product meetings for the BIPV systems in several cities to refine product designs and to develop business partnerships

Phase III Planning

We have identified five principal tasks for Phase III:

- Task I: Fabrication of Demonstration Arrays;

- Task II: Installation of Prototype Arrays;
- Tasks III-IV: Field Demonstrations and Monitoring;
- Task V: Business Development and Product Refinement; and 0 Task VI: Project Management, Coordination and Reporting.

Below we briefly review Tasks I-V.

Task I.- Demonstration Array Fabrication

Three prototype arrays will be fabricated: a 1.9 kW shingle-module array using double-junction same-bandgap cells; a 300 W shingle module array incorporating state-of-the-art spectrum-splitting cells; and a 2 kW metal roofing array using triple junction cells.

The United Solar 2 kW shingle array will be fabricated using 1 ft by 10 ft shingle modules for installation on the demonstration house in the Olympic Village next to the Science and Technology Museum. The 1.9 kW_{ac} system modules will incorporate same-gap double-junction cells. Approximately 120 modules will be required. Each module will consist of 10 submodules.

The United Solar 300 W high efficiency shingle array will be fabricated using state-of-the-art spectrum-splitting multijunction cells for installation on the annex/garage/demo area at the Olympic Village house. These cells will be fabricated in a batch research reactor, and have the following structure:

- a ZnO film on top of a textured Ag back reflector film, both deposited by RF magnetron sputtering;
- a silicon-germanium alloy cell structure consisting of $N_1P_1N_2I_2P_2N_3I_3P_3$ layers deposited sequentially by conventional glow discharge deposition;
- and a transparent conducting oxide film of indium-tin-oxide deposited on the large area cell using a reactive evaporation process.

ECD shall fabricate a 2 kW metal roofing array for the NAHB Townhouse being built by the NAHB Research Center in Prince George's County, Maryland. This array will consist of twenty 19 ft long by ≅ 1 ½ft wide metal roofing PV modules. These modules will use spectrum-splitting triple-junction cells. Each module will have 19 cells in series.

Task II.- Array Installation

United Solar will subcontract the National Association of Home Builders (NAHB) to install the shingle PV modules on the Olympic Village demonstration house; ECD shall also contract with NAHB for installation of the metal roofing array on the NAHB townhouse. Via these demonstrations, ECD/United Solar wish to demonstrate that these modules can be installed by conventional roofing contractors and electricians. Consequently, we shall develop instructions, connectors and junction boxes to "standardize" this operation. NAHB shall then contract with a local roofing company and electricians to install the PV system. ECD/United Solar and NAHB shall observe and document the process and then modify the installation procedure and instructions based upon these observations.

Tasks III and IV.- Field Demonstrations and Monitoring

The Beaver Island 1.8 kW PV system, installed at the Bluebird Bed and Breakfast, is already being used to gather data: on 21 June '95 the system was generating 2.2 kW, and no power has been drawn from the grid for over 2 weeks. The Inn is booked solid for the next 10 weeks, and descriptions of the PV system are being prepared for each guest's room. The system uses an Infinity 6 loadcenter with an Omnimeter data acquisition system for logging voltage, current, ampere-hours, watt-hours, watt-hours available from the batteries, and percentage of charge efficiency. The system will log data every few minutes, and the owners of the Bed and Breakfast, Bill Palladino and Claudia Schmidt (husband and wife), will download the data every few days as the buffer becomes filled. This data will then be transferred via disk or telephone lines to United Solar.

The NAHB townhouse computer data logging system will have remote modem capability and will monitor:

- The current in each of the 3 sets of modules, total current from the array, DC current to the inverter and AC current from the inverter, AC current to the grid, and DC current to and from the battery.

- The voltage of the array and the batteries.

- The NAHB townhouse is a "Smart House"; consequently we are also investigating whether we can hook the data acquisition computer to the Smart House processor and also log power from major appliances, such as the refrigerator, air conditioning unit, furnace, kitchen appliances, etc.

- The temperature of the batteries, temperature of the array (between metal roof and felt paper), and the temperature underneath the sheathing in the attic. The wind speed and ambient temperature will also be measured, We shall also measure in plane (and possibly horizontal) insolation.

These data will be analyzed by ECD and NAHB personnel. The system will be shown to members of the housing production chain and utilities; the reactions of these groups shall be analyzed and evaluated.

NAHB shall work with the local utility to operate this grid-connected battery-backup system in a number of different modes to evaluate the economic performance.

The Olympic Village House monitoring system will have computer and modem interfaces. The parameters monitored will include:

- for the 1. 9 kW system, at 10-minute intervals:

  I_{max}, V_{max}, P_{max}, irradiance, ambient temperature, temperature under module

- for the 300 W battery charging system (also at 10 min intervals):

  amp hours delivered, irradiance, ambient temperature, and temperature under module.

Task V- Business Development and Product Refinement

Our commercialization activities for Phase III include:

- Identification of near-term niche products and markets
- Development of distribution channels
- Development of business groups
- Refinement of products based upon demonstration/monitoring projects and market response
- Initiation of product offering of rooftop PV arrays developed under Phase II

United Solar is presently introducing its next generation of advanced building integrated PV products to replace conventional roofing and building materials, including the systems developed under the PV:BONUS program, in a series of Advanced Product Meetings taking place in major cities across the U.S. The purpose of these meetings is to solicit interested companies for business development partnerships to complete the product development, and define and establish sales and service networks for these products. The first Advanced Product Meeting in Sacramento resulted in very positive responses from the participants, and a number of BIPV demonstration projects were suggested.

United Solar plans for market entry early in the Summer of 1996. To accomplish this, the Advanced Product Meetings shall continue through mid August, at which time we shall begin a couple of months of business partner meetings. From the late fall through next summer we shall refine the product designs, and install additional demonstrations. ECD, working with United Solar, shall concentrate on refining these products in a number of areas:

1. Working with architects, builders, inverter manufacturers, etc., design several "standard" adaptable PV packages, including the BOS, which can be used to address multiple segments of both the residential and commercial new and retrofit markets.

2. Further refine the product lines for UL approval.

3. Refine the products to further reduce the product cost, and increase the product life.

ECD's METAL ROOFING MODULE

ECD's metal roofing module design and demonstration program is summarized in the following NAHB Phase II Final Task Report. In this section we provide additional information concerning the module design and testing not included in that report.

Lamination Machine

In order to fabricate these long modules, ECD constructed a large area (31/2 ft x 24 ft) lamination machine. Even using slow-cure EVA, this machine is capable of laminating 1 MW of PV modules/year. The machine was recently upgraded from 3 to 9 independent closed loop heating systems in order to ensure uniform heating over the entire useful area.

Module Testing

ECD has performed testing in 4 principal areas:

Roll-forming PV modules in metal roofing machines

Installation techniques

Outdoor testing

Qualification testing

Roll-form Testing

As mentioned in the NAHB report, there have been 3 roll-forming trials. As a result of the first set of tests in January '95, both the PV module and roll-forming machine were altered. Modifications to the PV modules included:

- replacing the tubular cell bypass diodes with flat chip diodes;
- moving the current busses from edges of the cells to the back of the cells; and
- tapering the lamination thickness at the sides of the module.

A new set a rollers for the roll-form machine were also designed and fabricated. Subsequent roll-forming tests in March on a new set of prototype modules were very successful. In April ECD fabricated full length dummy and working modules which were successfully roll-formed in May.

Installation Testing

The module design was also modified as a result of building the prototype arrays and studying the installation techniques. Experience gained in fabricating the first prototype array for NREL led to a redesign of the connector location and the location of the first cell with respect to the top of the module. In addition, it was found to be necessary to also taper the lamination thickness at the bottom of the module in order to allow this portion of the module to be easily bent under the end of the roof sheathing to prevent wind lift and penetration by water. An array incorporating these improvements was then built for outdoor testing at ECD; a third array was also build as a second NREL deliverable.

Outdoor Testing

Pictures of the prototype array are shown in the accompanying NAHB report on pages 24 to 35. The second prototype array has been used for outdoor testing at ECD, and was also used as a display model for the ECD metal roofing system at the United Solar Advanced Product Meetings in Sacramento CA and in Troy MI. The efficiency-time and V-1 measurements this 6-cell array are shown in Figures 1 and 2.

Based upon measurements of this array, the NAHB townhouse array specifications (see page 28), have been updated, and are detailed in the following table:

Table I. Summary of cell, module, and array parameters for the NAHB townhouse metal roofing demonstration project.

PARAMETER	SYMBOL	VALUE	UNITS
	Cell Properties		
Efficiency	E	7.1	%
Cell Width	W_c	0.315	m
Cell Length	l_c	0.28	m
Cell Open Circuit Voltage	Vc,oc	2.1	V
Cell Short Circuit Current	$I_{c.oc}$	5.25	A
	Module Properties		
Number of Cell/Module	N_m	19	
Module Open Circuit Voltage	$V_{m,oc}$	39.9	V
Module Short Circuit Current	$I_{m,sc}$	5.25	A
Nominal Module Voltage	$V_{m,p}$	30	V
Nominal Module Current	$I_{m,p}$	3.95	A
Nominal Module Power	P_m	0.119	kW
	Array Properties		
Number of Modules/Array	N_a	18	
Array Open Circuit Voltage	$V_{a,oc}$	79.8	V
Array Short Circuit Current	$I_{a,sc}$	47.25	A
Nominal Array Voltage	$V_{a,p}$	60	V
Nominal Array Current	$I_{a,p}$	35.5	A
Nominal Array Power	P_a	2.13	kW

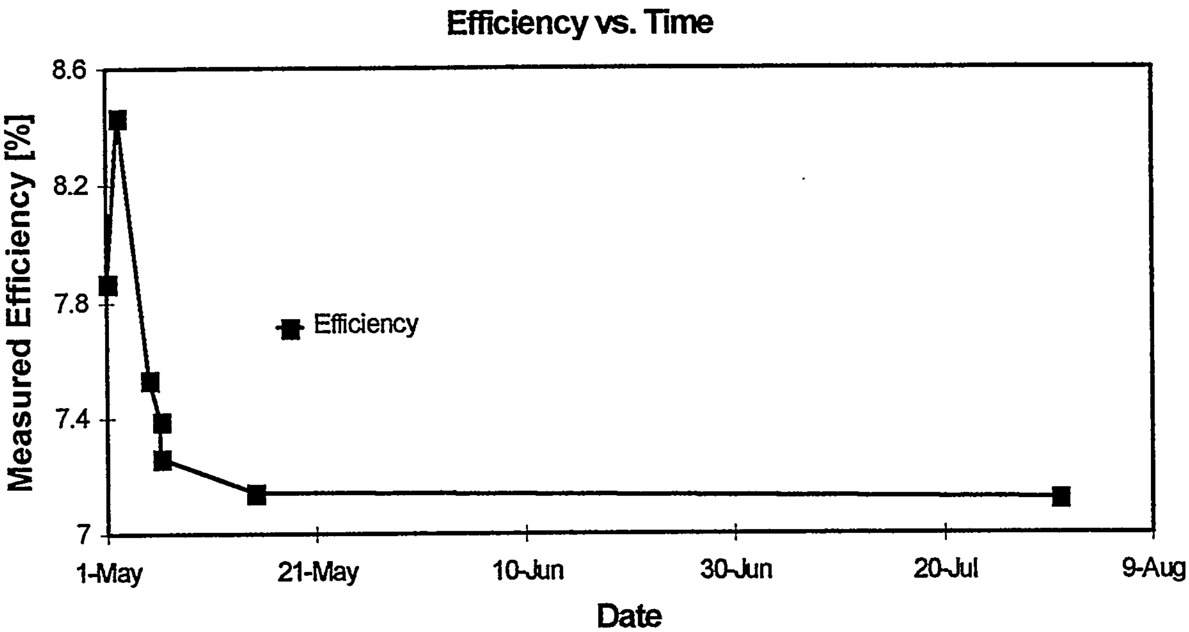


Figure 1. Efficiency as a function of time for ECD's outdoor prototpye metal roofing array.

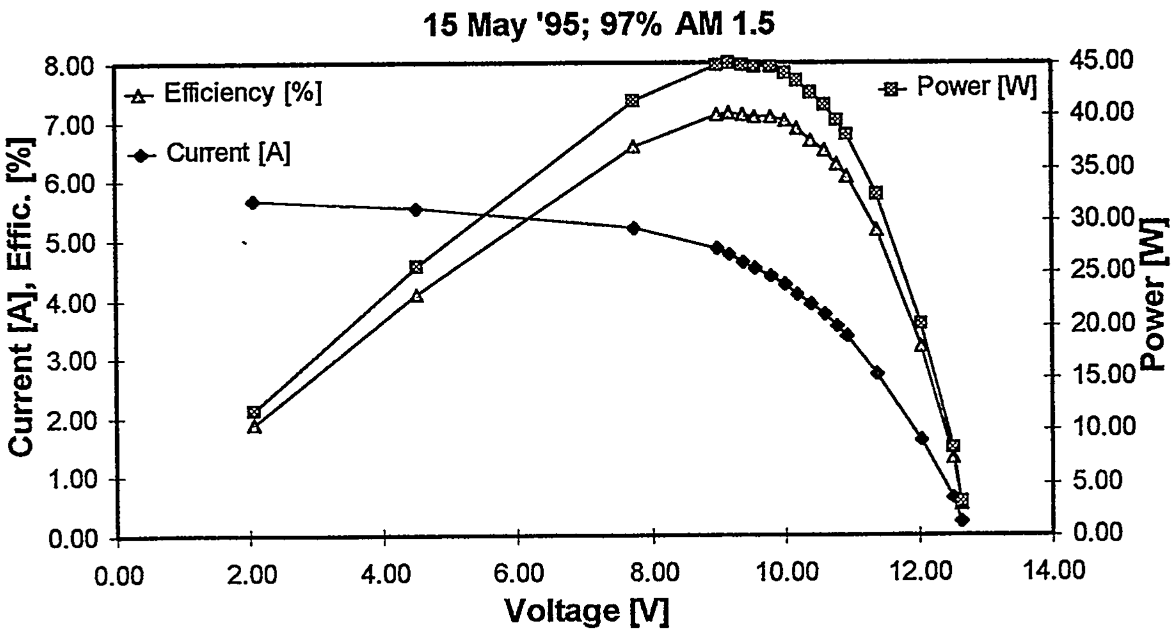


Figure 2. I-V curve for the outdoor prototpye metal roofing array.

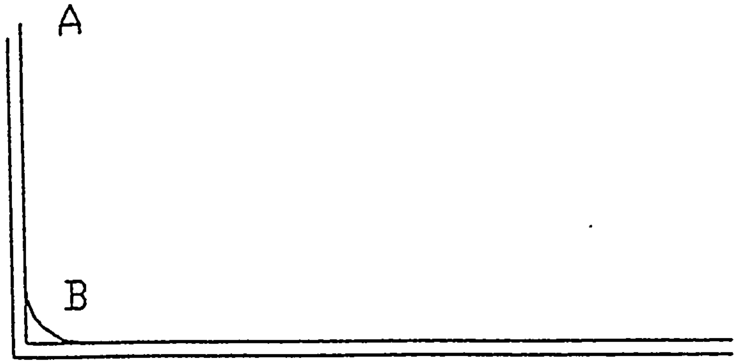


Figure 3. Schematic showing Tefzel delamination at the rolled corner of the metal roofing module.

Qualification Testing

Three foot prototype modules have been used for qualification. The results are summarized below:

- Initial (50 cycle) thermal cycling: All modules pass.

- Thermal (150 cycles) cycling: Modules pass subsequent Electrical, Surface Cut Susceptibility, Wet Insulation Resistance, and Electrical Hi-Pot testing. We did observe a cosmetic problem, however: the top Tefzel layer tends to de-laminate at the comers where the modules are bent 90', as shown in Fig. 3. Although this problem does not affect the module electrical performance (it merely moves the "edge" a little closer to the cells),modules with several improvements are being tested. These improvements include: (1) the use of non-oriented Tefzel (which will not shrink at high temperatures); ending the Tefzel ;layer before the bend; and using improved curing and preparation techniques (such as EVA directly extruded onto the Tefzel to avoid any dirt or grease contamination).

- Humidity Freeze: initial humidity-freeze per the SERI IQT standards (85°C, 85% RH, 4 hrs) tests showed small amounts of micro-delamination on the surface of the modules. As a result, the lamination procedure was changed. Subsequently new modules were tested, but using the more rigorous IEEE test (90°C, 85% RH, 20 hrs); these modules showed none of the micro-delamination observed on the previous tests; there was, however, severe delamination of the metal roofing paint (Hylar/Kynar) from the metal roofing. It was found that the manufacturer (ATAS) had delivered galvanized, rather than Galvalume, metal roofing material to us. The zinc on the galvanized steel oxidizes, forming a layer of loose white powder between the steel backing and paint, upon which the solar cells are laminated. We are now cycling new modules fabricated on Galvalume metal roofing to confirm that this problem was entirely due to the galvanized metal roofing.

Preliminary Product Specification

As mentioned in the NAHB report which follows, the metal roofing modules are being custom-designed for the NAHB Townhouse. An example of a possible more general product line is summarized in Table II and shown in Fig. 4 where 4 module lengths, ranging from 9 to 21 ft, each with > 4.3 ft of extra material on the end which can be cut off in the field, can be used for any roof span from 5 ft to 21 ft. It is not clear, however, that we could stock such modules due to the large number of available colors. We are investigating the aesthetics of having standard modules on a neutral color such as black, rocky gray, or slate gray (the latter two are very popular choices in the residential market). These colors may blend well with other colored roofs.

Table II: Specifications for possible standard metal roofing modules

Module	Length [ft/mm]	Weight [lb/kg]	Power [W]	V_{MaxPwr} [V]	I_{MaxPwr} [A]	V_{OC} [V]	I_{SC} [A]
AM - 8	9/2.8	16/7	39	14.2	4.2	18.6	5.2
AM - 12	13/4	24/11	79	14.2	5.5	18.6	6.9
AM - 16	17/5.2	32/14	118	28.5	4.2	37	5.2
AM - 20	21/6.4	39/18	158	28.5	5.5	37	6.9

The modules use only two types of cells:

- 12 in long x 12 3/4 in wide cell for the 21 ft and 13 ft foot modules, and
- 9 in long x 12 1/4 in wide cell for the 17 ft and 9 ft modules

Each module has either 16 (AM-20 and AM- 1 6), or 8 (AM- 1 2 and AM-8) cells; two of the longer modules, and four of the shorter modules are connected in series for charging a 48 V system, which seems to be a good compromise between low voltages and small conductors.

These modules are shown in Fig. 4.

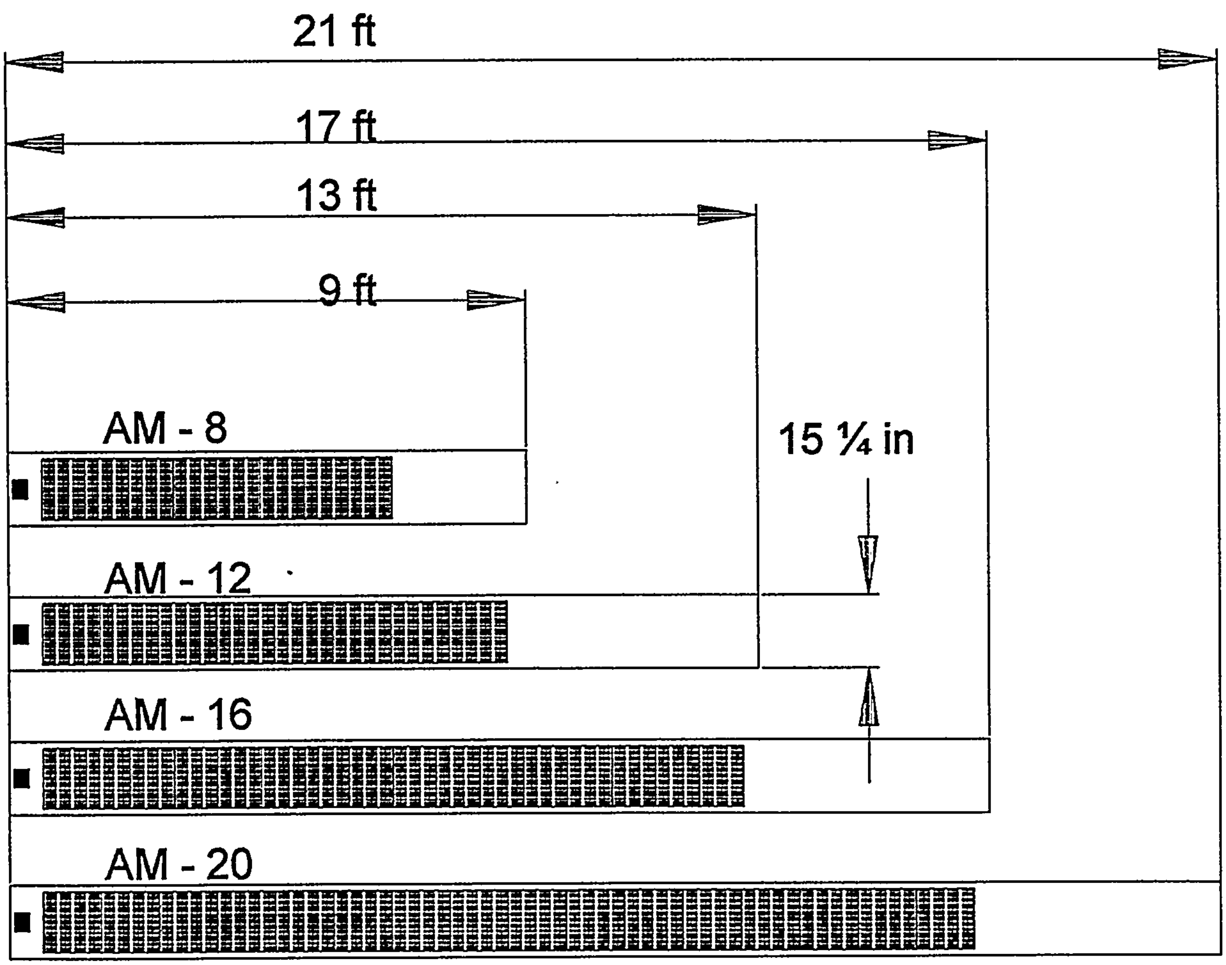


Figure 4. ECD - Galvalume PV metal roofing modules

Manufacturing Diagram

The following five pages summarize ECD 's Conceptual Design of a 100 MW Manufacturing Plant for producing long metal roofing modules. These modules can be used in rooftop or longer array applications.

100 MEGAWATT CONTINUOUS ROLL-TO-ROLL a-Si PV MANUFACTURING PLANT

A CONCEPT DESIGN SUMMARY

PRODUCTS: LARGE AREA, FLEXIBLE, FRAMELESS, PV MODULES
24 FT X 1.5 FT MODULES -- FOR ROOFTOP OR SOLAR FARM APPLICATION

PRODUCTION EQUIPMENT:

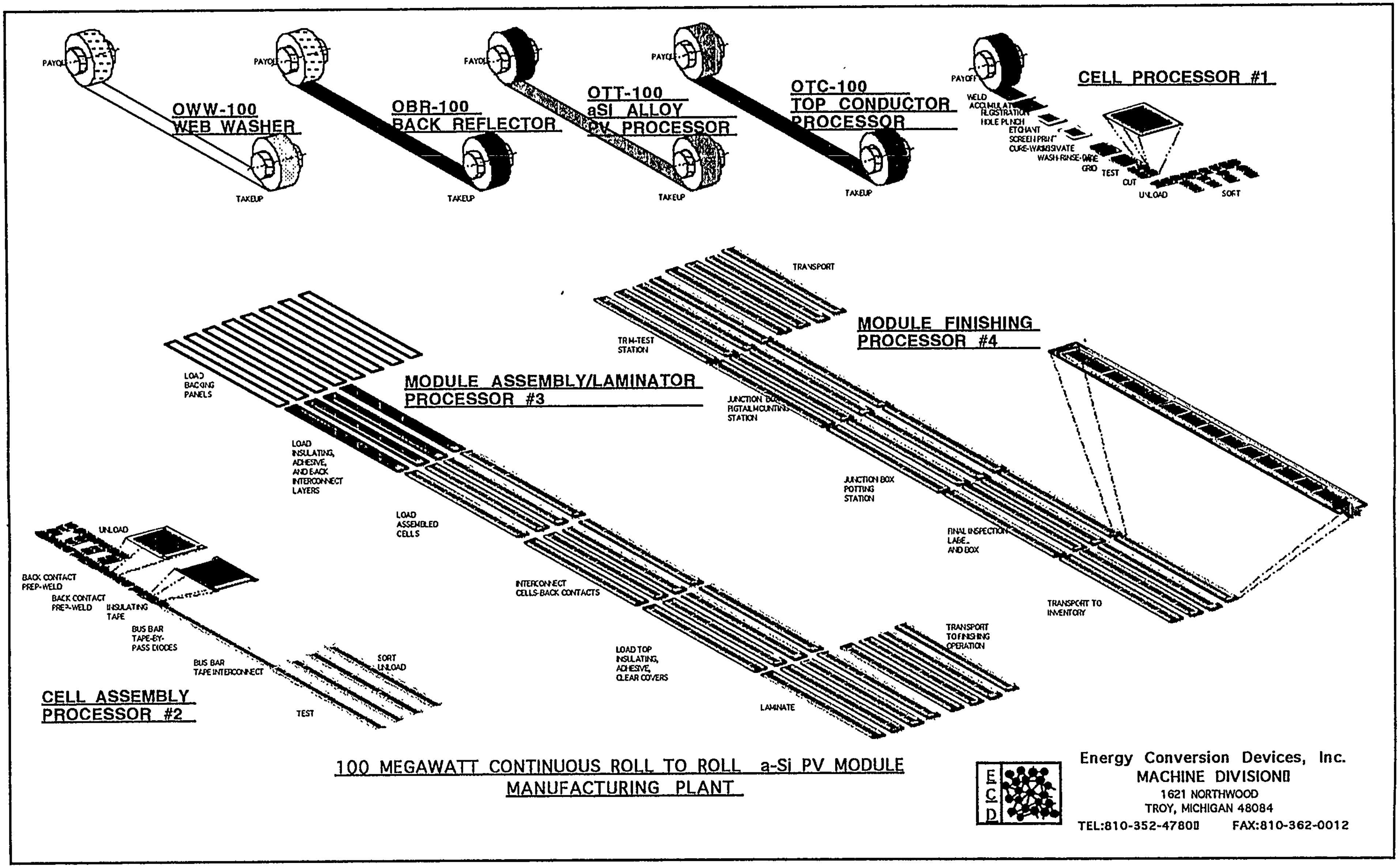
- DEPOSITION: CONTINUOUS ROLL-TO-ROLL DEPOSITION PROCESSORS -- WEB WASHER, BACK REFLECTOR PROCESSOR, a-Si ALLOY PROCESSOR, TOP CONDUCTOR PROCESSOR; 3 FT WIDE SUBSTRATE AT 15 FT/MIN LINE SPEED

- MODULE ASSEMBLY: CELL PROCESSOR #1, CELL ASSEMBLY PROCESSOR #2, MODULE ASSEMBLY LAMINATOR PROCESSOR #3, AND FINISH ASSEMBLY PROCESSOR #4

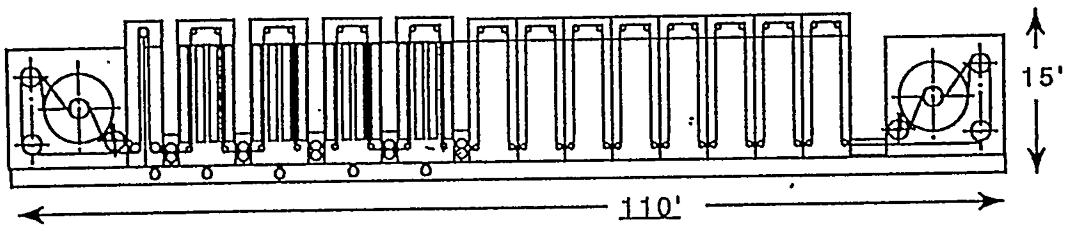
CAPITAL EQUIPMENT COST: APPROX. $60,000,000

FLOOR SPACE: APPROX. 150,000 SQ. FT.

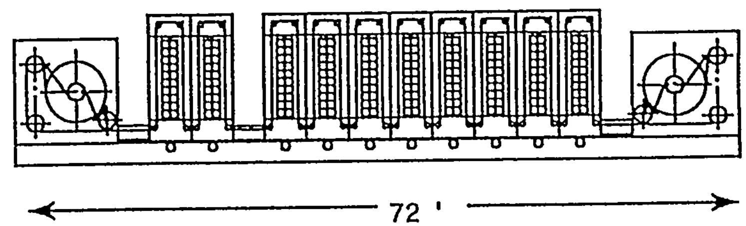
MANUFACTURING COST OF PV MODULES: LESS THAN $1.00/WATT


OWW-100
WEB WASHER
OBR-100
BACK REFLECTOR
OTT-100
aSI ALLOY
PV PROCESSOR
OTC-100
TOP CONDUCTOR
PROCESSOR
CELL PROCESSOR #1
PAYOFF
TAKEUP
WELD
HOLE PUNCH
ETCHANT
SCREEN PRINT
TEST
CUT
UNLOAD
SORT
GRID
TRANSPORT
MODULE FINISHING
PROCESSOR #4
TRIM-TEST
STATION
MODULE ASSEMBLY/LAMINATOR
PROCESSOR #3
LOAD
BACKING
PANELS
LOAD
INSULATING,
ADHESIVE,
AND BACK
INTERCONNECT
LAYERS
LOAD
ASSEMBLED
CELLS
JUNCTION BOX
POTTING
STATION
FINAL INSPECTION
AND BOX
INTERCONNECT
CELLS-BACK CONTACTS
TRANSPORT TO
INVENTORY
UNLOAD
BACK CONTACT
PREP-WELD
BACK CONTACT
PREP-WELD
INSULATING
TAPE
BUS BAR
TAPE-BY-
PASS DIODES
BUS BAR
TAPE INTERCONNECT
SORT
UNLOAD
TRANSPORT
TO FINISHING
OPERATION
LOAD TOP
INSULATING,
ADHESIVE,
CLEAR COVERS
CELL ASSEMBLY
PROCESSOR #2
TEST
LAMINATE
100 MEGAWATT CONTINUOUS ROLL TO ROLL a-Si PV MODULE
MANUFACTURING PLANT
E
C
D
Energy Conversion Devices, Inc.
MACHINE DIVISION
1621 NORTHWOOD
TROY, MICHIGAN 48084
TEL:810-352-4780
FAX:810-362-0012

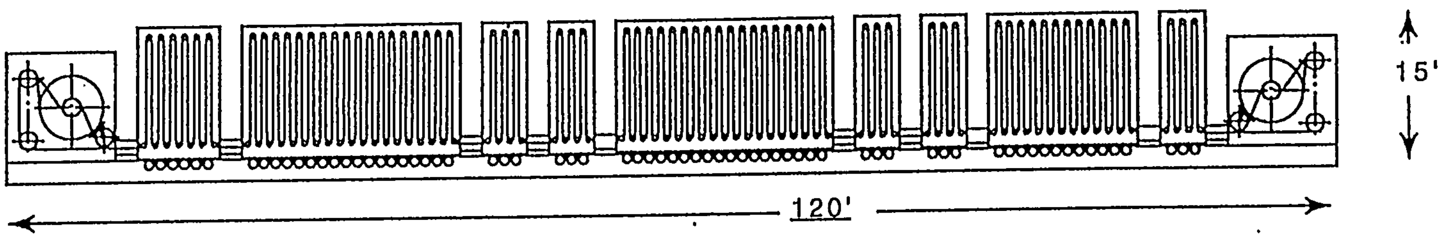
OVONIC PV CELL DEPOSITION OPERATION



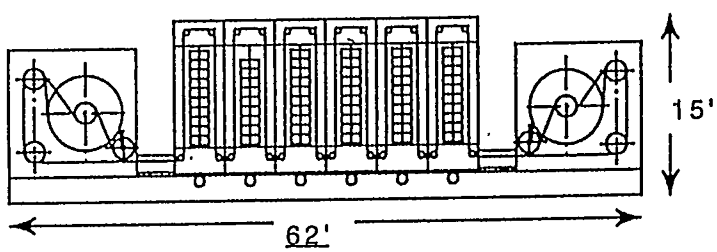
OVONIC WEB WASHER
MODEL OWW100



OVONIC BACK REFLECTOR SPUTTERING PROCESSOR
MODEL OBR100



OVONIC MULTI SPECTRUM AMORPHOUS ALLOY PLASMA PROCESSOR
MODEL OTT-100



OVONIC TRANSPARENT CONDUCTOR SPUTTERING PROCESSOR
MODEL OTC 100

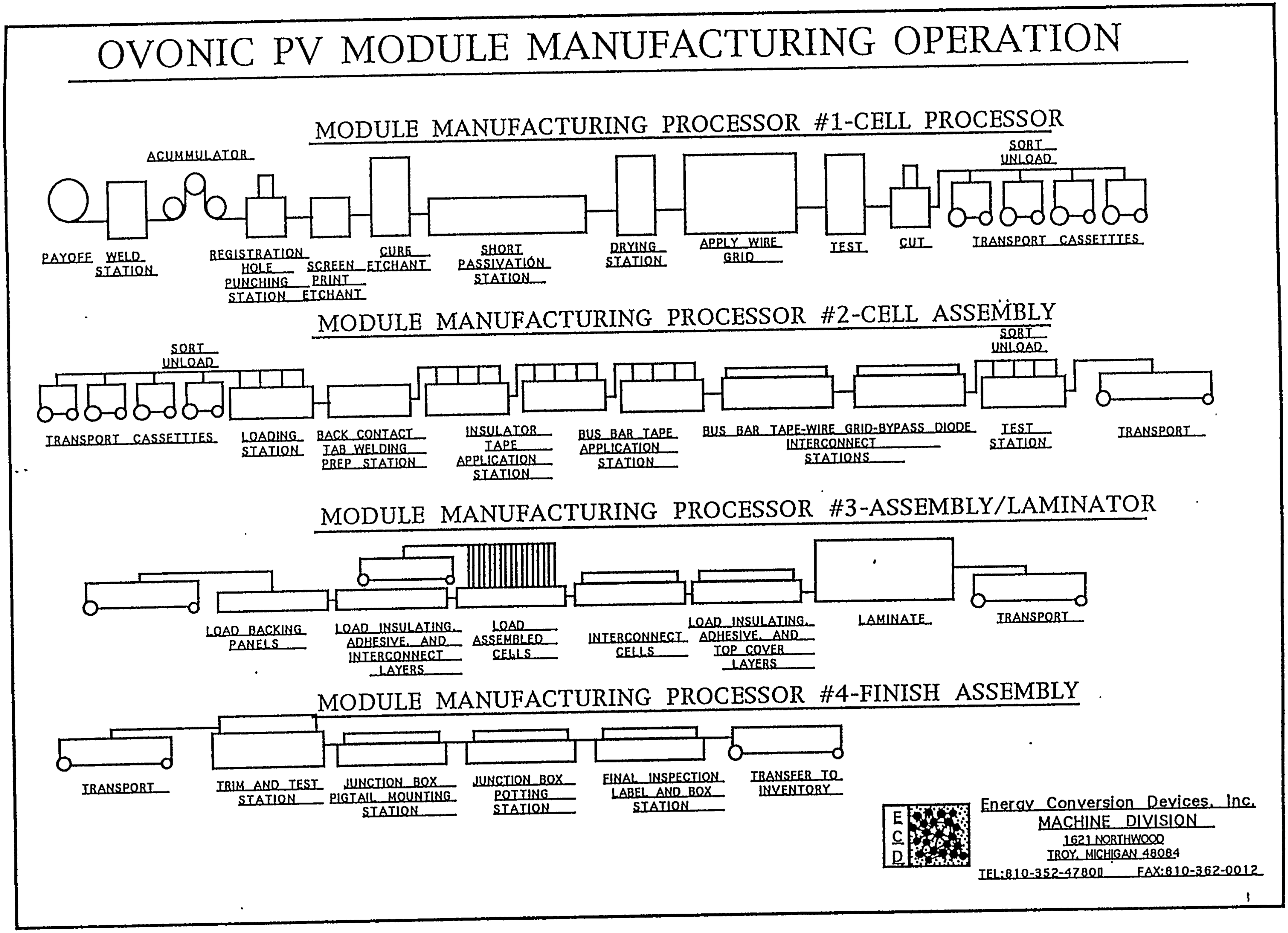
E C D

Energy Conversion Devices, Inc.
MACHINE DIVISION

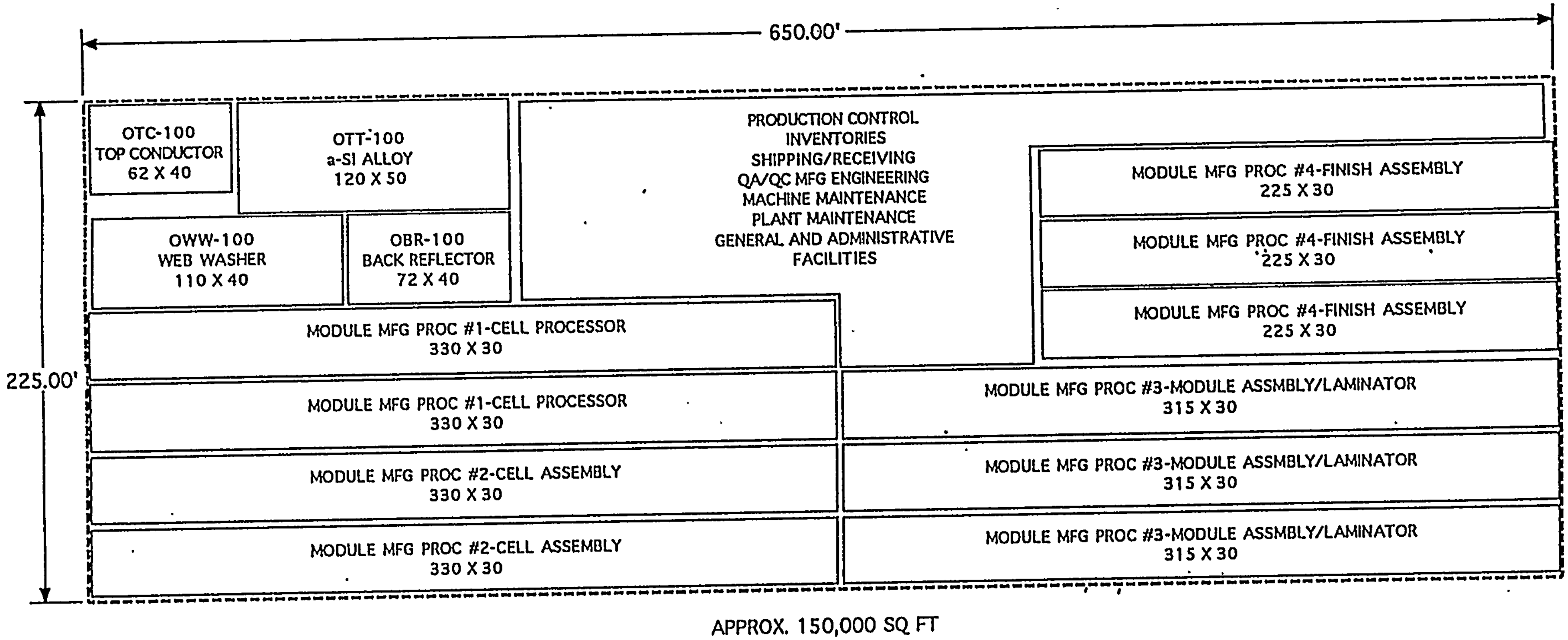
1621 NORTHWOOD
TROY, MICHIGAN 48084

TEL:810-352-4780 FAX:810-362-0012

HCO 5-16-95


OVONIC PV MODULE MANUFACTURING OPERATION
MODULE MANUFACTURING PROCESSOR #1-CELL PROCESSOR
PAYOFF
WELD STATION
ACUMMULATOR
REGISTRATION HOLE PUNCHING STATION
SCREEN PRINT ETCHANT
CURE ETCHANT
SHORT PASSIVATION STATION
DRYING STATION
APPLY WIRE GRID
TEST
CUT
SORT UNLOAD
TRANSPORT CASSETTES
MODULE MANUFACTURING PROCESSOR #2-CELL ASSEMBLY
SORT UNLOAD
TRANSPORT CASSETTES
LOADING STATION
BACK CONTACT TAB WELDING PREP STATION
INSULATOR TAPE APPLICATION STATION
BUS BAR TAPE APPLICATION STATION
BUS BAR TAPE-WIRE GRID-BYPASS DIODE INTERCONNECT STATIONS
SORT UNLOAD
TEST STATION
TRANSPORT
MODULE MANUFACTURING PROCESSOR #3-ASSEMBLY/LAMINATOR
LOAD BACKING PANELS
LOAD INSULATING, ADHESIVE, AND INTERCONNECT LAYERS
LOAD ASSEMBLED CELLS
INTERCONNECT CELLS
LOAD INSULATING, ADHESIVE, AND TOP COVER LAYERS
LAMINATE
TRANSPORT
MODULE MANUFACTURING PROCESSOR #4-FINISH ASSEMBLY
TRANSPORT
TRIM AND TEST STATION
JUNCTION BOX PIGTAIL MOUNTING STATION
JUNCTION BOX POTTING STATION
FINAL INSPECTION LABEL AND BOX STATION
TRANSFER TO INVENTORY
ECD
Energy Conversion Devices, Inc.
MACHINE DIVISION
1621 NORTHWOOD
TROY, MICHIGAN 48084
TEL:810-352-47800 FAX:810-362-0012

HCO 5-16-95



OVONIC 100 MW PV MANUFACTURING PLANT
IDEALIZED FLOOR PLAN

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NAHB FINAL REPORT:

PHOTOVOLTAIC-METAL ROOFING PRODUCT DEVELOPMENT

PHOTOVOLTAIC-METAL ROOFING PRODUCT DEVELOPMENT

The PV-Metal Roofing Module is designed, fabricated and tested as a dual purpose building material which combines the functions of a roof covering with that of electrical power generation. The roof covering is a durable standing seam metal roof; the power generator is a renewable, solar energy device which directly converts sunlight to dc electricity.

Initial Photovoltaic Roofing Product Concept

As originally conceived, the innovation of the building integrated PV-roofing module resides in the PV module's dual function as a building material (roof covering) and as an electrical power generation device. This module concept sought to optimize the union between a traditional PV module and traditional roofing products. Some module features which were planned for further development included:

- the use of inexpensive backing (substrate) materials,
- the elimination of rigid framing,
- simplified installation requirements,
- minimal and uncomplicated sealing techniques,
- increased flexibility, and
- handling durability.

The PV-roofing product which emerged from this analysis can be described as a large area module, approximately 40 square feet, attached directly to the roof sheathing by means of an adhesive and/or a low profile batten strip. The module would have an electrical cable attached which would penetrate the sheathing into the attic or rafter space.

In this module concept, various building construction issues surfaced which were pertinent to the module function:

- The necessity to incorporate wind uplift resistance especially if adhesives were to be exploited as the primary means of fastening.
- The proper application of adhesive coatings.
- The differences in expansion coefficients for the PV and batten materials.
- The aesthetics of a large, smooth, unbroken surface on a slopped roof installed adjacent to other traditional roofing materials.
- An initial concern over wire penetrations through the roof sheathing. This concern was alleviated with the use of a weather barrier which provides excellent sealing capability.

Product Concept Modifications

In conjunction with the experience provided by the building industry, a strong advantage was viewed in either imitating or modifying an existing roofing product to advance the PV-roofing product concept. The benefits of this approach reside in the PV-roofing product capability to function easily as a roofing product while adding value as a renewable, electrical power production device. As an important critique, one of the greatest values lies in refining an existing product, is the ready acceptance of the PV module as a roofing product. By comparing the initial PV-roofing concept with existing roofing products, standing seam metal roofing appeared to exhibit an excellent match to the PV module requirements. Further product development continued along the path of developing a PV-metal roofing module.

Product Developments

Initial efforts to develop the PV-metal roofing module concentrated on the selection of the most advantageous metal panels, the lamination of the PV cells to the metal roofing panels, and electrical specifications for the PV-metal roofing modules. In this effort, particular attention was paid to product requirements specific to fielding the PV-metal roofing product in one of the townhouse units under construction by the Research Center (figure 1).

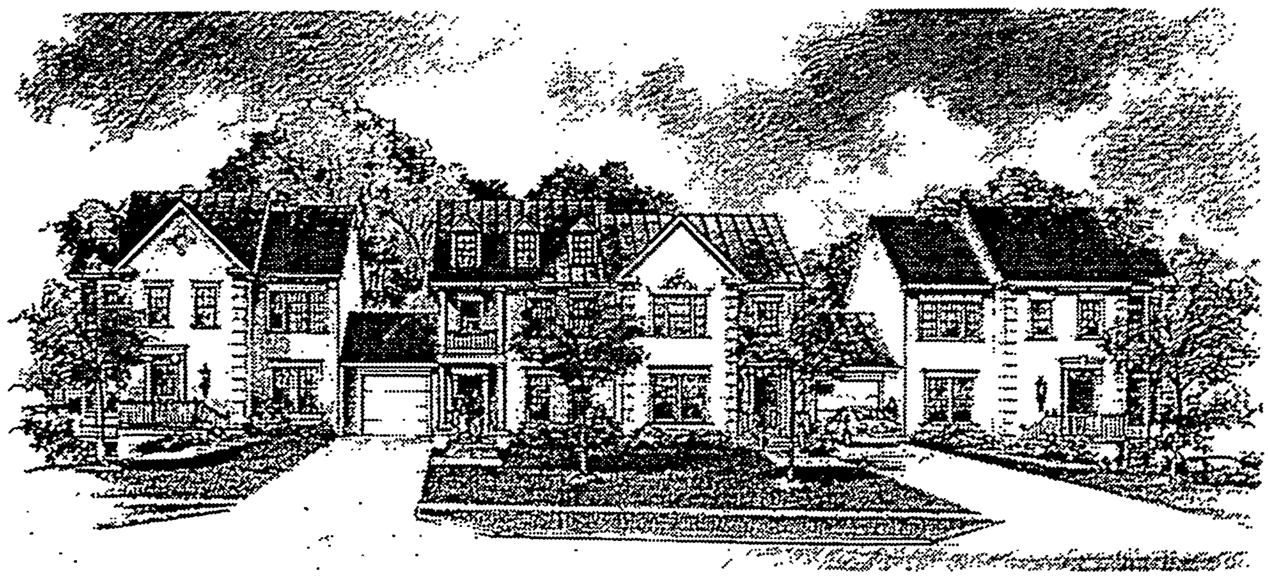

Figure 1
Rendering of Townhouses

The PV-metal roofing module was developed to meet the specific physical requirements of the townhouse roof profile. In this respect, the product is customized for one particular application. In contrast to current PV module designs that generally match rectangular module sizes to conform to the PV cell size, the PV-metal roofing module concept configures the PV cell size to conform to the selected metal roofing panel.

Focusing product development relative to a specific installation was an acceptable path since the lamination and construction of a PV-metal roofing module for the townhouse units would push the limits of module lamination currently available in the industry. Acquiring the expertise to construct long modules would serve further product development in most directions that might be considered (figure 2).

Final product specifications will develop as experience is gained with this first custom installation. In the long run, a standard product or set of products has production benefits as compared to custom designs for each application. Lessons learned in this custom application will be an important proving ground for further design modifications necessary for optimal PV-metal roof module commercialization.

Figure 2
Product Development Flow Chart

PV-Metal Roofing Module Dimension Considerations

The metal roofing panels must conform to the available roof structure of the townhouse application. The overall length of the roofing panels is dependent on the roof shape including the overhang length and configuration, the ridge venting system, and any breaks in the linear flow of the roof such as dormers or hip sections. Currently, the panels of most standing seam metal roofing systems are customized to fit a particular roof shape. The only metal roofing panel feature that can be selected apart from the installation requirements is the width of the panel.

In converting metal roofing panels to PV-metal roofing panels, PV cells are placed on the metal roof panels. To take the greatest advantage of the available surface area for the PV cells, and since the PV cells are activated by sunlight, shading effects of the seam must be minimized while maximizing the available PV area of the panel. As a result, the size of the PV active area is dependent on the length and width of the panel available for PV cells. Attention must also be paid to factors such as the spacing between the cells, location of the electrical bus, and the location of the power connector (figure 3).

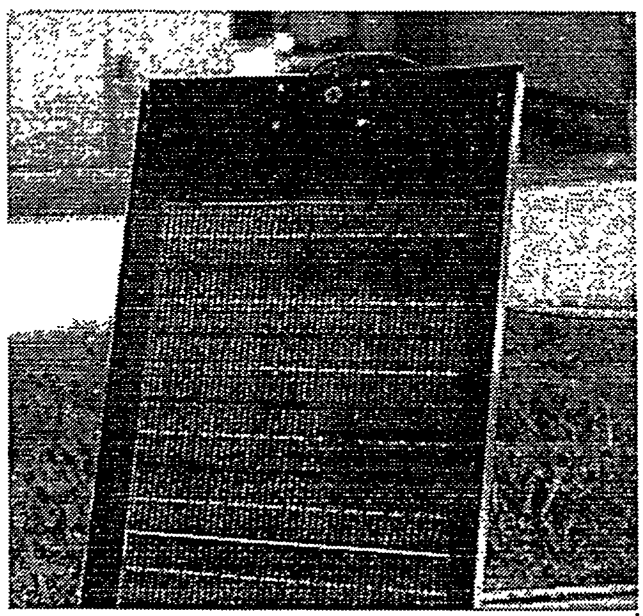

Figure 3
PV Cells Laminated to Metal Roofing Panel

Working from the architects' drawings for the townhouse roof size, the length of the original PV cell active area was designed by ECD to be 211 inches (17 feet 7 inches). The length of the middle section of roof, from the peak to the eave as designed by the architect, is about 19 feet, a sufficient length for the PV active area including space for the ridge and eave transitions. The distance from the top edge of the PV cells to the top edge of the roofing panel was designed to be 5". This 5" inactive area must accommodate the electrical connector and the ridge vent details discussed later.

The left section of roofing (figure 4) is constructed with a different truss design from the middle section. The left section has a shorter bottom cord than that of the middle section while the slope, 8:12 (≈ 34°), remains the same. Consequently, the left section of roofing will be shorter than the middle section by about 10 inches. Since the overall length for the panels is different for each section, the PV-metal roofing panel could either be adapted for the specific length of roof or a "standard" length could be produced that will fit both sections. The latter option was selected.

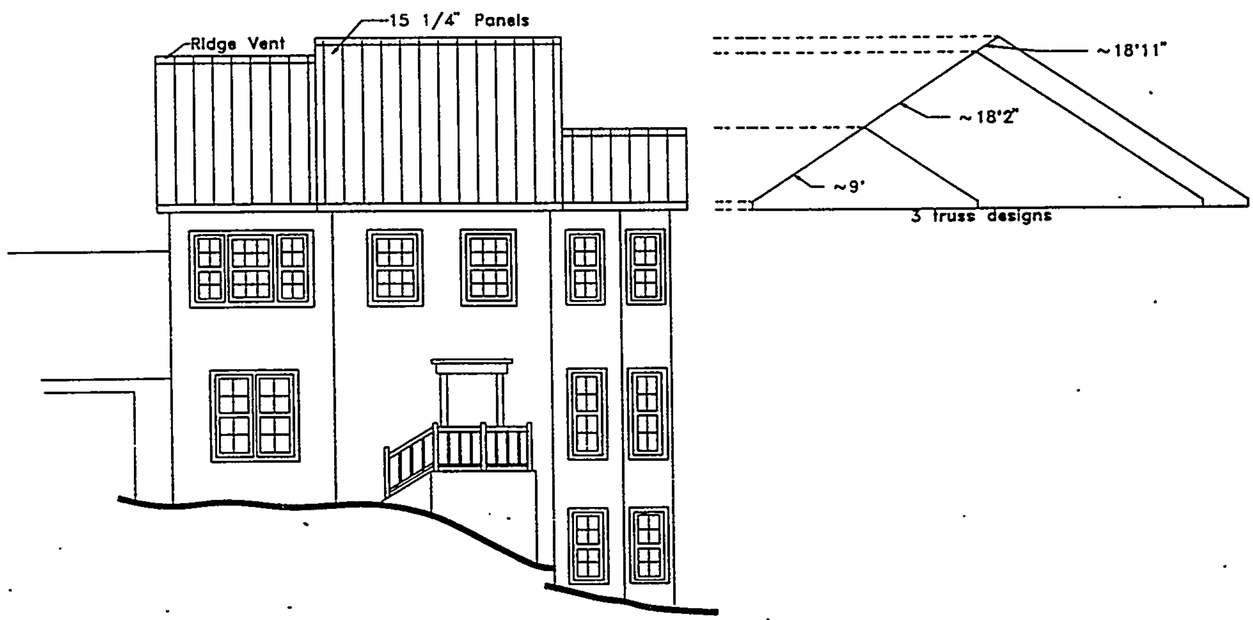

Figure 4
Townhouse Roof Profile

The ridge construction is also important to the module design. The detail shown in Figure 5 is typical of residential ridge venting for standing seam metal roofing except for the ridge width, which is available in different sizes. The sheathing is cut back about 1 inch from the peak to create the vent area. The metal roofing panel will be placed even with the sheathing edge. A louvered "Z" strip is cut to fit within the panel and fastened through the metal panel to the sheathing. The ridge cap sits above the roofing by about 1 1/2 inches. The base of the "Z" strip which attaches to the roofing panel, is about 1 inch, and the louvered edge of the "Z" strip is about 2 1/4". The exact location of the "Z" strip is dependent on the distance the roofing panel is installed down from the peak. The placement of the "Z" strip is typically decided at the time of the field installation. The module design will be required to be flexible enough to accommodate changing field conditions including the actual vent opening, the actual distance of the top edge of the panel to the sheathing edge and the actual width of the ridge vent.

The distance between the "Z" strip and the top edge of the roofing panel is important since the connection for the electrical cables will most likely be made in this area. The type of connector and its attachment to the PV-metal roofing module must be selected to ensure its integrity both during installation and in operation.

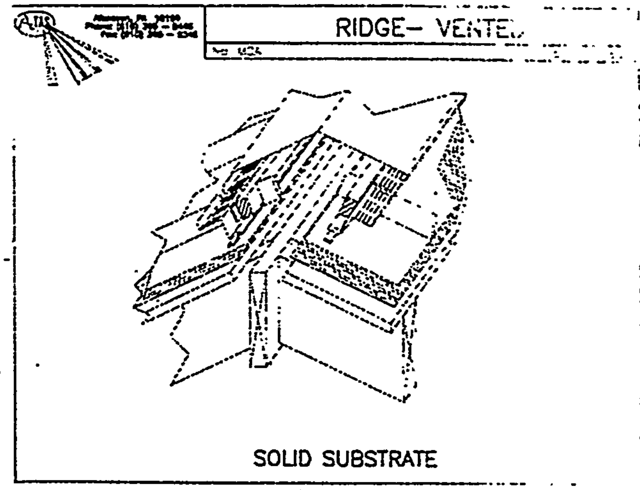

Figure 5
Ridge Vent Detail

PV-Metal Roofing Module - Forming the Metal Panel

An innovative feature of the PV-metal roofing module is its ability to function mechanically similar to standing seam metal roofing. Many standing seam metal roofs are designed without horizontal seams from the peak to the eave. The lack of horizontal seams is beneficial for both the appearance and long term water resistance performance. The vertical edges of long metal roofing panels however, cannot be formed using a break form machine. Rather, roll form machines are used to form the long metal roofing panels to the appropriate seam profile. The PV-metal roofing module will use a 90° bend in the edge of the panel to produce a 5/8" high butt edge between roofing panels. Use of the roll form process permits the roofing material to be processed in various lengths with great speed. The PV-metal roofing module will also benefit from the roll forming process, but applying this process to a laminated module needs to be evaluated for potential design issues.

Four PV-metal roofing samples, each 3 feet long with 2 cells laminated in the center were produced by ECD. The cells were approximately 12 inches wide leaving about 2.25 inches on each side of a cell to the edge of the panel. An electrical bus was installed next to the cells to carry the electrical current and for placement of bypass diodes. The cells and bus were laminated leaving an edge of approximately 1-3/4 inches available for forming.

The PV-metal roofing samples were taken to the ATAS Aluminum manufacturing plant for test on their roll form machine. Following a test form of a sample, adjustments were made to the machine rollers for height, and to some extent, the bevel of the rollers. As a result of the test formings, potential modifications to the PV-metal roofing module design were suggested in the following areas:

- reduce the lamination thickness from the edge of the cell to the edge of the panel
- reduce the thickness of the bypass diodes
- relocate the electrical bus and diodes to the center back of the PV cells
- modify the lamination material at edges of the panel

Changes to the roll form machine were also suggested as a result of the test formings:

- modify the width of the machine rollers, possibly using a tapered edge
- consider aligning the machine rollers with a slight bevel to accommodate the lamination thickness

Any of these areas may be modified to produce a module that can be subjected to the roll form process while preserving the integrity of the module construction.

A combination of the suggested modifications were selected and another set of 3 foot sample modules were constructed. The primary mechanical features of the new samples included a tapered lamination from the edge of the cell to the edge of the panel, use of flat diodes, and placement of the diodes and bus in the center rear of the cells. The roll form machine roller units were also modified to include a bevel edge. The alignment of the roller would remain in a standard parallel configuration with the panel surface.

The new test samples were formed using the new rollers. A combination of using a thinner laminate at the edge, the tapered rollers produced excellent results. The edge was formed to within 95% of a 90° bend and no crushing or discoloration of the laminate material was evident. As a result of these tests there was sufficient confidence that this roll form process could be applied to long PV-metal roofing modules.

PV-Metal Roofing Module Electrical Considerations

Specific electrical characteristics of a photovoltaic module are dependent on the cell characteristics and the cell interconnection configuration. Some of the preliminary cell and module characteristics for the PV-metal roofing module are listed in Table 1.

Table 1
Preliminary PV Cell and Module Specifications

Nominal System Power Output	2000	watts
Nominal Module Voltage	24.0	volts
Cell MPP* Voltage (Vc,mp)	1.7	volts
Cell MPP Current (Ic,mp)	4.68	amps
Cell Open Circuit Voltage (Vc,oc)	2.33	volts
Cell Short Circuit Current (Ic,sc)	5.98	amps
Cell Length (1.03 feet)	0.315	meters
Cell Width (1.03 feet)	0.315	meters
Cell Area (1.07 ft^2)	0.10	square meter
Number of Series PV Cells	17	
Estimated Cell Efficiency	8.0%	
Power Density @ 8.0% (7.43 watts/ft^2)	80.00	watts/m^2
Module Active Area (18.16 ft^2)	1.69	square meter
Module Maximum Power (Vm,mp)	135	watts
Module MPP Current (Im,mp)	4.68	amps
Module MPP Voltage (Vm,mp)	28.9	volts
Module Short Circuit Current (Im,sc)	5.98	amps
Module Open Circuit Voltage (Vm,oc)	39.61	volts
Number of Modules	18	
Maximum Array Power Output	2429	watts
* Maximum Power Point		

The module voltage output at the maximum power point, 28.9 volts dc (Vdc), is designed to be sufficient to account for changing climatic conditions and a limited voltage drop due to internal module losses and in the wiring from the PV module to the utilization equipment. A nominal 24 Vdc module voltage is selected to accommodate different system options for application of the modules except for 12 Vdc and odd increments of 12 Vdc systems. Given the style of module and its application to larger roof surfaces, it appears prudent to optimize the module voltage to a level which can both satisfy different system configurations while limiting the internal module components, sized for the current level, to a manageable size. The nominal 24 volt output can be configured to operate systems at 48, 72, 96, 120 .... 240 volts dc or higher by series connection of the modules. Other combinations of 12 volt increments such as 36, 60, 108 etc. are much less common in practice and would be available through dc-dc conversion only.

There exists a growing body of equipment which function at 24 Vdc primarily for use in remote homes which may or may not be connected to utility grid power. Use of 12 Vdc has traditionally been common in the recreational vehicle and marine markets and has moved to the residential market by default. However, there is a growing market for the 24 - 48 Vdc equipment due to the component savings as a result of reduced current levels. For example, one very common inverter for use in both stand alone and utility interactive systems has only 24 and 48 Vdc input options available. Operation of the PV-metal roofing module at a nominal 24 Vdc can serve the most common system configurations while optimizing the component sizes within the module itself.

Another aspect of the module electrical design is the termination of the module bus conductors into a suitable harness or connector. The use of a wiring harness is considered since in this module design, the top of the module will end at the ridge of the building. Provided that the roof design includes a ridge vent system, the module harness can be placed through the ridge vent opening by the installer without the need to make any electrical connections.

If a connector is used, the connector must be placed at the top of the module, however, with the use of the "Z" strip described above, the connector must be placed to accommodate the width of the "Z" strip. The "Z" strip is placed to accommodate the ridge cap. Also, the use of a connector may require the electrical installer to access the connector from atop the roof with the ridge vent cover removed. The coordination of the mechanical installation of the module with the electrical installation may be difficult to achieve in this regard. If however, the connector is placed so that it faces out the rear of the module unit, the installation may not require this level of coordination between the trades. The roofing installer will however be required to make allowance for the connector in the installation of the PV-metal roofing panels.

The selection of the cable to be used for the harness configuration is based on the ambient conditions in which the cable will function. The PV-metal roofing module is installed in a manner that is generally classified as a direct mount system. This mounting method may be considered a damp location, implying that the wiring must be suitable for use in damp locations. Different cable types can be applied in these ambient conditions. Two common types are a THWN copper cable which is a thermoplastic insulation and can be constructed with 19 strands for flexibility. Another cable type is a parathene-XL USE type cable also with 19 strands but with a Rubber thermoset insulation. The XL type cable was suggested by one manufacturer as the more applicable cable type.

PV-Metal Roofing Module Aesthetic Considerations

In addition to performing mechanical tests on the samples, the Research Center evaluated some of the potential aesthetic issues. The PV cells were laminated to standard painted metal roofing materials supplied by two different manufacturers. Two different shades of blue were selected as preliminary color backgrounds. The copper bus adjacent to the cell was covered by black electrical tape in one sample and by blue electrical tape in another. The resulting roofing sample is then a laminate of the PV cell bordered by a 3/4 inches tape strip on a blue roofing panel. portions of the blue panel are visible on the side and top and bottom edges of the PV-metal roofing module.

Due to the inconsistencies in the color of the PV cell, the effect of the laminate in reflecting light, and a limited selection of standard colors from which to choose, the initial effort to blend the PV cells with the painted roofing material was not achievable. ECD agreed to laminate different color samples from which to make a selection.

An aesthetic issue that often surfaces when attempting to select colors to border the PV cells in a residential roof is whether it is preferable to blend, or to contrast, the PV cells with the background color. Color choices are typically not germane to most PV installations. The PV-metal roofing module, however, uses a host material that offers a range of color choices. The optimum color selection may be different depending on customer experience with various options of the product all of which may help to determine suitable product designs.

Photovoltaic-Metal Roofing Module Design Specifications

The final product design, though not greatly altered from original concepts has adapted to various requirements related to the field installation. The final shape of the PV-metal roof module is dependent on the metal roof panel product manufactured by ATAS Aluminum, though the PV cell lamination portion is determined by the PV manufacturer. The length of the metal roof panel is limited by shipping constraints. At this time, the PV cell lamination is limited to about 20 feet.

Metal Roofing System

The PV-metal roofing product is similar to standing seam products. However a batten and clip system is used to join the panels; no mechanical seaming tool is used on-site. The panel width is 15 1/4" and the batten height is 1". The panels are installed with mechanical attachment at only the top of the panel. At all other attachment locations, the panel is free to move slightly. At the eave end, the panel is bent around the sheathing edge.

Metal roof panels are typically made of 24 gauge steel with either a galvanized (G-90) coating or a galvanized-aluminum coating. Through a series of tests performed by ECD, the galvanized-aluminum material was found to be the most appropriate material for the PV-metal roofing modules.

Metal roofing details are available for valleys, rake ends, plumbing stacks, skylights, wall seams etc. The PV-metal roofing modules however must be installed on open areas of roof where the metal panel extends unbroken from the ridge the full length of the PV cell (PV active) area. At this time, the bottom edge of the PV-metal roofing panel must terminate at the eave so that the non-PV active laminate edge can be trimmed to the precise length and folded under the eave detail. As experience is gained, termination in a valley may be acceptable if any (non-PV active) laminate edge that may be cut on site is acceptable. Figure 6 shows the concept of using PV-metal roofing modules with standard metal roofing panels in the townhouse unit.

The PV-metal roofing module consists of the following features:

- a PV-active area up to 20 feet in length,
- a 90° bend seam with a batten cover,
- a weatherproof connector at the top of the panel with conductors attached, and
- use of galvanized-aluminum substrate material finished with a fluoropolymer paint.

Figure 6
Townhouse Diagram with PV-Metal Panels

Two PV-metal roof modules are shown in figure 7. The edges of the module have not been rolled and the connector is not installed.

Electrical Characteristics

The PV-metal roofing module is designed to produce dc current at a nominal 24 volts. The current level is dependent on the size of the active area and the intensity of the sunlight. The anticipated maximum output is rated at 2000 watts. The modules may be wired in series or parallel to supply an energy storage system or an inverter.

The conductors connected to the PV-metal roofing module are rated for outdoor exposure though they must be terminated in a junction box. The modules are equipped with internal bypass

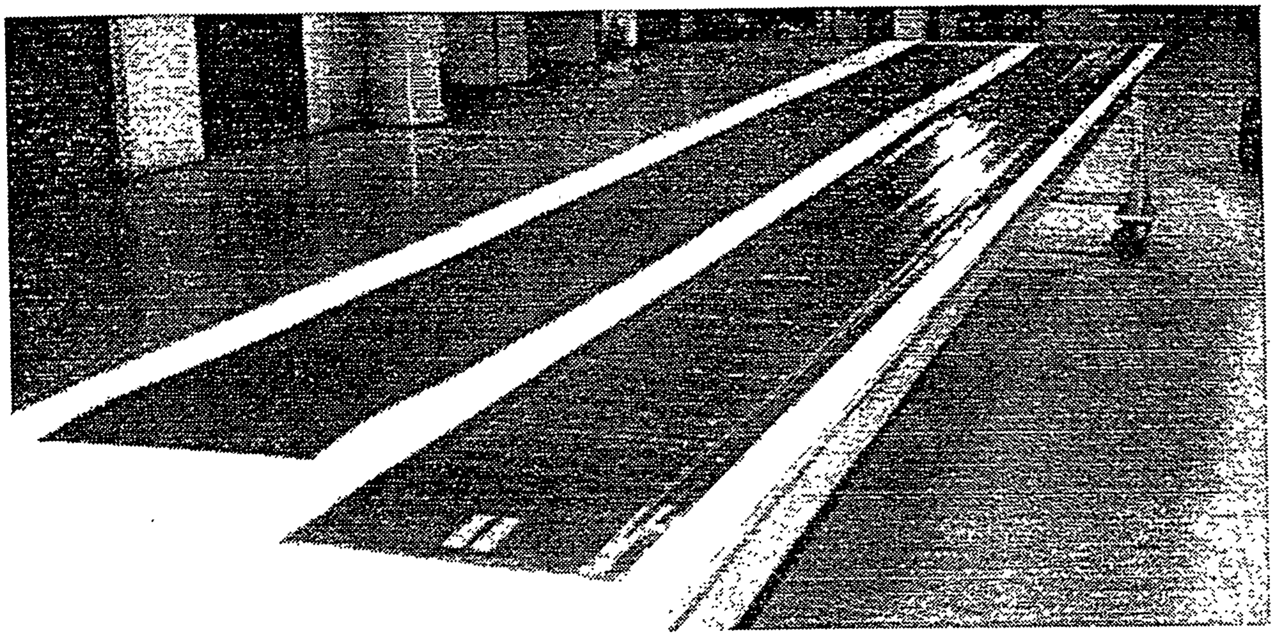

Figure 7
Fabricated PV-Metal Roof Module

diodes. A drawing of the PV electrical system including the balance-of-system components is shown in figures 8 and 9.

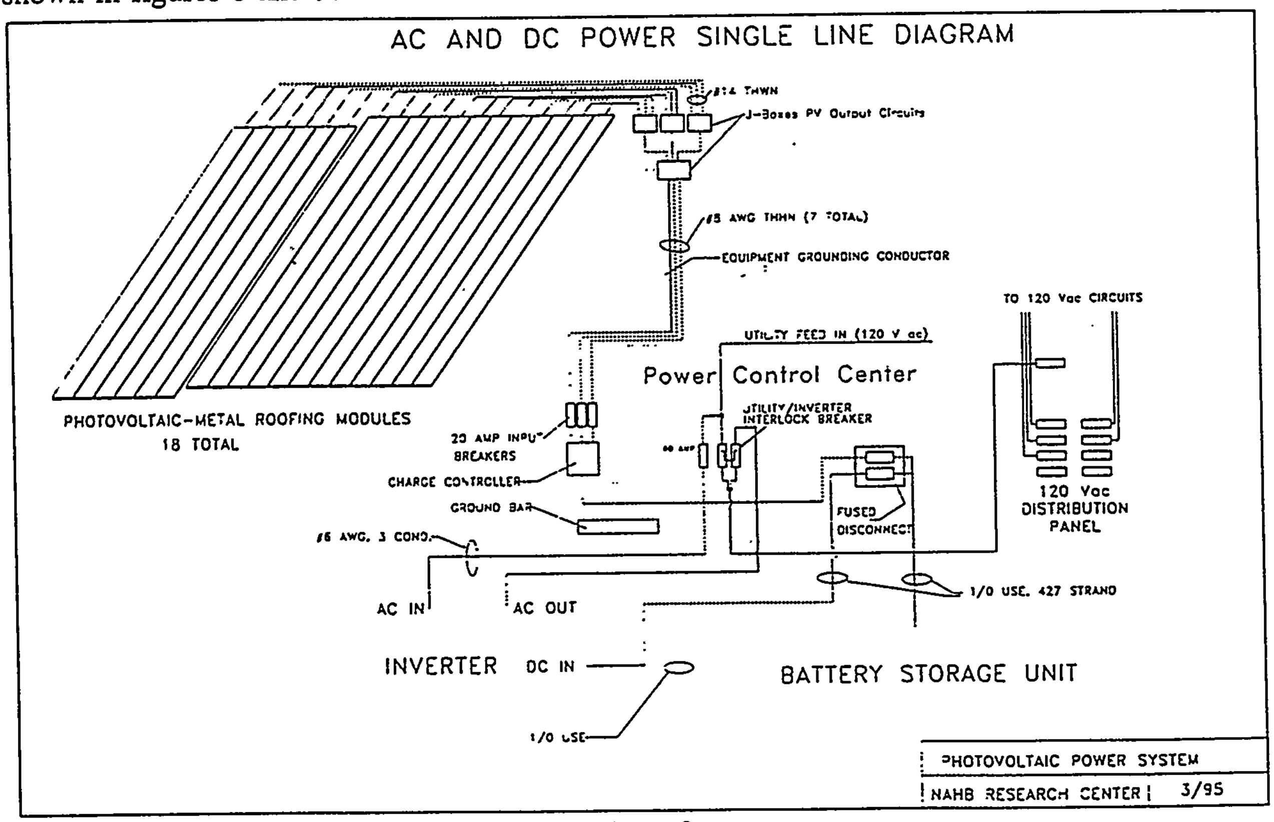

Figure 8
Townhouse PV System Electrical Design

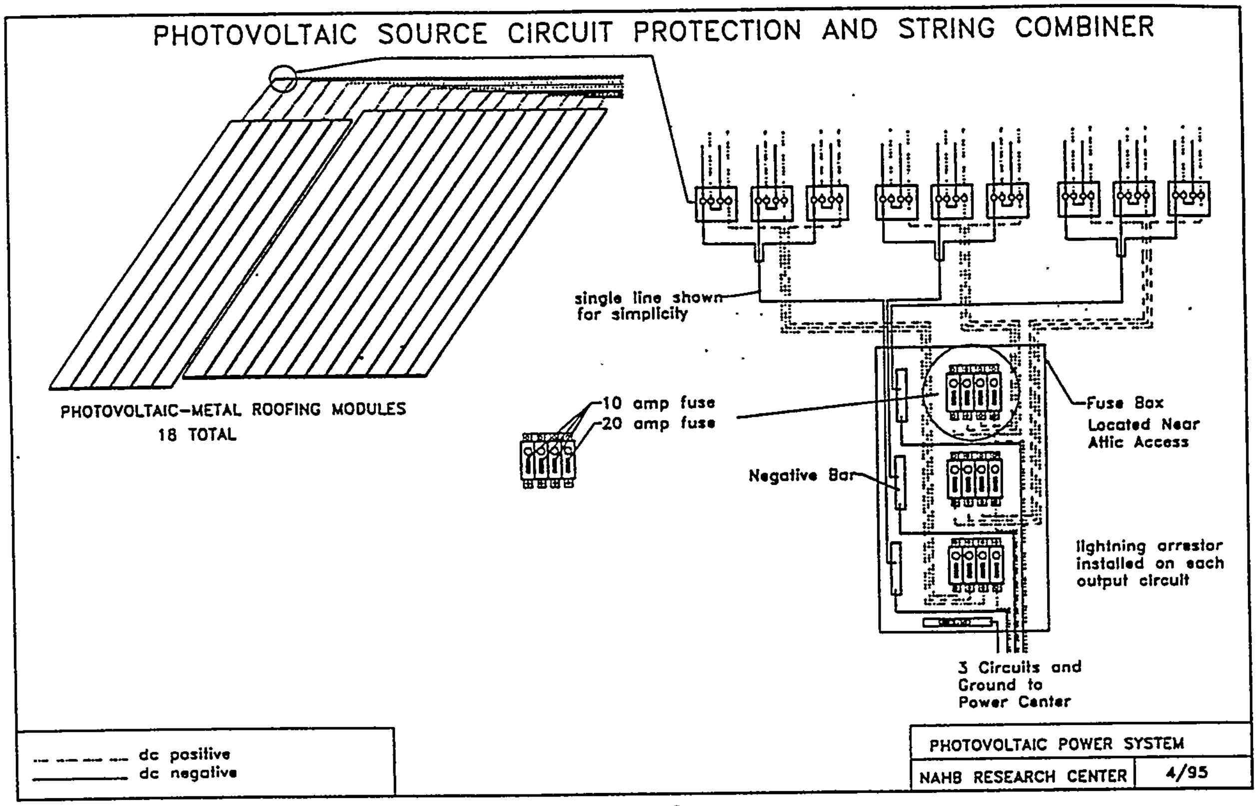

Figure 9
PV System Combiner Enclosure

UNISOLAR'S SHINGLE MODULE

United Solar's Shingle Module

Introduction

United Solar has produced amorphous silicon alloy-based PV material on long rolls of thin stainless steel sheets for several years. Thus, the technology exists that has the inherent attribute of flexibility crucial to a PV roofing shingle concept. In the present effort, we used to our advantage this flexible PV technology in order to develop a shingle roofing module designed to emulate the conventional asphalt shingle in form, structural function, and installation. This module's form is illustrated conceptually in Fig. 1. The module is meant to be used as the roofing material; additional shingles are not required to be underneath. The shingle module can be installed at the same time as a building is roofed with standard asphalt shingles, using similar techniques and achieving aesthetically appealing integration between the PV and asphalt shingles. Thus, the module will become the roofing material, as well as supplying PV power. The installation procedures envisioned for this module have two distinct advantages: (1) a roofer can physically install the PV shingle using essentially identical procedures to that for conventional asphalt (roofing brads), and (2) the electrical interconnection of the PV modules may be performed as a completely independent task, thereby separating trades during installation. The combination of both advantages offer the opportunity of introducing PV into the market without the need to develop a new trade.

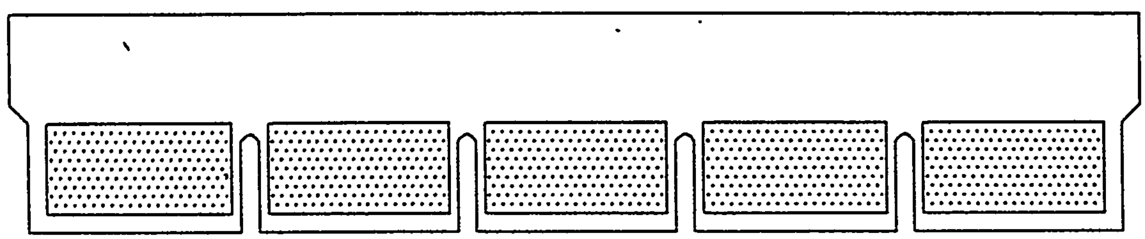

Figure 1 Schematic of shingle module footprint. The shaded area represents the exposed PV.

A shingle roofing module offers considerable economic advantages, as well, when compared to other applications of photovoltaics. This is primarily due to the fact that a mechanical supporting structure is not needed for a shingle module. The structure is present at no additional cost in the form of the existing roof deck. The need for module framing is also negated for the same reason. We report that United Solar's thin, flexible PV material combined with module construction technology developed with PV-BONUS can produce environmentally protected modules without the need for edge protection and/or framing. Further, these modules are suitable for use as roofing materials as well as for generating PV power.

Asphalt Shingle Industry

The asphalt roofing industry produces more than 80% of all residential roofing applied in the United States[1]. Thus, asphalt roofs represent the largest single segment of the country's roofing market. As a result of research and development, asphalt shingles have been designed to meet all fire, weather, and wind resistance standards. Products are available in numerous colors and dimensional depths to complement a variety of architectural styles. There exists a huge infra-structure of installers throughout the U.S.

Module Design Considerations

Module Geometry

In the early months of this program, we designed and constructed several generations of prototype modules. The purpose of these design iterations was two-fold. First, we desired to explore alternate construction techniques in order to settle on the scheme that would be most favorable for manufacturing modules in volume production. Some of the considerations involved will be detailed below. The other motivation for design iteration, and most important, was to determine the module geometry that made the most sense in terms of installation and use. Many sizes and shapes were considered. The most promising were made into prototypes and, in some cases, many prototypes combined into mini-arrays for evaluation. We engaged in a series of focus evaluations, both formal and informal, some internal to United Solar, others among outside experts.

It was determined in the course of these surveys that the primary attribute contributing to the pleasing aesthetics of integrating PV shingles with conventional asphalt shingles was the concurrent lines of "shadow symmetry". Shadow symmetries of asphalt shingles are created in the horizontal direction by the ridges formed by the overlapping shingles. These are also seen in the vertical direction and are due to evenly spaced notches cut into the shingles. We realized that we could make our module using similar geometries and create the same effects, thus aiding the PV shingle's integration with the remainder of the roof.

Our final concept for the new module's geometry became nominally 12 inches by 132 inches, the width of a conventional asphalt shingle but having more length. The horizontal shadow lines discussed above are created in the same manner as conventional shingles, i.e. overlap. We artificially constructed vertical shadow lines by embossing the PV shingle laminate emulating the notches on asphalt shingles. The justification for the length of the module is somewhat arbitrary but there are certain considerations. The length is dictated by factors, such as weight, ease of handling, electrical connections, and integration with asphalt shingles. As is the case of conventional shingles, the PV shingles will also be overlapped in such a manner as to expose only 5 inches when installed. Therefore, the PV (which is burdened by larger manufacturing costs) need only be 5 inches. This has been illustrated in Fig. 1.

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[1] H.O. Laaly in "The Science and Technology of Traditional and Modern Roofing Systems" Vol.1, Laaly Scientific Publishing, 1992, pg. 16-2

Materials of Construction

A shingle module is composed of several PV sub-panels integrated by laminating the elements together. The sub-panels consist of various thin-film coatings deposited onto thin sheets of stainless steel. The materials used in the module are illustrated in Fig. 2.

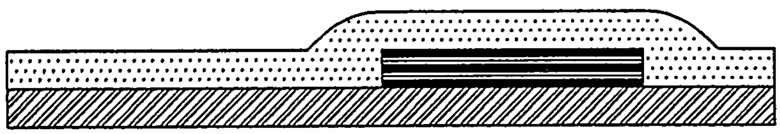

Figure 2 Shingle module materials stack-up

Environmental protection is provided by ethylene vinyl acetate (EVA) and Tefzel. A polyester based material is used on the back surface. The shingle also includes interconnecting wires and current bypass diodes (not shown). Electrical inter-module connections will be made below the sheaves of the roof.

Electrical Feedthrough

There will be one roof penetration for each module via the use of a sealed insert. We contemplate providing an electrical conduit which will penetrate the roof for each module in such an array. The conduit is one of the keys to our design philosophy which includes separation of the trades, namely the electrician and the roofer. Therefore, the conduit must be easily installed by the roofer so that the electrician can subsequently use the module's wires to make the array interconnections. Our present design for the conduit is represented in Fig. 3. The dimensions of this item are envisioned to be ½"-¾" long (depending on the roof sheet thickness) with a hole size i.d. of ⅜". The flange will be used to promote sealing between the shingle module and the underlayment. The material used for the conduit is nylon.

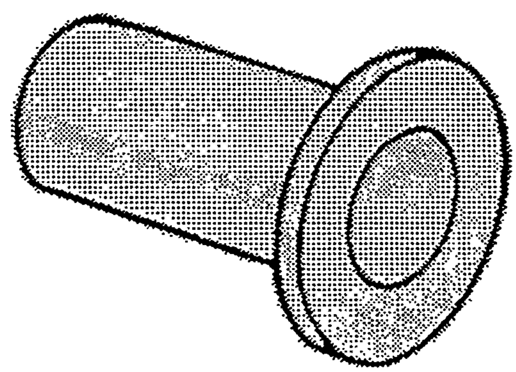

Figure 3 Stylized image of the electrical conduit to be used for the United Solar's shingle PV module.

Material Optimization

We completed an effort to reduce the manufacturing cost of the PV shingle module. The primary focus was to reduce the amount of lamination materials. The lamination materials (Tefzel, EVA, polyester, etc.) represent the largest material cost of the module. Our strategy was to take advantage of the United Solar's R&D group's proprietary grid fabrication technique that has a low height profile. This low profile provides the opportunity to reduce the amount of lamination materials in the module package, as the need for abrasion protection is much reduced. In order to prove that our module had adequate abrasion resistance, we fabricated prototype modules with reduced lamination materials and subjected them to a cut test procedure (UL 1703 - Standard for Flat-Plate PV) surface at critical areas and that the module subsequently pass a wet current leakage test at high voltage. This procedure ensures that the module lamination protection is not violated, proving that the abrasion did not create the risk of electrical shock. After reducing the lamination materials by 50%, we easily passed the cut test. In addition, we modified the module lamination layout to eliminate EVA and Tefzel from the shadowed areas of the PV shingle. The total effort, therefore, resulted in a 70% reduction in the volume of lamination materials used for the module.

Installation

The following general procedure was envisioned to be used to install the PV shingles:

(1) roofer drills holes in roof board using template and pounds in feedthroughs

(2) roofer lays out PV shingle and nails into place using standard roofing brads

(3) interface of PV with conventional shingles made by conventional staggering

(4) electrician completes wiring underneath the eaves of the house

The procedure was subjected to review by the National Association of Home Builders (NAHB) Research Center, the Chief Electrical Inspector for Prince Georges County, Maryland, and by many roofing professionals. The NAHB Research Center performed a prototype installation (described later) and addressed several issues related to installation[2] such as: transition to standard shingles, the use of roof jacks, ease of lifting, ease of fastening, simple roof penetrations, and need for special underlayment. Originally, we used flashing to integrate the PV shingles with conventional shingles. The Research Center concluded that the flashing was not necessary. Therefore, this was the procedure of item (3) and roofing systems were subsequently made without flashing. Further, the NAHB Research Center review indicated that installation of the United Solar PV shingle modules are well within the ken of the *present* roofing industry.

Design Review

We have subjected our design concepts to formal review by focus groups of architects, NAHB Research Center personnel, and by a working group of roofing professionals.

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[2] Task Report by NAHB Research Center, Inc. "PV Roofing Shingle Concept Development", Oct. '94 to Jan. '95.

ARCHITECTURE Focus Group

A design focus group hosted by ARCHITECTURE magazine with 7 contracting architects was convened for the purpose of reviewing our design concept. Highlights of the group's considerations are:

* Many comments on cost-benefit of roofing PV

* Liability concerns discussed

* Weather proofing issues discussed

NAHB Research Center Analysis

NAHB Research Center personnel have performed extensive review of both the product concept and identifying pertinent design philosophy. Their complete findings and analysis are available[3]. The scope of review included the following:

* Appearance characteristics identified for aesthetic impact

* Size and weight criteria

* Weather proofing issues identified

* Installation procedures reviewed for code compliance

The NAHB Research Center made these significant conclusions:

A. The overall concept of our design appears to be sound. That is, United Solar's technology can be utilized as a PV shingle. The shingles can be successfully integrated into the design of a conventional roof.

B. The installation can be accomplished by using conventional construction techniques while separating the building trades (i.e. roofers and electricians).

[3] Task Report by NAHB Research Center, Inc. "PV Roofing Shingle Concept Development", Aug. to Sept. 1994.

Review by Roofing Professionals

To obtain product refinement suggestions, information was gathered from several roofing professionals[4]. Comments are included below:

» The appearance of a plastic material on the roof may be unappealing to some consumers.

» A better match between the PV-Shingle material and an asphalt shingle material can probably be found with other shingle products. A new asphalt shingle product may need to be developed.

» It will be unacceptable for the electrician to be on the roof installing roofing materials, both for the roofer and the electrician.

» Any unintended "wave" in the roofing product is unacceptable from an aesthetic view.

Two roofers were invited to review the PV-Shingle concept at the Research Center. One roofer divides work evenly between commercial and residential. He installs mostly shingle products on residential buildings. He obtains his material from roofing supply distributors because of the convenience for getting the material on-time and delivered to the roof. He likes the variety of roofing products that the distributors offer.

Both roofers have similar responses which include the following comments and suggestions:

» No glaring difficulties are obvious for the installation crew. Training in the installation of the PV-roofing product is possible (and necessary). The crew supervisor's job is to ensure the PV-Shingle is located properly, that it is aligned and laying flat. (The supervisor ensures that the product is installed correctly both mechanically and aesthetically.)

» A similarity exists between the installation of the PV-Shingle and a product such as an attic vent or other roof mounted power equipment.

» Leave the end tabs of the PV-Shingle inactive to allow for overlapping with asphalt shingles.

» Use a glue strip to form a seal between layers of shingles similar to what the asphalt manufacturers use now.

» If a separate seal strip is used on the tabs of the PV-Shingle which requires a paper covering to be removed, make clear in the installer instructions that the strip requires removal of the paper backing.

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[4] Task Report by NAHB Research Center, Inc. "PV Roofing Shingle", Feb. to June 1995.

» Use of a drill by the roofer will not pose any special problems.

» The roofer can use a templet to locate the hole for the module wire without encountering any special problems.

» The roofer will probably layout the roof for each of the holes after the first module is located, drilling all holes prior to installation of the modules.

» Caulking can be added to the hole in the roof decking at the time when the cable is being passed through the hole to the attic space.

» Water leakage through the holes in the roof decking is very unlikely.

» Typically, with the installation of roofing materials on sloped roofs, one or two roofers lay the shingles out on the roof while standing on the roof decking above the shingles. Simultaneously, a third roofer nails the shingle from below while standing or kneeling on the shingles.

» If necessary, roofing jacks can be used on the roof with boards straddling the PV-Shingle. The jacks can be spaced up to 12 feet.

» If necessary, and permitted, a board can be placed onto the PV-Shingle to distribute the installer's weight. A piece of plywood can be used as well to distribute the weight.

» A minimal amount of walking on the PV-Shingle may be inevitable when the roofing jacks are being removed.

» The use of glue tabs may eliminate any wave in the PV-Shingle.

» Some waviness in the PV-Shingles may not be so prominent when adjoined with architectural (multilayered) asphalt shingles.

» Flat packaging will make the PV-Shingle difficult to handle. The PV-Shingles should be rolled and packaged in a box for ease of handling and to allow the distributor to deliver the boxes to the roof.

The roofers liked the product and thought that it would be attractive for custom homes and people already willing to pay more for a roof covering. If commercialized they would like to have a source for the product, possibly one supply house that carries the product. In their view, it would be acceptable to send someone to pick up boxes of PV-Shingles at a distributor; much as they would make a special stop to purchase skylights or other roof mounted equipment.

Review by Chief Electrical Inspector

The chief electrical inspector for Prince George's County, Maryland was invited to the Research Center to evaluate the PV-Shingle prototype installation. He also functions on a part-time basis for another large county in Maryland. He saw significant value in the concept of the photovoltaic modules integrated with the roofing material. He anticipated no particular problems with the module wiring being placed through the roof decking.

The PV-Shingle wiring would require termination in a junction box (as opposed to having splices made directly in the attic space without junction boxes). A bushing would need to be in place to protect the wiring where it passes through the hole in the roof decking, but this can be part of the module. The module should be listed (or labelled) for the particular application in which it is to be installed, namely over sheathing with holes drilled in the sheathing for wire passage.

The chief inspector indicated that building or electrical inspectors in general will look for a label to assure the product is constructed according to some standard and is safe for use in the building. A label is the easiest way for an inspector to assess the correct application of the product. Standard wiring methods should be employed including wiring requirements relevant to section 690 of the National Electric Code (NEC).

No specific prohibitions exist for the PV-Shingle in the NEC. All photovoltaic installations are required to meet certain requirements if installed in buildings. These requirements will be refined in future editions of the NEC.

In summary, he deemed the concept sound and indicated that a commonplace electrician could easily perform the required wiring terminations within compliance to building and electrical codes.

<u>Reliability</u>

Throughout this program, we have been executing an ongoing policy to insure that the module will meet long term reliability requirements. We have subjected submodules (nominally 1 sq. ft. each) to the tests contained in the <u>Interim Qualification Tests and Procedures for Terrestrial PV Thin-Film Flat-Plate Modules</u> (Doc. SERI/TR-213-3624). This procedure has served as the de facto standard for thin-film PV reliability in recent years. Though the test program was written for "flat-plate" modules, the tests are applicable to rooftop shingle modules with the exception of the mechanical loading test. The choice of using submodules for this portion of the testing program may be justified by: (1) the convenience of the size of the submodule for the use of existing equipment, such as environmental chambers, (2) the fact that the submodules are made with the same materials and techniques as the full-blown module (the submodule should be considered to be a section of a full modules), and (3) the fact that the completed module will be tested eventually.

In our laboratory, we demonstrated early in the module development program that the submodules withstand the 200 thermal cycles, 20 humidity/freeze cycles, dry hi-pot, wet insulation, and the surface cut susceptibility test. The other tests in the IQT procedure have historically not presented any difficulties to our technology. The thermal cycles and surface cut tests posed some difficulties to the shingle module due to our plan of material optimization (see above discussion on material optimization). We adjusted some of the proprietary process parameters to insure passage of these tests.

To demonstrate the shingle module's suitability as a PV material, we tested using the complete IQT (except for the inappropriate mechanical load test). We fabricated mini-modules for this work. The mini-modules are identical to full-size shingle modules except for being only 2 ft. long (instead of 10 ft.). The mini-modules have the advantage over the submodules used previously in that they allow us to stress the module internal electrical interconnects also. The only reason for testing IQT with mini-modules as opposed to full modules is their size; the mini-modules can fit in our existing test equipment. The IQT procedure is shown in Fig. 4 along with the changes of efficiency measured by electrical performance. All mini-modules have passed each visual and electrical inspection as dictated by the IQT procedure. This greatly improves our confidence in the reliability of the PV shingle module product in the field.

Shingle Roofing Systems

Two roofing systems have been built as part of this project with installed PV roofing shingles. There were two primary purposes for these systems. First, they were used as vehicles to help us understand installation and aesthetic issues. Secondly, the roofing systems served as outdoor exposure facilities. Both systems have been shown (in person and by photograph) to many roofing and photovoltaic experts to elicit their comments and advice. Also, comments were received regarding aesthetics by many types of visitors to both sites. These comments have been seriously considered by our design team in the course of the module's design evolution.

PV Shingle Roofing Structure in Troy, MI

United Solar's R&D department has designed and built a structure for the installation of the shingle modules. The purpose was to provide a vehicle for mounting prototype modules in a realistic application setting. Figure 5 shows a diagram illustrating the structure's dimensions. Figure 6 shows our original plan via a normal view of the roof with prototype modules installed. The structure is designed to be completely enclosed. It houses PV monitoring equipment. The benefits of this project are manifold: (1) we have a life-size demonstration of the product to aid our engineers, researchers, and consultants in aesthetic evaluation, (2) we gained experience in mounting procedures, (3) we gained practice in the module fabrication process, (4) we can use the structure for outdoor reliability studies, (5) we can perform both PV power measurements and auxiliary measurements (i.e. temperature) on the modules, and (6) it can be used as a marketing tool for showcasing United Solar's shingle module.

Construction

The original installation of integrated modules was made as per the designs of Figs. 5 & 6. As a result of design review, we re-made the roof with our present design. This is shown in Fig. 7. Both the asphalt shingles and the PV shingles were mounted using conventional roofing nails onto a ½" wood deck. The underlayment consisted solely of "ice & water shield" manufactured by GAF. The module's attached output wires were inserted through feedthroughs designed by United Solar. (Details of the feedthrough design are given above). In the field, we expect that templates will be used for feedthrough hole location but we merely measured with

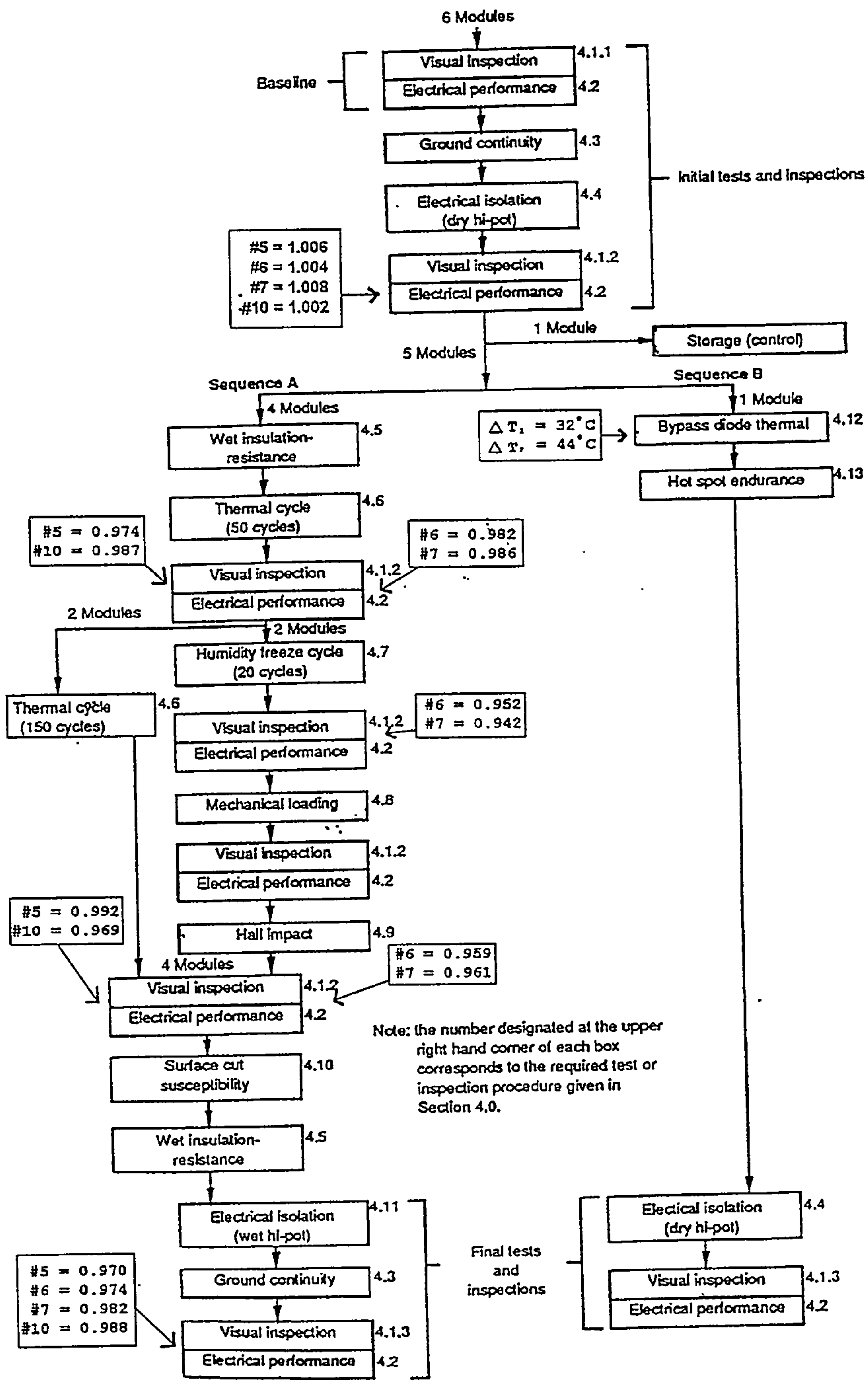


Figure 4 Qualification Test Sequence. Normalized module power is indicated at various "Electrical performance" steps. The power is normalized w.r.t. initial.

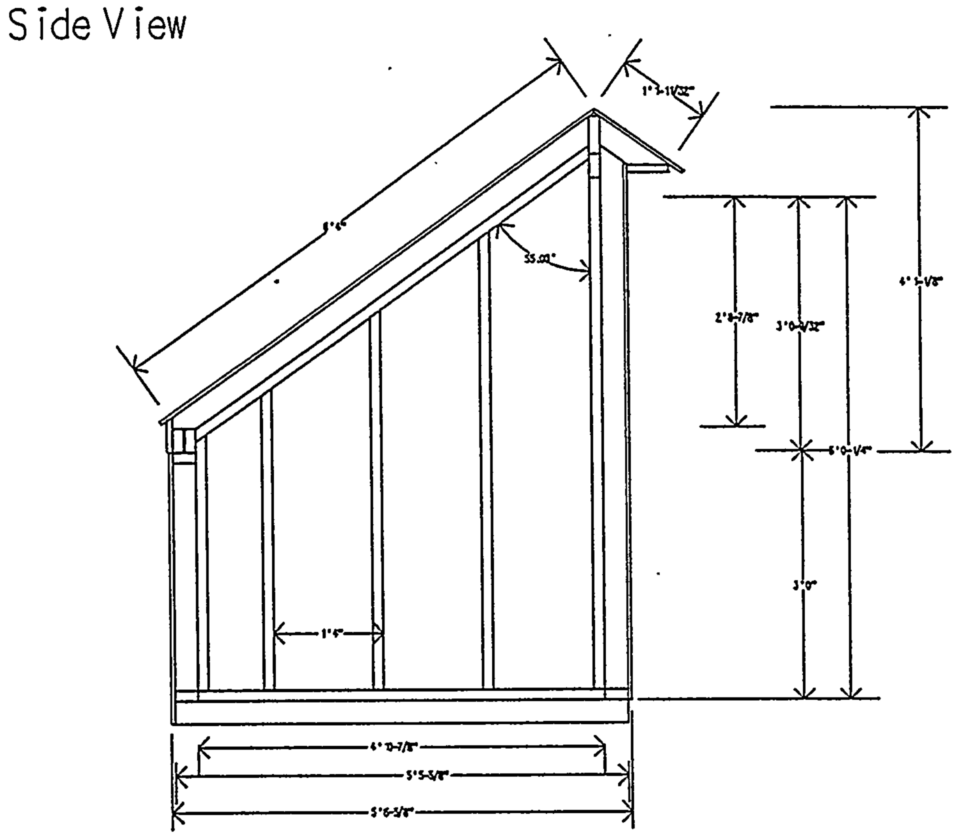


Figure 5 Scale drawing of structure for mounting PV roofing shingles.

a scale to determine their location in this instance. Custom made flashing was used to integrate the left and right edges of the PV shingles with their asphalt counterparts. No flashing was used at the top interface. The PV shingles extended to the bottom edge in this particular installation, as can be seen in the photo of Fig. 7. Type K thermocouples were encased inside the lamination of certain modules to provide means to monitor PV operating temperature. This was done because we do not know the expected operating temperature versus ambient or versus solar insolation as this is a new design in a unique application.

In summary, the roof was installed in a manner similar to that expected on the roof of an actual customer's home.

Performance

The system has been repeatedly exposed to rain, ice, and snow storms but there is no evidence of leaking through the roof or other degradation in the PV shingle's appearance. We have continually monitored the performance of the array since the installation of November

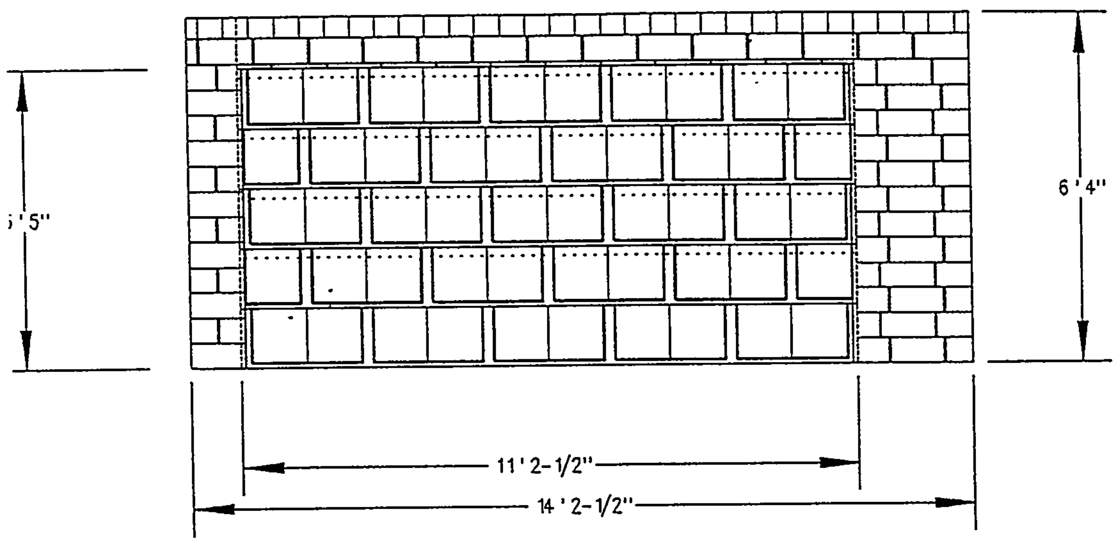


Figure 6 Scale drawing of asphalt shingle roof with mounted PV shingles.

1994. Lights were installed that are powered by the PV. Performance data is shown in Fig. 8. The initial drop and subsequent leveling of the efficiency are characteristic of the Staebler-Wronski effect. We believe this efficiency is a very reasonable number taking into account the material used for this demonstration array. The PV material used in this array was from United Solar's production line.

PV Shingle Roofing Structure at NAHB Research Center in Maryland

We fabricated 20 modules for a demonstration building at NAHB Research Center. The modules are photovoltaically inactive but are identical to working modules in all other respects (i.e., all construction materials are present). This demonstration was built for two basic reasons. First, to provide a vehicle for NAHB to gain hands-on experience with the installation of these modules, which will result in suggestions on installation procedures. Second, key people from the building industry, inspectors, builders and installers are viewing the demonstration and give feedback in order to improve module and system design.

Some of the installation highlights were:

1) used standard felt paper -- no water and ice shield
2) staggered seam design -- as in normal shingle layout
3) no flashing -- shingles overlap inactive PV ends
4) ability to fit irregular geometry such as roof hips
5) installation similar to regular asphalt roof shingles

All twenty modules were received by the NAHB Research Center on December 20, 1994.

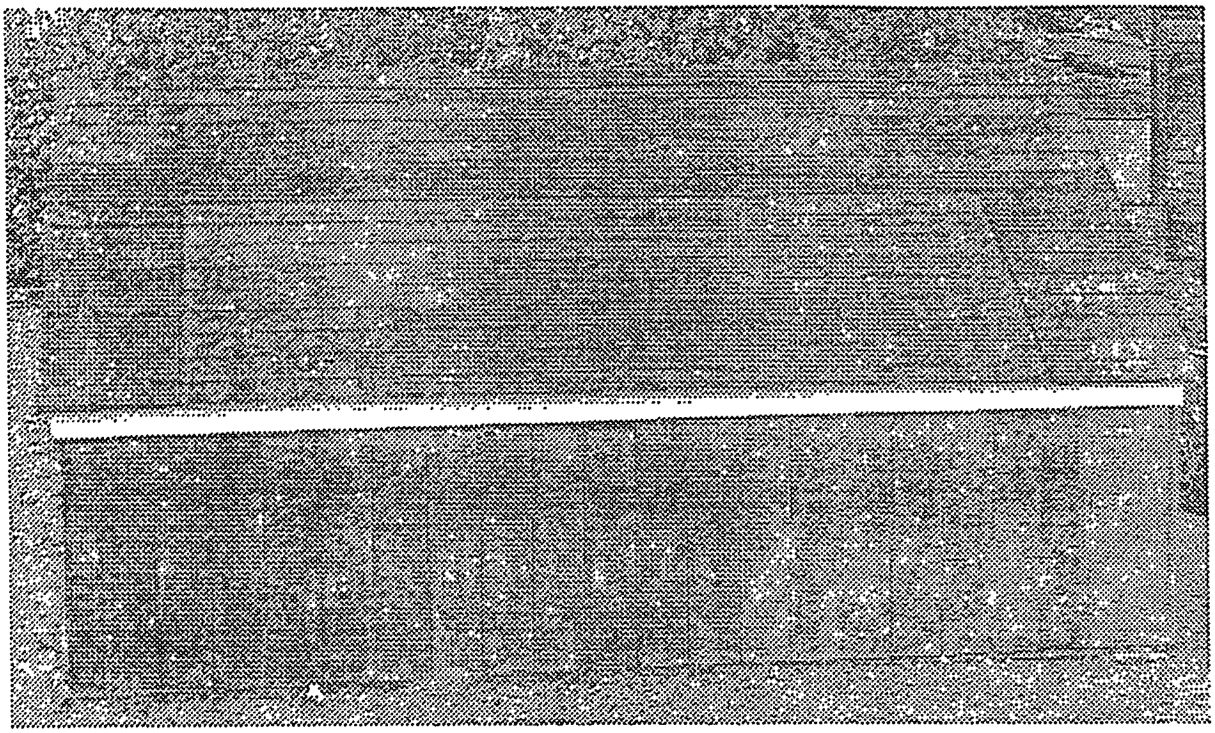


Figure 7 Photograph of United Solar's shingle module mounted on a roofing structure designed to emulate a field installation.

The accompanying activity report from the Center details the installation and provides assessment of the project (Task Report by NAHB Research Center, "PV Roofing Shingle Concept Development", Oct. '94 to Jan. '95.)

Continued review of this installation by builders, consumers, manufacturers, subcontractors and others resulted in these assessments:

* the shingles lay as flat as they ever have; the weather has been warm with some temperatures reaching to the 80's (°F).

* There remains ≈ 1/3 of the PV-shingle tabs which are not flat against the previous row; this makes the PV-shingles appear uneven and installed incorrectly.

* With the warmer weather, the fiberglass shingles adhere to each other extremely well with no tabs raised above the preceding row.

* The PV-shingles adhere to one another to varying degrees; at some points it is very difficult to pull the PV-shingle apart from the preceding row, in others it is relatively easy.

* The PV-shingle row above a fiberglass shingle row adheres to the shingle glue strip but can be separated when pried. After an extended warm spell, the shingles are very difficult to

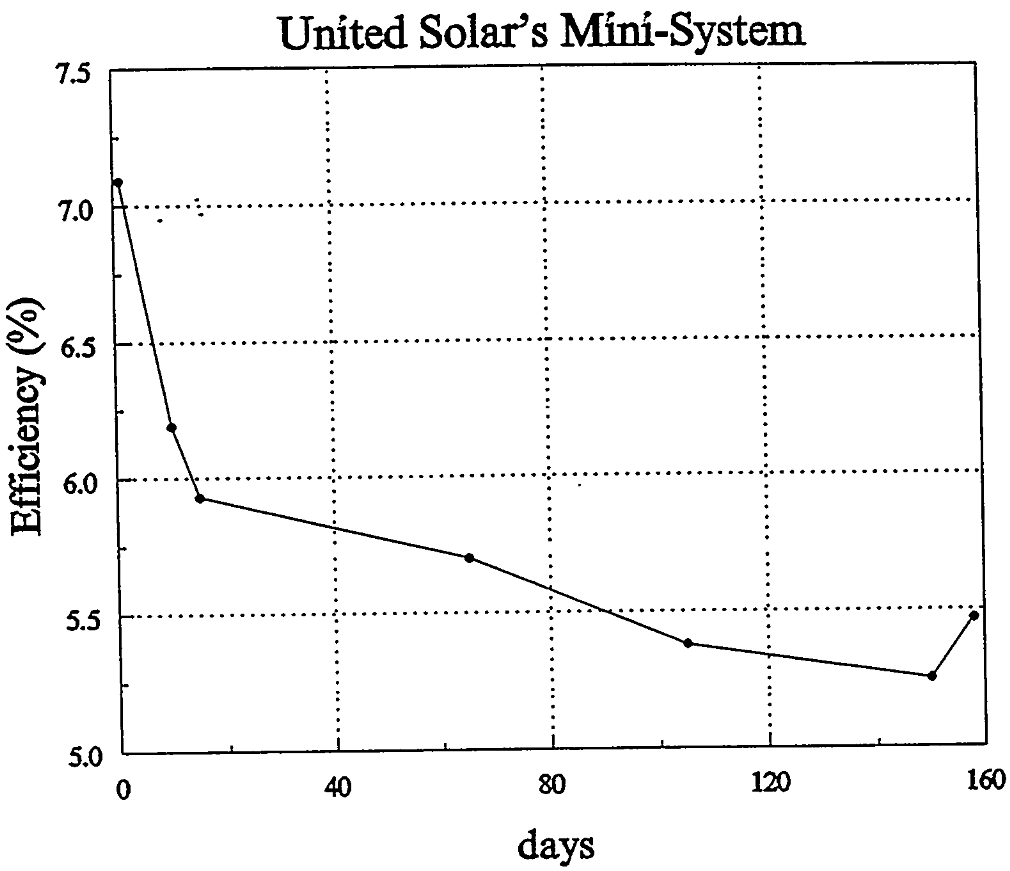


Figure 8 Efficiency plot vs. deployed days of United Solar's mini-system of rooftop PV shingles.

separate.

* Due to the rigidity of the PV-shingle, even if separated from the preceding row, the shingle is difficult to raise very high.

* The acceptance of the differences in color between the PV and standard shingles encompasses all ranges; a question often raised is whether the PV-shingle will be available in various colors.

* When prepared that they would be viewing a "solar (PV) roof," visitors were surprised that they did **NOT** see something mounted above the roof; many are surprised that the technology is this developed. When reviewed in this context, the PV-shingle is then evaluated for its likeness to the surrounding shingles, and differences in color and texture are noted.

* A fiberglass shingle manufacturer made the following comments after reviewing the concept:

* appearance of plastic on the roof may be questionable;

* a better match can probably be found with other shingle products, one may need to be developed;

* it is unacceptable for the electrician to be on the roof installing roofing materials;

* any "wave" is unacceptable.

Generally there is enthusiasm surrounding the PV-roofing concept. The improvement over the public's perception of a solar system is marked. The building-integration aspect is of major importance.

Conclusions

United Solar Systems Corp. R&D group have developed under PV-BONUS a new concept in building integrated photovoltaics, a PV shingle. The PV shingle module exhibits the following advantages:

- Emulates Conventional Asphalt Shingle in Form & Function
- Aesthetically Appealing - Blends with Standard Roof
- Small Shadow Loss - Less than Conventional PV
- This module is a Roofing Material - Additional Shingles are Not Required Underneath
- Separation of Trades During Installation - i.e. Roofer and Electrician Work Independently

Through the work of this program through Phase II, we have made these significant accomplishments:

(1) IQT reliability testing

(2) Design focus group performed with NAHB Research Center

(3) Market focus group performed with architects

(4) Review by Chief Electrical Inspector

(5) New module fabrication equipment built

(6) Installation procedures established

(7) Demonstration shed built

(8) Demonstration roof at NAHB

Completion of Phase III of this PV-BONUS effort will position United Solar to make an exciting inroad toward the goal of providing residential photovoltaic power to millions of homes.

DEMONSTRATION PROGRAM

As mentioned in the introduction, there are three definite demonstration projects, and a number of others being considered. One of the demonstrations, the Beaver Island Blue Bird Bed and Breakfast, was installed as a part of the PV:BONUS Phase II program. The Olympic House and the NAHB townhouse will be installed as a part of the Phase III program. The Olympic House has the highest priority.

Beaver Island

United Solar Product Development Personnel completed the installation of the 1.9 kW system on 5 June 1995 and the system was put into operation that same day. This system used the United Solar Horizontal Batten Seam system, and is shown in the figure below.

Figure 5. The horizontal batten seam BIPV system as installed on the Beaver Island Blue Bird Bed and Breakfast.

Highlights:

- Since the installation, the inn has operated with a full complement of guests solely on PV-generated power.
- Brown out and periodic black-outs, which plague Beaver Island in the summer, have not affected the Inn.
- Severe thunder storms in the area have caused neither leaks nor wind damage to the system.
- Power output has remained high through the months of June and July: the 1.8 kW rated system has been consistently generating 2.1 kW DC, and has had outputs as high as 2.2 kW.
- United Solar believes that there is a large market for such systems on vacation homes in this part of the state, and that the Inn will be an excellent demonstration to help develop this market.

DEMONSTRATION INSTALLATION OF PV-METAL ROOFING

The NAHB Research Center is sponsoring the construction of four townhouses demonstrating the use of innovative and energy efficient building materials. Numerous product suppliers, trade associations and government agencies are supporting this effort, including the Department of Energy and the National Renewable Energy Laboratory (NREL). With NREL support, Energy Conversion Devices (ECD) will demonstrate a new building integrated photovoltaic (PV) system. The PV system will be the first to use an integrated PV-metal roofing module, installed by a roofing company and connected to the utility grid.

The photovoltaic (PV) modules fielded as part of the photovoltaic energy system installation in the Research Center townhouse project will feature PV-metal roofing modules integrated with the house roof to form a building integrated photovoltaic roof system. The PV-metal roof modules are unique to the building industry in that the roofer, trained in asphalt shingle installation, will be trained on-site to install residential metal roofing including the PV-metal roof modules.

Building integrated roofing systems are uncommon in the United States so that the integration of photovoltaics with standard building products is major step forward in lowering costs for the installation of roof-mounted solar systems. Building integration of the PV modules are expected to make substantial advances in overcoming the negative attitudes towards roof-mounted solar systems.

Townhouse Application of the PV-Metal Roofing Modules

Of the four townhouse units constructed by the Research Center (figure 10), the east end unit will host the photovoltaic system. The front of the townhouses face 20° east of south, a result of the plat development process some years prior. Initial design efforts by the architect to rotate the end unit by 20° to the west proved infeasible. This townhouse unit is constructed of an aerated autoclaved concrete product with a stucco exterior coating and interior sheetrock. The wood roof trusses are designed with an 8:12 slope (34°) on all surfaces. The roof consists of three surfaces each of which are independent of the other. The middle section of roof is approximately 300 square feet (sf), the left section roughly 195 sf, and the right section of roofing is almost 53 sf.

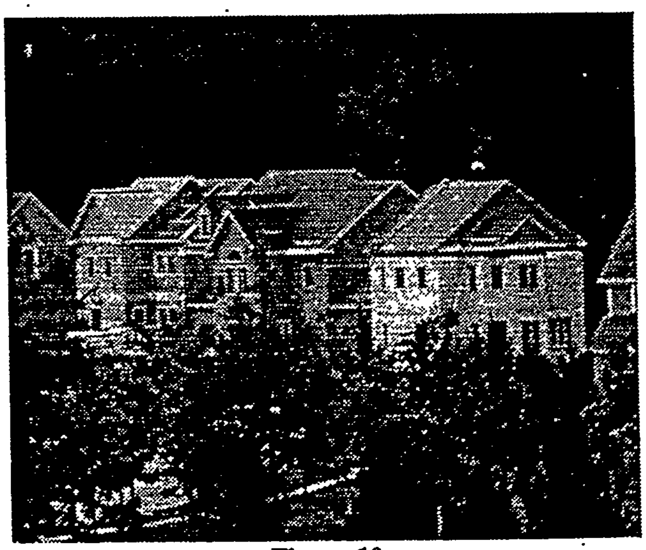


Figure 10
Research Center Townhouse Units
(unit on right will host PV system)

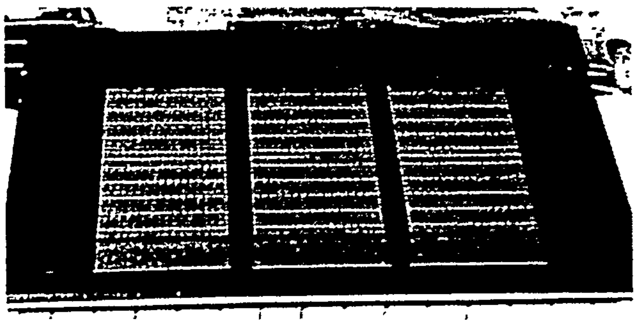


Figure 11
Sample PV-Metal Roof

The two larger sections of roofing will host the PV-metal roof modules with a combined surface area of roughly 495 sf. Utilizing the PC standing seam metal roof product supplied by ATAS Aluminum, this area will be covered with almost 21 roofing panels. Each panel is 15 1/4" wide. The gable trim detail covers approximately 4" in from the gable end.. The Regal Blue paint fluoropolymer finish comes with a 20 year warranty. Figure 11 shows all the metal roofing components in place for a sample roof constructed by ECD.

PV-Metal Roofing Modules

Physical Characteristics

In the final PV-metal roofing design for the townhouse project, 18 PV-metal roofing modules will be installed. The PV cells are laminated to the metal roofing panels creating an area of the panel which will produce dc electrical current when illuminated by sunlight. Approximately 75% of the roofing panel area will be covered with PV cells. The border between the cell and the seam is about 1 3/8". There is 7" between the top cell edge and the top of the panel. The bottom panel area, from the bottom edge of the cells to the end of the panel, is determined by the overall length of the panel.

The metal roof industry markets standing seam roofing panels in various widths. The intention for the original PV product design was to make the panels as wide as possible, but use of a smaller standard product emerged as the most cost-effective and aesthetic solution. Factors affecting the choice of the panel width are the wind uplift on large surface areas, the necessity for secure attachments, and aesthetics. In regard to the latter, an important goal of the PV product design is to simulate the look of existing metal roofing products. The choice of the largest width panel available, up to 24", fits the technical requirement for surface area, but many metal roof installation use panels that are less than the 24" width. For application to the townhouses, a smaller width panel was the preferred choice by the architect with the additional stipulation that the roof panels on each unit be of a similar, though not identical, width. According to manufacturers, the most common width for residential and many commercial roofs is approximately 14" to 16".

Using the original drawings for the townhouse and working within the constraint that the PV roofing matches closely with the surrounding roof on that unit, the intent was to use one entire section out of the three roofing sections, for the PV roofing product. As a result, no other non-PV roofing panels would be required on that section of roof. When the final architectural drawings were developed, the intended roofing section was not sufficient to provide the necessary area for a nominal 2000 watt PV system. Also, the builder felt that with current construction methods, the ultimate roof size could not be adjusted in the field to account for the installation of the PV roofing product. Therefore, a few inches on either side would be necessary to account for any anomalies typically encountered on the construction site. Because of the many opportunities for error, roofing sections should not be sized precisely to fit a predetermined number of PV roofing panels. These two constraints, the panel width and the allowance for field adjustment, are commonly encountered in building practices. Designing reasonable flexibility into the PV product design is extremely beneficial.

The metal roofing manufacturer, ATAS Aluminum, produces 19-1/4", 15-1/4" and 11" roofing panels as standard products, Using the overall dimensions of the middle section of roofing and allowing for part of one panel on each gable end of the roof to account for field adjustments, the active PV surface area available with a 19-1/4" panel was slightly less than when using 15-1/4" panels. Also, the active area for the 11" panel was over 5% less than for the 15¼" panels. As a result, 15-1/4" panels were chosen because they do not compromise the available active area given these particular installation constraints. Furthermore, the market for the middle width panel is larger than that of both the very wide and very narrow panels combined. Table 2 summarizes some of the physical characteristics of the PV-metal roofing product for the townhouse installation.

Table 2
Final PV-Metal Roofing Product Specification Summary

Panel Width	15-1/4 inches	Adaptable to manufacturing requirements
PV Cell Active Area Width	12-1/2 inches	Based on panel width, seam height and PV cell optimization
PV Cell Active Area Length	17 feet 5 inches	Compromise between the sections of roof on the townhouses - one PV cell size applicable both sections
PV Cell Active Area	0.955 square feet	0.089 square meters
PV-Metal Roofing Panel Active Area	18.14 square feet	1.69 square meters
Center Roof Section Total Active Area	218 square feet	20 square meters
Right Roof Section Total Active Area	109 square feet	10 square meters
Total PV Active Area	327 square feet	30 square meters
Total PV Panel Area	426 square feet	77% average area use for the PV-metal roofing panels
Total Roof Area (Center/Right)	497 square feet	66% use of total roof area (middle/right)
Roofing Panel Color	Regal Blue	PV color dependent on manufacturer

Electrical Characteristics

The intended photovoltaic power output (at peak sun) is 2 kilowatts (kw). Each PV-metal roofing module will have a maximum power output of around 135 watts; the peak output of 18 modules then, is about 2430 watts. However the modules will most likely not operate at their peak output potential since the voltage of the load will most likely not match the peak output voltage of the modules. Some of the projected electrical performance specifications are shown in Table 3.

Table 3
Anticipated Electrical Performance Characteristics

Characteristic	Anticipated Performance	Comment
Cell Size	0.955 square feet	.089 square meters
Open Circuit Voltage (Vc,oc)	2.33 volts	
Short Circuit Current (Ic,sc)	5.34 amps	estimate
Cell MPP* Voltage (Vc,mp)	1.7 volts	
Cell MPP Current (Ic,mp)	4.18 amps	estimate
Cell MPP Power (Pc,mp)	7.1 watts	estimate
Module Active Area	18.14 square feet	1.69 square meters
MPP Module Power (Pm,mp)	135 watts	estimate
Total Array Maximum Power	2430 watts	estimate
*Maximum Power Point		

Power Connector

The PV cells in the PV-metal roofing module are series connected with the electrical bus connection terminating in a connector at the top edge of the module. The connector (shown in figure 12) is located 1/2" from the top edge of the module and is 3 7/8" wide by 2" deep. In the current design, two conductors emanate from the connector. A third conductor will be included as a ground connection for the metal panel and will be attached to the rear of the panel. The connector is weather tight and cannot be removed from the metal panel without damage to the panel and the PV. Rivets secure the connector to the panel; an epoxy cement provides the weather seal.

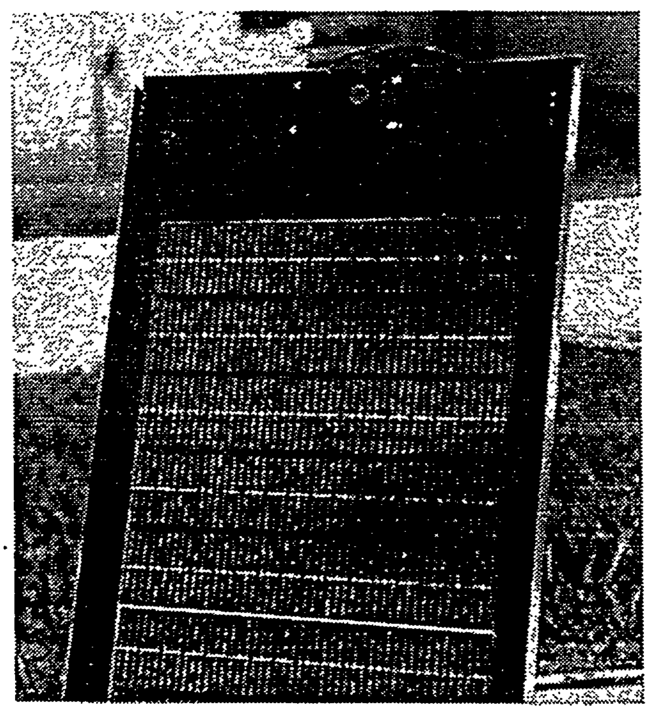


Figure 12
Prototype PV-Metal Roof Module

The connector is intended to be installed above the "Z" strip support for the ridge cap. In this position, the connector will not experience direct exposure to the elements although it will be subject to ambient temperatures and temperatures similar at the metal roofing panel. However, the connector is constructed in such a manner that it may be exposed; the conductors are rated for outdoor exposure and is UV resistant.

The PV cell electrical bus is centered under the cells and is approximately 2 1/2" wide. The PV-metal panel will be fastened at the top edge of the panel and care must be taken to exclude this area from .placement of the fasteners. The "Z" strip may require a notch to accommodate the connector, however, this is not the preferred method of installation and most likely will not be necessary in the townhouse installation. Figure 13 shows a small prototype installation of the PV-metal roofing module with the connector and a notch in the "Z" strip.

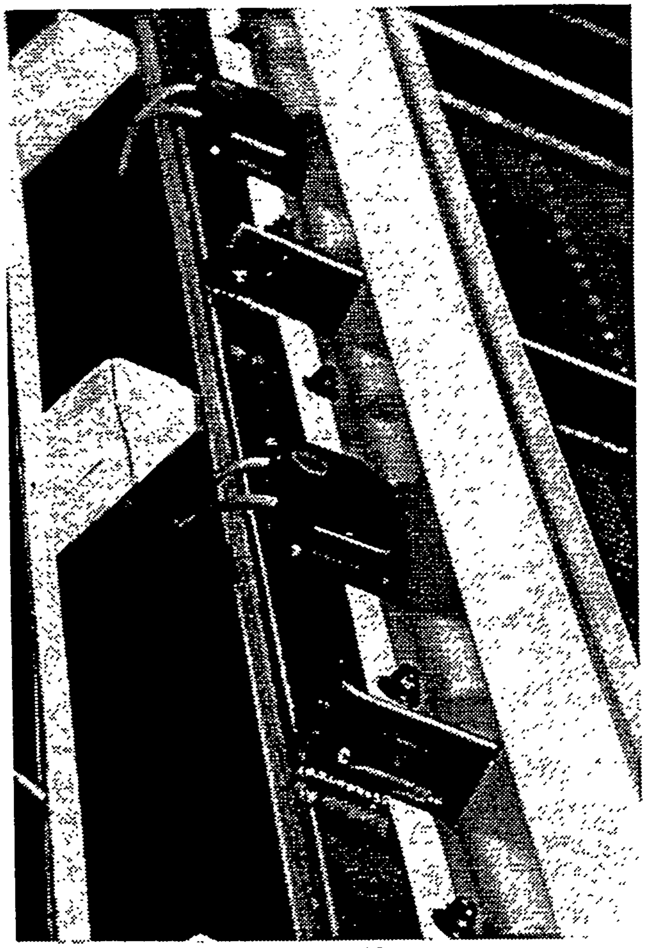


Figure 13
Prototype Installation of PV-Metal Module

Installation of the PV-Metal Roofing Modules

The metal roof panels installed at the time of construction of the townhomes will not include the PV-metal roofing product. The PV-metal roofing will be installed some months later.

Once the roof trusses are in place, 1/2" sheathing is placed over the truss members. The roof covering on all four townhouse units is a metal standing seam type with each roof being supplied by a different roofing manufacturer. The standing seam metal roofing products are typically used in both residential and commercial buildings. The non-PV roofing panels are manufactured from galvanized 24 gauge steel. The roof dimensions are sent to the manufacturer and the roofing panels are manufactured from the drawing specifications. All metal roofing panels are shipped to the site for installation in the locations specified by the manufacturer. Each installation is a custom design with roofing panels manufactured for a specific roof profile.

The roofing was installed on the PV townhouse unit is performed by a roofing company which specializes in asphalt and built-up roofing. The installers received training in the installation of residential metal roofing from the manufacturer. When the PV-metal roofing modules are available for installation, this same crew will remove 18 of the south facing roofing panels and replace them with the PV-metal roofing panels. The PV-metal roofing has the identical profile to the existing roofing panels making the retrofit a simple and straightforward process.

Figures 14 through 18 show one of the metal roofing panels being installed. Once the PV-metal roofing modules are fabricated, they will be installed in a similar manner. Figure 18 shows the completed middle section of roof with 12 panels which will be replaced with 12 PV-metal roofing modules.

Figure 14
Placement of Metal Roofing Panel

Figure 15
Metal Roofing Panel Slid Into Place

Figure 16
Clips Installed to Hold the Metal Panel

Figure 17
Batten Placed Over the Standing Seam

Figure 18
12 Panels Installed on Middle Section

Olympic Village

United Solar personnel are now engaged in manufacturing the modules for the 1.9 kW main array; and recently made a trip to Atlanta to coordinate the activities of the builders, architects, and the United Solar research group. A rendering of the Olympic House is shown in the figure below.

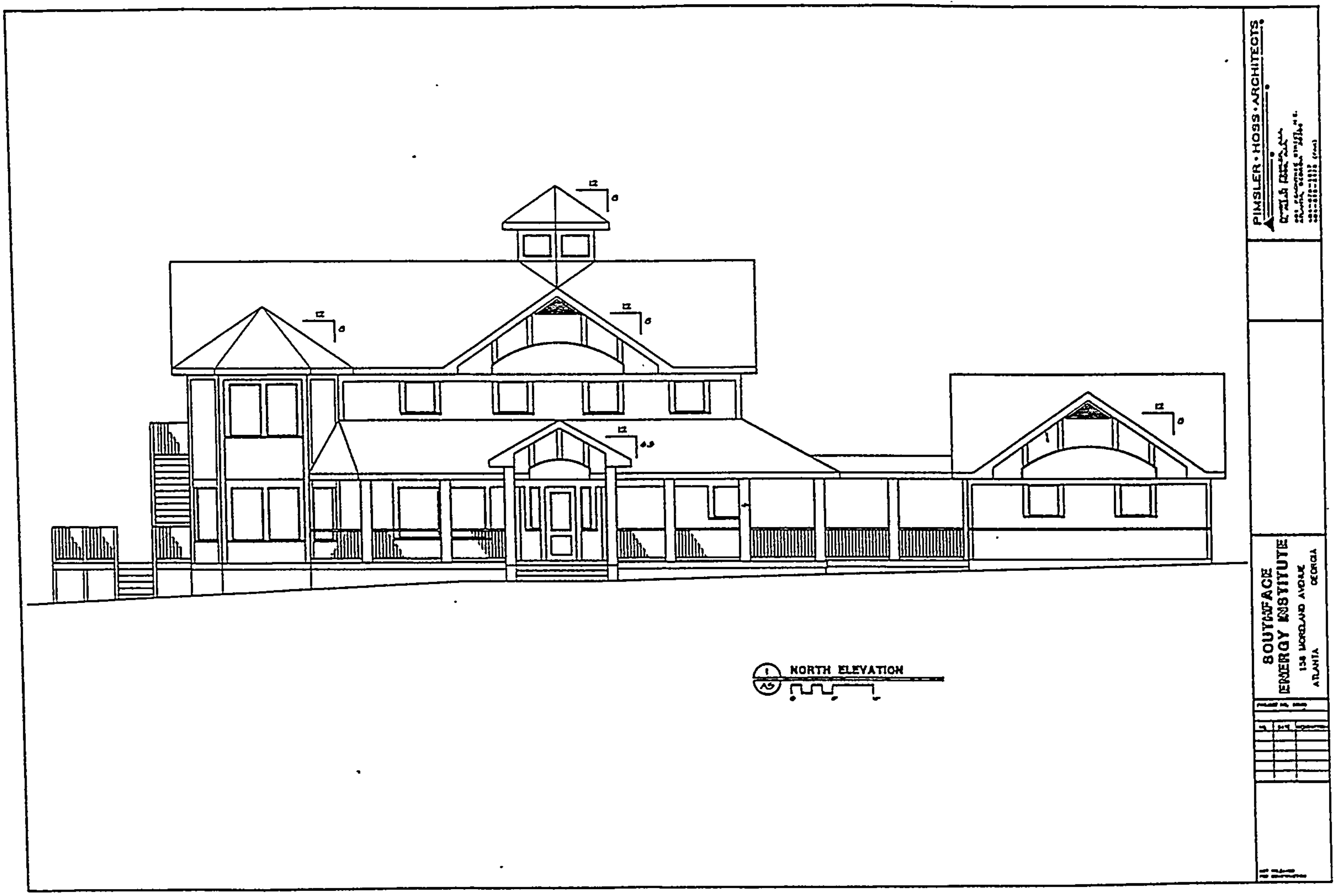


Figure 6. Artists rendering of the Olympic House with the United Solar shingle module BIPV system installed.

BUSINESS DEVELOPMENT

It is expected that the BIPV systems being developed under this PV:BONUS will become the principle PV product marketed in this country for the next several years. These systems, which compete in the retail (@ 10-150/kW-hr) rather than the wholesale (@ 3-50/kW-hr) power market, appear to be the most economically favorable near and medium term markets as the production volume increases and PV costs decrease.

United Solar is planning on entering the market with these products in the summer of 1996, after the commissioning of the new production facilities in Troy, MI. In order to prepare for this, United Solar has recently conducted a series of Advanced Product Meetings at several cities across the U.S. to obtain technical and market input from selected groups for the proposed BIPV systems. They are also soliciting interested companies for business development partnerships to complete the product development and to define and establish sales and service networks for these products. Supporting this work are two accompanying NAHB Research Center reports: *Metal Roofing Industry Overview, and a Photovoltaic Roofing Commercialization Study.*

On the following pages we include the brief product descriptions for the United Solar shingle module and ECD standing seam module used in the Advanced Product Meetings.

Below we summarize some of the initial feedback about these two products:

Shingle PV Roofing Module

Pros:

- Simple and easy to install
- Potentially lowest cost
- Clearly the most common form of roofing
- Color is impressive
- Easy ability to access wiring
- Unique appearance makes this system identifiable as BIPV
-

Cons:

- Difficult to remove or replace modules
- Plastic-like appearance doesn't integrate well with asphalt shingles
- Avoided costs are unfortunately low

Standing seam roofing module

Pros:

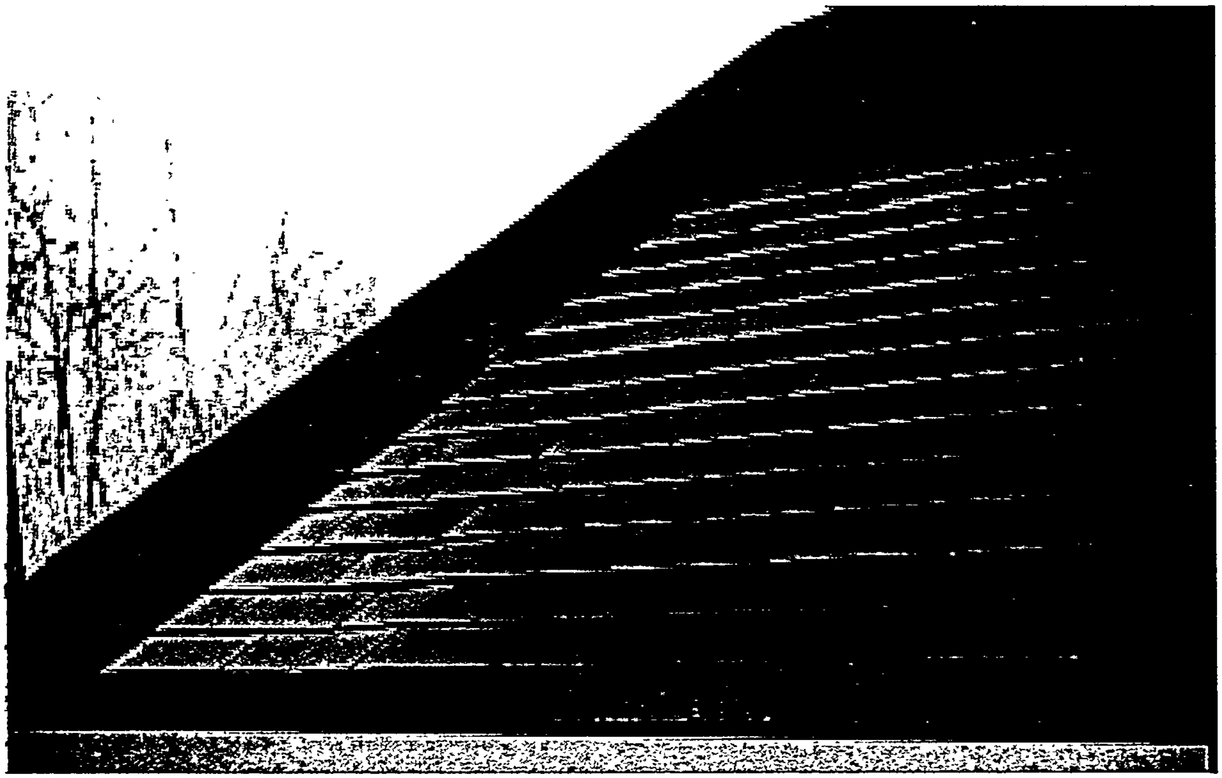
- Similar to contemporary metal roofing
- Ability to access wiring easily
- Easy to replace modules
- Recommend using a standard ridge cap design
- Wiring along top under ridge vent is OK with long laminate
- Not the most handsome, but looks more durable (editor's note: although we strongly disagree with the first part of this statement, we have included it unedited)
- Could be used for retrofits
- Maintenance might also be easier than with the horizontal batten seam system
- Appearance makes the system well suited for commercial/industrial applications

- In snow country, standing seam is used because battens are pulled off by ice and snow

Cons:

- Maintenance and service should be high priority to increase builder comfort
- Codes and Standards need to be worked with national organizations as early as possible

SHINGLE
PV ROOFING MODULE



- NAHB Research Center
  Upper Marlboro, MD

- Demonstration installation by NAHB Research Center Personnel to evaluate weatherability and installation.

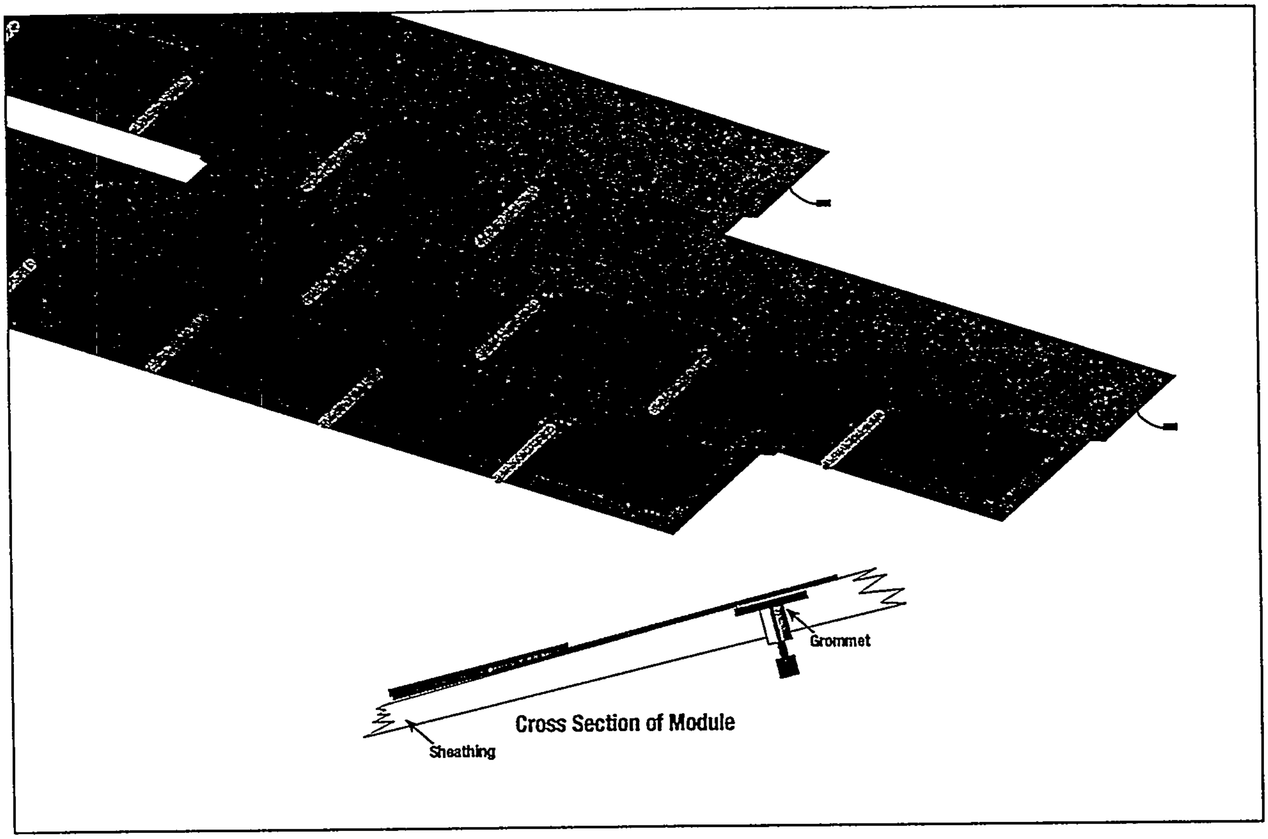
- Olympic Village House
  Atlanta, Georgia

- Utility grid-connected system will showcase PV Shingle system. System will provide supplemental power for lighting and building loads.

- 0.8 kWac/100 SF electrical output (approx.)

- Scheduled completion Spring 1996.

UNI-SOLAR®



- Shingle PV Roofing Module
- Flexible 10-tab shingle laminates are nailed onto roof decking prepared with standard roofing felt.
- Modules overlap in standard shingle fashion.
- Electrical connections run from back of modules through 1/2" diameter grommets penetrating roof deck.
- Electrical interconnections are made in attic.

UNI-SOLAR®

STANDING SEAM PV ROOFING MODULE

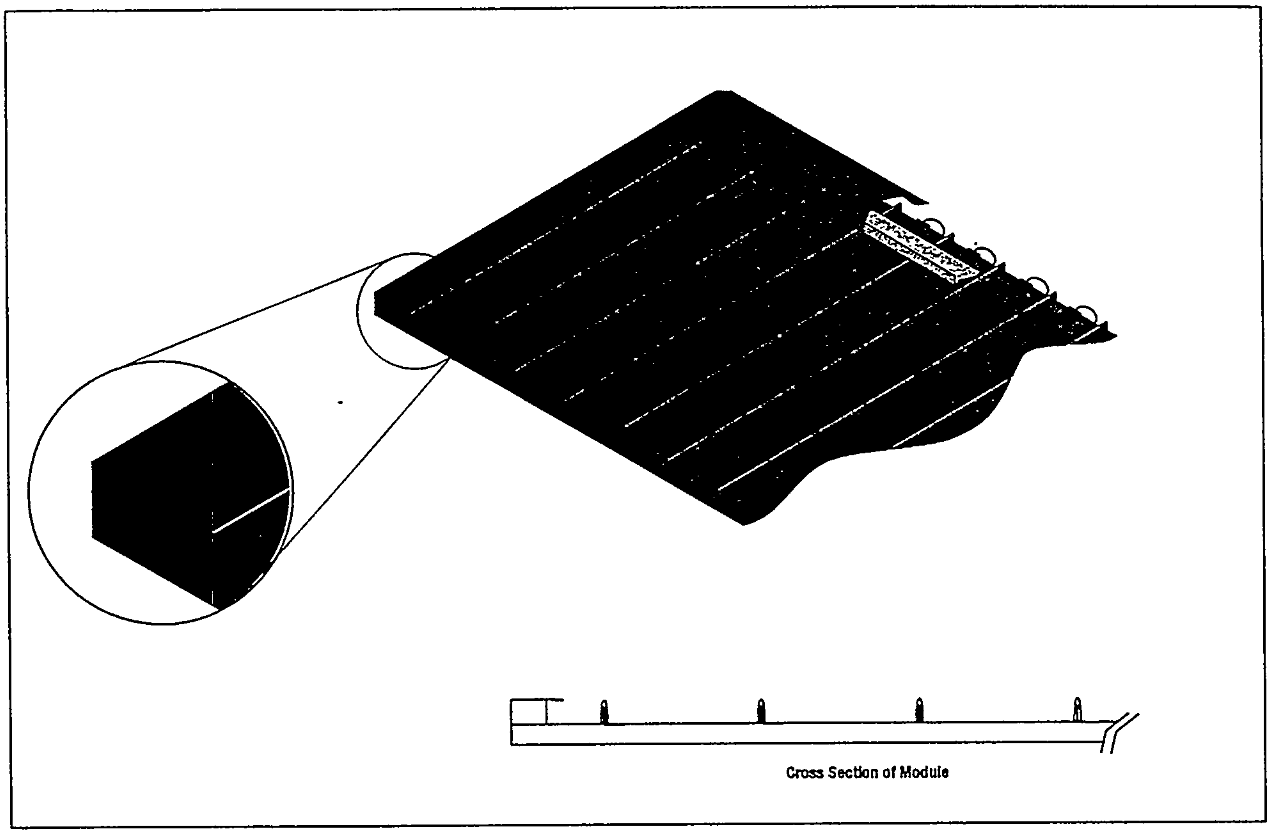
- NAHB Research Center
  21st Century Townhouses
  Bowie, MD

- Utility grid-connected Standing Seam PV Roofing system with battery backup using 20-foot modules. System installed on far right unit provides supplemental power for lighting and building loads. Project demonstrates alternative building materials and energy efficient systems.

- 2.8 kWac/100 SF electrical output (approx.)

- Scheduled completion Fall 1995.

UNI-SOLAR®



- Standing Seam PV Roofing Module
- Galvalume backing plate is bent up 90° along vertical edge of 20-foot long modules.
- Modules are mounted to roof decking with standard metal roofing clips.
- Seam is then capped with protective batten.
- Electrical connections are fed into attic beneath ridge cap.
- Electrical interconnections are made in attic.

UNI-SOLAR®

APPENDIX "A"

NAHB RESEARCH CENTER FINAL REPORT:

METAL ROOFING INDUSTRY OVERVIEW

APPENDIX "A"

NAHB RESEARCH CENTER FINAL REPORT:
METAL ROOFING INDUSTRY OVERVIEW

METAL ROOFING INDUSTRY OVERVIEW

A review of the market for metal roofing systems in residential construction has identified an increase in the use of metal roofing products. The installation of the products is performed by companies familiar with metal roofing systems and reroofing is a large part of current sales.

The Metal Roofing Market

Exploring and understanding trends, markets, and technologies are vital to introducing innovative products to the home building industry. Known data sources for metal roofing of new and existing housing are identified and summarized below. In addition, new data from trade association sources was sought and is summarized below including a scrutiny for its soundness.

Trends. Overall, the quality and quantity of data available on the metal roofing industry are not good enough to identify and analyze trends with confidence. The size of the roofing market for new construction is large: over one million homes were built in the United States during 1994. However the small market share that metal roofing possesses in single-family homes—less than 1 percent—is not large enough to validate apparent trends. Further, because trade association data (the most detailed available) covers only two years, implications of any emerging trend is indeed risky.

Markets. Study of the roofing industry results in a fairly complicated analysis. While manufacturers of metal roofing are few and fairly easy to find through trade publications, installation contractors are numerous and small. Installers are more mobile than home builders and enter and exit the industry with ease, proving a more difficult data gathering exercise for researchers.

The residential metal roofing market is small, predominantly found in high-end houses. However, this exclusive market niche is well-established, with contractors obtaining jobs through builder referral. For home owners in this market, aesthetics—not short-term cost or long-term cost savings—is the most important aspect of installing a metal roof. Metal roofs are long-lasting, but most mass-appeal homes are marketed on a first cost basis.

Technology. Interviews showed that both metal roofing and photovoltaics are familiar to contractors, builders, and home buyers, and that these parties can visualize the marriage of the two. One key to the successful mass commercialization of a new product to compete with traditional products and systems, is that the product either decreases the initial investment of the home buyer or increases the value of the home.

Market Data Sources

Bureau of the Census. The Bureau conducts two major housing surveys. The bi-annual *American Housing Survey* samples about 60,000 homes to estimate and characterize the housing stock of the United States and the residents of those homes. The annual *Characteristics of New Housing (C-25)* surveys recent housing completions, and estimates the number and general attributes of those new homes. Neither survey addresses roofing materials.

The *Census of Manufacturers* estimates the number of manufacturers and the value of the products they produce according the *Standard Industrial Classification* (SIC). The SIC code for sheet metal work—3444—includes metal roofing. However, the Bureau does not estimate metal roofing separately from the overall sheet metal category.

F.W. Dodge. This private research firm conducts a detailed annual survey with home builders to characterize single-family and multifamily homes—both at national and regional levels. The reports lag the estimates by two years; 1992 is the most recent data available. While estimates of types and quantities of roofing have always been part of the survey, it was not until 1985 that Dodge began including metal roofing in their tabulations. The percentage of new homes using metal roofing and average amount of roofing per home as reported by Dodge are summarized in Tables 4 and 5 below. Note that in Table 4 single-family attached units are shown to use metal roofing at a higher rate than detached units.

Table 4
F.W. Dodge Estimates of
Percentage of New U.S. Homes with Metal Roofs

Unit Type	1985	1986	1987	1988	1989	1990	1991	1992
Single-Family Detached	0	0	0	0	0	0.2	0.3	0.3
Single-Family Attached	0	0	0	0	0	0.9	0.4	0.6
Multifamily Low-Rise	0	0	0	0	0	0.9	1.5	1.0
Percentage estimates of metal roofs were rounded by F.W. Dodge to no decimal places from 1985 to 1989.								

Table 5
F.W. Dodge Estimates of
Average Square Feet of Roofing per New U.S. Unit

Unit Type	1985	1986	1987	1988	1989	1990	1991	1992
Single-Family Detached	2,416	2,470	2,462	2,509	2,500	2,390	2,200	2,200
Single-Family Attached	1,253	1,313	1,451	1,524	1,300	1,280	1,220	1,270
Multifamily Low-Rise	638	614	634	642	600	570	570	530
Estimates of average square feet per unit were rounded by F.W. Dodge to the hundreds in 1989 and to the tens from 1990 to 1992.								

National Roofing Contractors Association (NRCA). NRCA conducts an annual market survey of roofing contractors for new construction and reroofing jobs on residential and commercial buildings. NRCA sends out 5,000 surveys (half to members, half to nonmembers) and receives about 500 responses. From those responses, NRCA survey estimates—for the nation and its regions—market shares for each type of roofing material, but it makes the estimate in terms of dollar value of the job rather than square footage of roof area.

For the United States as a whole in 1993, metal held about 6 percent of the value of new construction roofing and about 3 percent of the value of reroofing. The results are summarized in the graph and table below. For the four Census regions, while metal had its biggest percentage share in the Northeast (9 percent), by dollar value the South was the biggest market (8 percent or $14 million). Figure 19 and Table 6 summarize the NRCA results.

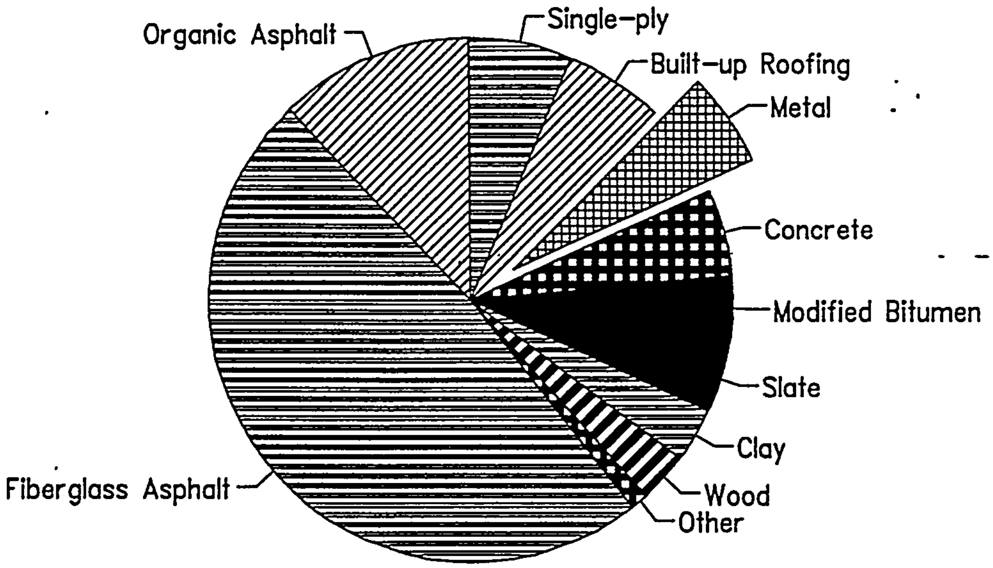


Figure 19
Contractor Installed Roofing on New Residential Construction by Value of Job
Source: National Roofing Contractors Association, 1993.

Table 6
NRCA Estimates of Roofing Market by Value of Job

Type of Job	1992		1993	
	All Roofing (in billions)	Metal's Share	All Roofing (in billions)	Metal's Share
New Construction	$0.60	1.5%	$0.60	5.7%
Reroofing	$2.58	2.7%	$3.50	3.4%

Metal Construction Association (MCA). MCA sponsors an annual metal roofing and siding survey, making estimates by square feet of product manufactured and the product's end use. In 1993, the survey drew responses from over 40 percent of the known manufacturers of metal roofing and siding products. MCA's report notes, however, that the response rate was lower among smaller firms. Whether this sampling bias towards larger firms skews the results is unknown.

The survey estimated that the industry fabricated over one billion square feet of metal roofing. Of that total, 9 percent or 90 million square feet was employed on single-family homes (presumably both detached and attached) and 3 percent went to multifamily strucutres.

The survey breakes out the metal roof market by region, steel versus aluminum, and product thickness, but it does not differentiate roofing by product style (e.g., standing seam versus 5-V crimp). Figure 20 below shows MCA's estimate of what types of building metal roofing is used.

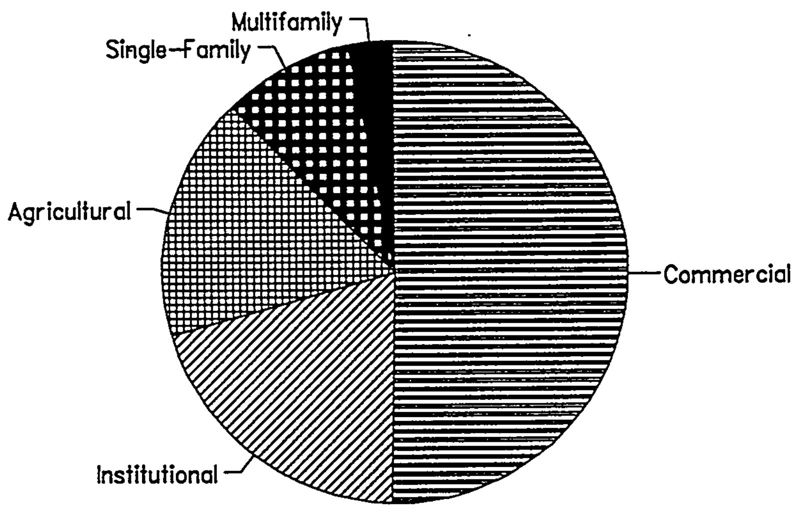


Figure 20
Distribution of Metal Roofing on Buildings.
Source: Metal Construction Association, 1993.

MCA breaks the United States out into five regions (in contrast to the four that the Bureau of the Census uses) without listing what states fall into which regions. The distribution of metal roofing falls about evenly into the five regions: Northeast, North Central, South Atlantic, South Central, and West.

Interpretation of Data

The surveys from Dodge, NRCA, and MCA do not and cannot be made to coincide for several reasons. Neither the Dodge nor the NRCA survey has a sufficient response rate to be considered a complete and unbiased representation of builders and contractors. (Surveys conducted as these are typically have response rates of under 10 percent.) Bias is a result of over representation of one segment of a population in a survey. The effort to meld the surveys is hampered by the possibility of bias and is a reason for skepticism of the NRCA results. For example, while the estimate of total value for the New Construction roofing market did not change for the United States as a whole from 1992 to 1993, metal's share of that market increased nearly four fold over the same period. If the NRCA sample size is small compared to the total number of roofing contractors, then the inclusion of a few contractors who exclusively install metal will greatly skew the results.

Further, because the surveys measure different variables, there is no clear way to compare their results, and data that appears to suggest a connection may simply be coincidence. In comparison to the Dodge and MCA results, NRCA's measurement of metal roofing use by the value of jobs will overstate metal's relative market share because of higher material and installation costs relative to other roofing materials such as asphalt shingles. Telephone interviews with manufacturers and installers suggest that the installed cost for standing seam metal roof is between five and ten times that of asphalt shingles.

Given these suspicions of the reliability of the survey results and not knowing the characteristics of the underlying sample or population, it may be best to discard the results of these three surveys outright and rely, instead, on field interviews and anecdotal evidence. The MCA survey claims to have a sufficient response rate to put some credence in its results; at least it is a good point from which to start and shape in-depth field interviews.

Evaluation of Metal Roof Market

The range of estimates for residential metal roof application varies tremendously. Dodge estimates that about 0.3 percent of single-family home built in 1992 used metal roofing. Using the Dodge estimate of average square feet of metal roof installed per home and the estimate of starts supplied by the Bureau of the Census, this equates to about 9 million square feet of metal roofing in single-family application. By contrast, MCA estimates the single-family total at 90 million square feet—a ten-fold difference. Estimates made by NRCA (even if convincing) are proportionally higher because they estimate job value and metal roofing has a much higher value job than other roofing materials. Given the difficulty in estimating the metal roofing market as a whole, attempts to quantify the relative market shares for different types of metal roofing—such as standing seam and 5-V crimp—will prove even more perplexing.

National and regional trends in roofing are difficult to tell without consistent, reliable, and long-term data. Again, reliance on anecdotal evidence—obtained through in-depth field interviews—may prove most revealing and least costly.

Sources of Cost Data On Roofing Materials

RS Means. This widely used and respected cost estimating guide looks at each component part of homes with respect to material, labor, and installed cost. The data are presented as nationwide averages with locality multipliers. The latest data available are 1994.

Means estimates that the cost to the general contractor of an asphalt roof, inorganic, Class A, 210 to 235 pound per Square is $0.63 per square foot. After a 10 to 15 percent general contractor mark-up, the cost to the home buyer is about $0.70 per square foot. By comparison, a 25 gauge standing seam roof costs $6.60 per square foot installed and about $7.25 to $7.50 per square foot after general contractor mark-up. Cost is about evenly split between installation and materials for both metal and asphalt roofing.

Fine Homebuilding. In its December 1994/January 1995 issue, *Fine Homebuilding* presented the article, "Choosing Roofing". Though the great majority of the article was devoted to architectural, aesthetic, and wear characteristics, it also presented an outline of the range of roofing costs the magazine found in its research. Table 7 summarizes the results.

Table 7
Comparison of Roofing Materials

Cost per square foot	Asphalt	Metal
Material	$0.25-0.56	$0.35-2.50
Installation	$0.65-1.25	$0.35-4.00
Source: *Fine Homebuilding*, Dec. 1994/Jan. 1995, p.49.		

Neither the table nor the article specify the type, grade, or weight of the material compared. The cost data for metal probably combines standing seam with other less expensive products.

Telephone Interviews. With the exception of American Buildings Roofing, the installed cost to home owners for a standing seam metal roof was between $4.50 and $8.00 per square foot of roof.

Metal Roofing Interviews

Since little or no quantitative data exists on metal roof prices and installation practices, the Research Center sought qualitative or "real world" data through interviews with metal roof manufacturers and installers. The comments and experiences noted below are attributable to the people that were interviewed and cannot be accepted as valid generalizations concerning industry experience with metal roofing. However, the value of interviewing lies in its potential to describe a range of practices as well as to design further study.

Using *Metal Architecture*'s "1994 Metal Roof Systems" issue (November 1994) as a reference, manufacturers and the installers they recommended were interviewed by telephone between January 3 and 12, 1995. Topics for the interview included:

- types, widths, and finishes of metal roofing typically installed on homes;
- location of roofing fabrication (in-plant or on-site);
- installed cost to home owners;
- market segment or price of homes typically using metal roofing;
- marketing efforts;
- the level of installation training that contractors receive;
- any installation problems encountered or any area of installation that requires particular attention to detail; and
- the likelihood that standing seam and photovoltaics can be integrated and accepted by home buyers.

Champion Metals, 8981 Huff Avenue, Brooks OR 97305, 503-390-5121

Champion produces a one-inch high 12-inch o.c. standing seam with concealed fasteners, coated with SMP.

Kerry Keebler
KAK Construction, 503-399-3636/503-585-2870

A long-time builder who learned the trade from his father, Mr. Keebler says that about 60 percent of his roofing business is now in standing seam, and the majority of this work is reroof. His materials come factory-order, though he makes trim pieces in the field.

His cost to the home owner is 78 cents a linear foot. (This is the only installer to quote a price in linear feet. The quote translates to 78 cents per square foot based on Champion's 12-inch o.c. product.) In his geographic area, this is about double the cost of asphalt roofing, about equal to wood, and less than tile. Mr. Keebler says these comparisons can vary even in a small area such as Portland OR, though he did not state a reason for believing this.

Mr. Keebler began building with his father at age 13 and sees a progression from those learned skills and experience with metal and vinyl siding to his current work with metal roofing. He stated no formal training.

Vent pipes and other penetrations of the roof do not pose any problems for KAK Construction; boots do the job. If there are any areas of concern it is the "valleys" where roof lines change direction (such as at ells or dormers) or where pitch changes. Mr. Keebler trusts his crew to solve these problems by "imagining where the water flows."

Tom Carroll
Rib-Roof Industries, 2745 N. Locust Avenue, Rialto CA 92376, 909-875-8529

This San Bernadino-area manufacturer of standing seam has sold but six residential metal roofs in the last eight years, the most recent on a 5,000 square foot "log cabin". Mr. Carroll says that he cannot compete with tile roof in Southern California. Installed, standing seam roofing costs $4.50 a square foot; tile costs between $1.15 and $1.45 a square foot. Because of the threat of fire, wood roofs are not permitted in Southern California; asphalt is permitted in special circumstances.

Bill Chandler
MetFab, 7450 Montevdeo Road, Jessup MD 20794, 410-799-1414

MetFab manufactures a variety of metal roof products including a 12-inch o.c. standing seam for residential application. Mr. Chandler—a former builder and installer—sees very few metal roofs in the Washington-Baltimore area. Those he has seen were on out-of-the-ordinary jobs where cost ranged from $800 a square for a reroof in old-town Alexandria VA to $2,200 a square for a 18/12 pitch roof on a high-end home in Potomac MD.

Mr. Chandler says that while MetFab offers no formal in-plant training, they do offer "guidance" to installers—something he says is more than most fabricators do. Installers get training and experience from other installers, following SMACNA (Sheet Metal and Air-Conditioning Contractors' National Association) guidelines. Mr. Chandler sees no particular areas of concern in installation; rubber boots work fine on vent pipes.

Tom Goode
Goode Roofing, 410-686-7558

Recommended contact for MetFab; did not return phone calls.

UNA-CLAD, 1405 N. Highway 169, Minneapolis MN 55441, 800-426-7737

UNA-CLAD manufactures no-clip and standing seam, 24 ga, 9½ to 29½ inches o.c., covered in Hynar or Kynar.

Specialty Systems, 612-894-5111

An installer of standing seam, this company does mostly commercial properties but will do residential jobs. Homes generally use 16-inch o.c. standing seam that costs between $6 and $8 a square foot installed. Specialty Systems's representative says that, to these home owners, the look of the roof is the most important selling point; many homes with standing seam are on lakes.

With the price of these homes, the relatively high cost of standing seam, and "R-50 in the attic", the representative does not see the cost of fuel or the electricity-producing capabilities of PV as important concerns for these home owners.

Proper installation is especially important in snow country where exposed screws and improper installation can cause snow to grab and pile up. Concealed clips are vital.

Specialty Systems has not experienced any problem areas—provided that plumbers place vent pipes as instructed. And if the plumbers do not follow instruction? "We tell them to saw [the pipes] off and move them," the representative says.

Lee Ann Morris
Fabral, PO Box 3618, Jackson GA 30233, 404-775-4484

This manufacturer of "Stand'N Seam" near Atlanta makes its most popular product in 16-inch o.c. Galvalume®. The company has not yet begun marketing in the Atlanta area; Florida remains its most important market.

Bill Alexander
813-286-2493

Sales manager for Fabral in Florida; did not return phone calls.

MBCI, Richmond VA, 804-526-3375

MBCI makes standing seam in 26, 24, and 22 gauge Galvalume® in widths of 10, 12, and 18 inches o.c., finished with silicone or Kynar. MCBI's representative says that material costs run around $3.00 a square foot; installation costs about $300 a square.

MBCI Richmond has seen little metal roof in residences—only one Florida room roofed with metal—and, therefore, is not aware of any particular problems or concerns associated with it.

MBCI, Tampa FL, 813-752-3474

The best sellers for MBCI Tampa are 12-inch o.c. screwed Craftsman panels as well as "true" standing seam.

Fred Mauser
PDF Roofing, Sarasota FL, 813-359-1199

The majority of PDF's total business is in 5-V crimp, though they do a great deal of residential work in standing seam on exclusive custom homes. Installed prices: $2.25 per square foot for 5-V, $4.50 for standing seam. Mr. Mauser believes his overhead costs would be lower if it were not for Florida's high worker compensation rates. Roofers in Georgia and Alabama have lower labor costs, he states, but would have to bear the costs of travel or relocation if they sought work in Florida.

Mr. Mauser estimates that 90 percent of their business is referral, so they spend little time marketing their services and products. Durability and aesthetics are standing seam's main selling points. Many applications are on homes at water's edge or those designed in a "Key West" style.

Salt water is an area of concern, but stainless steel screw appear to overcome any problems. The use of PVC vent pipe, neoprene underlayment, and aluminum frames (?) take care of penetration concerns.

Mr. Mauser says that his customers should be very receptive to innovative PV panels; he sees a lot of solar applications already. Roll-outs should fit into the use of standing seam quite well, provided it is installed by a professional. Solar panels installed on PDF jobs by someone other than PDF voids the roof's warranty.

Jerry Woodward
American Buildings Roofings, PO Box 800, Eufaula AL 36072, 205-687-2032

American produces both structural and architectural standing seam, with the majority of its products going to commercial applications. The architectural roofing, "Loc Seam", is 24 gauge with 2-inch ribs in widths of 12 and 16 inches o.c. Kynar 500 provides the finish.

Installation Training

Only American claimed to have a program of in-plant installation training. Installers generally have experience installing conventional roofing and/or siding materials. The implications are two-fold. First, if contractors know only conventional materials, installer labor costs remain higher than for experienced metal installers. Wasted time and wasted materials are the norm until crews learn to use the different tools and materials. Second, if contractors are coming from the siding business, their crews will be unfamiliar with roof geometry and safety. Here, too, wasted time and materials are the result.

Installation Problems

Neither manufacturers nor roofing contractors identified any particular areas of installation that require special attention to detail. Smart installers—following SMACNA guidelines—usually avoid problems. None of the interviewees identified any concerns switching between commercial and residential jobs.

Standing Seam and Photovoltaics

Many manufacturers and installers had no opinion on how an integrated roof/PV product might fare in the marketplace. However, all interviewees knew what photovoltaics do and agreed that a technically successful marriage of standing seam and a roll-out PV product can take place.

The contractor contacted in Florida sees a great number of active solar applications currently and he believes that the roll-out/standing seam combination could find a niche in his market. His only hesitation would be home owners or unqualified contractors attempting to retrofit the product to existing roofs, thus voiding the roofs' warranties. By contrast, the contractor in Minnesota sees little added value in installing photovoltaics: people with money enough to install standing seam surely do not worry about the cost of electricity.

Mr. Woodward says that American provides its installers with a 4-day in-plant training program, a program required to validate the roofing's 20-year warranty. American also employs third-party inspectors to ensure that its products are installed to specifications.

Mr. Woodward claims that the installed cost to home owners is between $1.50 and $2.00 a square foot. [The accuracy of this price quote is in doubt considering the quotes from other interviewees. Labor rates and material costs are not so much lower in Alabama as to make standing seam one-third the cost of similar installations in Florida. Mr. Woodward promised to provide the names of some residential roofers; to date, he has not provided those names.

SUMMARY

Types, Widths, and Finishes

Standing seam appears to be the predominant metal roof installed on American homes. The exception to this is in Florida, where there is a fair amount of 5-V crimp done. Residential widths are typically 12 and 16 inches o.c. Kynar seems to be the most widely-used finish.

Fabrication

All the manufacturers and contractors interviewed do only custom, factory-ordered work. Installers can do some trim work in the field.

Installed Cost

With the exception of American Buildings Roofing, the installed cost to home owners was between $4.50 and $8.00 per square foot of roof.

Market Segment

Because of the high cost relative to asphalt (and clay in California), standing seam is used on high-end homes where aesthetics are very important to the home owner. It appears that standing seam is used often on homes that front water. The importance of the aesthetics of standing seam over conventional roofing materials appears a real advantage in the marketplace. The high cost comes equally from both materials and installation labor, so any attempt to reduce installed cost to the home owner has to come from both sides.

Marketing

As a result of the dominant high-end market segment, contractors do not do a great deal of marketing to builders or perspective home owners. Instead, they rely on referrals and consumer inquiries.

APPENDIX “B”

NAHB RESEARCH CENTER FINAL REPORT:

COMMERCIALIZATION STUDY FOR PV-SHINGLE

AND

PV-METAL ROOFING MODULES

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Figures

PURPOSE AND SCOPE

The objective of this report is to assess strategic options for the distribution of photovoltaic (PV) shingles and metal roof modules in residential and commercial building markets. To accomplish this goal, it outlines existing and potential channels of distribution and evaluates their advantages and disadvantages for the commercialization of two types of integrated PV products. The study discusses issues related to the marketing or packaging of integrated modules with the balance of system components (BOS) and evaluates their potential impact on existing and proposed channels of distribution. It analyzes the terms and conditions of warranties offered by major shingle and metal roof manufacturers and their implications for the commercialization of integrated PV modules. The report is based on articles on roofing in journals and telephone and field interviews with manufacturers of metal and shingle roofs, roofing contractors, and builders.

CHAPTER I
ROOF PV-SHINGLE MARKET AND DISTRIBUTION

BACKGROUND

The three styles of asphalt shingles most commonly manufactured are: 3-tab asphalt or organic shingles; asphalt-fiberglass shingles; and, architectural or layered shingles that emulate the look of another material such as cedar shakes. All the shingles mentioned above are constructed around a base or mat of either organic felt or fiberglass. The organic mats, similar to roof felts are heavy and impregnated with soft, flexible asphalt. The fiberglass mats, on the other hand, are not impregnated with asphalt, and, as a result, are both thinner and lighter. For fire protection and bulk, the mats of both types of shingles are coated on top with a hard layer of asphalt stabilized with finely crushed filler such as such as ground limestone or slate. This layer is, in turn, capped by larger granules of colored, ceramic coated rock which protects the shingle from the damaging effects of the sun's ultraviolet radiation. Most asphalt shingles have an adhesive sealing strip which bonds shingle layers after exposure to the sun to increase their resistance to blow-off.

Fiberglass shingles carry a high underwriters laboratory (UL) class A fire rating while organic shingles carry a class C rating. Organic shingles are generally heavier, more expensive, have a better resistance to tearing and cracking, and perform better in cold weather. Fiberglass mat shingles, which comprise 90 percent of the asphalt shingle market, are lighter, less expensive, and have a superior fire rating. More details on the implications of these characteristics on the integrated PV-shingle are contained in a later section of this report on warranties.

Wood cedar shakes occupy an extremely small niche in the shingle market and generally follow the same pattern of distribution as the more popular asphalt shingles. Other roofing materials such as slate, clay tile, cementitious shingles, and recently commercialized plastic roof coverings occupy niche markets that are sufficiently different in form and application, not to be considered part of the shingle market for the purposes of this study.

THE RESIDENTIAL AND COMMERCIAL MARKET

The residential low-rise construction market is the primary outlet for shingled roofing, although some low-rise commercial buildings use shingles in an attempt to assume a "rustic" or residential look. For the most part, distribution of shingles to the commercial market is the same as that for the residential market, with the exception that an architect is more likely to be involved in the choice or specification in regard to style, color, and type of shingle.

NEW CONSTRUCTION AND RETROFIT

Retrofit roofing or re-roofing is estimated to account for from 70 to 80 percent of the total market for roofing shingles with new construction amounting to only 20 to 30 percent. Roofing subcontractors are important decision makers in both markets, particularly the retrofit market, while builders are more involved in the new construction. It is estimated that in the retrofit market 90 percent of the shingles are purchased by roofing contractors, while the customer base in new construction is about 60 percent roofing contractors and 40 percent builders.

DISTRIBUTION

The principal channels of distribution for shingles are roofing supply houses,[1] home centers, lumber yards, and manufacturer's distribution centers (See Figure 1). Roofing supply houses are considered wholesalers, while lumber yards and home centers are characterized as retailers. The bulk of the market is served by roofing subcontractors who perform retrofit installations and obtain their shingles through specialized roofing distributors. On the other hand, builders who put more emphasis on new construction use a wider variety of channels, but tend to favor lumber yards for distribution of their roofing products.

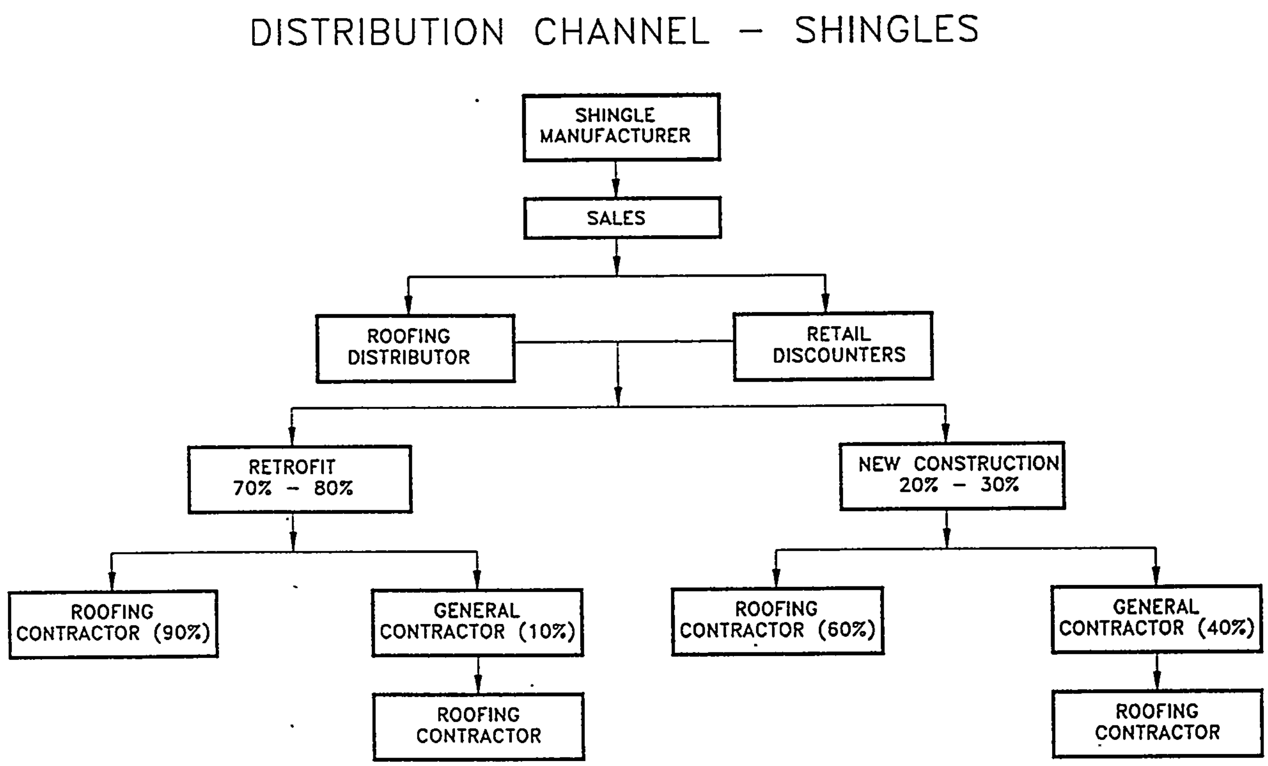

Figure 1
Shingle Distribution Channel

Data from a recent survey of the channels of distribution used by builders, conducted by the National Association of Home Builders (NAHB)[2] support these observations. They indicate that

[1] The term roofing supply house is synonymous with roofing dealers, roofing distributors, specialized roofing distributors or suppliers, used elsewhere in this report.

[2] National Association of Home Builders, Economics Division, *1994 Home Builder Industry Survey*

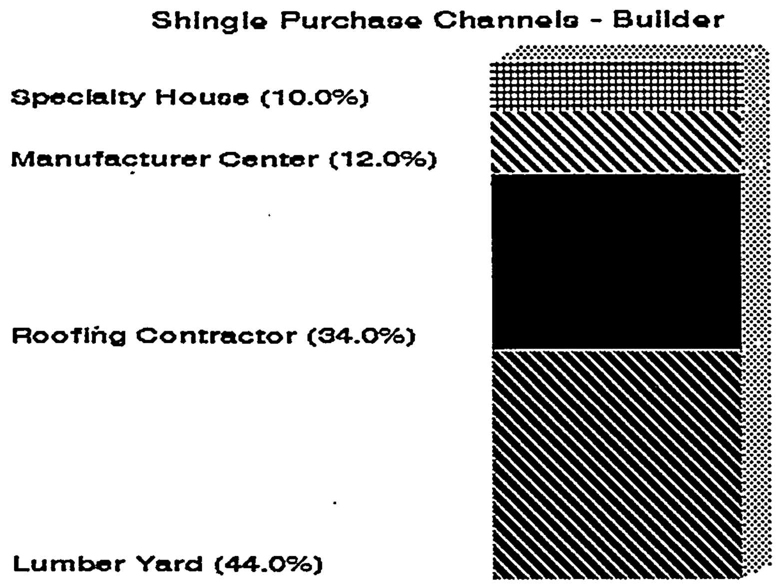

Figure 2
Shingle Distribution Channel

the largest segment of the building community, about 44 percent, rely on lumber yards for their roofing materials. The next largest portion of the builders, about a third, rely on roofing contractors to purchase their materials who, in turn, primarily use specialty roofing supply distributors to obtain their shingles. The manufacturer's distribution centers and specialized roofing supply houses are the next most important channels of distribution with shares of 12 and 10 percent, respectively. (See Figure 2.)

Roofing Distributor

The principal customers of shingle manufacturers are the roofing distributors. The roofing distributors, roofing supply houses, or dealers are often called one-steppers, because they purchase directly from the manufacturer and sell directly to the roofing subcontractors or builders in a one-step distribution process. Roofing contractors that have several crews and buy larger volumes are more likely to deal with roofing distributors because they carry larger quantities and a greater variety of shingles. Depending on local arrangements, the distributor may give discounts for large volumes. In this respect, the roofing distributor functions as a wholesaler. It is estimated that about 80 percent of the total shingle market uses one-steppers and that most, about 70 percent, of the re-roofing portion of the market use this distribution channel.

Shingle products are heavy and transportation to the site can be a significant irritant and cost for the manufacturer. This reason, among others, is why distributors are located in every region of the nation close to customers. This is particularly important in the residential sector where customers are dispersed and ubiquitous. Most distributors tend to specialize only in roofing and ancillary roofing products, but this varies among and within regions. In the Northeast and Midwest, for example, roofing distributors may also carry windows and siding, but in California they traditionally specialize only in roofing products. In the region around Washington D.C. both types exist: Washington Roofing is large distributor that specializes in roofing and flashing materials while Sinclair carries some other building products, but not the broad-based line of all building products carried by the large building supply or home centers such as Home Depot, Lowes, or Hechingers.

Home Centers

The home centers such as Home Depot in one sense are distributors, since they buy direct form the manufacturer, but they actually are retailers since they sell without any price differential not only to builders and roofing contractors, but to home owners involved in the do-it-yourself market. Because of their large customer base and ubiquitous location they exert considerable buyer power and influence over the manufacturers. Based on their ability to purchase large volumes of product, they are able to gain discounts by buying directly from manufacturers and selling at lower prices than other suppliers. Since home centers advertise in the mass media, they obtain considerable market pull from the consumer and use the manufacturer's trade name and brand recognition to their, rather than the manufacturer's, advantage. Manufacturers are not always happy to see their product advertised at a lower margin and price than they sell to other suppliers. Since roofing is one product among many, the home centers neither have the knowledge, expertise, or time to inform and guide the customer in the details of roofing products nor can they to afford to provide the space to carry a wide variety lines consisting of more specialized and higher priced items. They therefore tend to focus 80 percent of their roofing products on large volume, low-price, homogenous product lines that have quick turnover and make maximum use of their limited space. Some higher-priced architectural PV-shingles, however, are beginning to find space in the home center's inventory.

Lumber Yards

The other principal channel for distribution of shingles is the lumber yard. Since a lumber yard normally does not deal directly with a manufacturer, it is usually involved in a two-step distribution process, buying product from a roofing distributor or manufacturer's distribution center (see below) and re-selling it to builders and roofing contractors. The roofing distributor in this case is no longer a one-stepper and the insertion of the lumber yard into the distribution chain adds to the cost of the final product. This channel is most popular with builders involved in new construction because the lumber yard is familiar and convenient, often used for the distribution and purchase of their other building products. In this respect, the lumber yard functions as a retailer and carries a more limited quantity and range of roofing products for builders and roofing contractors purchasing small quantities. Some do-it-yourself (DIY) customers or remodelers involved in very small projects may also use this channel.

Manufacturer's Distribution Centers

Some of the larger integrated manufacturers that sell lumber and other building products in addition to roofing, principally Georgia Pacific and to a lesser extent Macmillan Bloedell and Weyerhaueser, do not deal with one-steppers. Instead they use a two-step distribution system in which they distribute to their own supply centers which in turn sell to lumber yards. Since they produce and sell a broad product line which includes lumber, nails, etc., they are able to achieve economies by allowing their roofing products to share distribution with their other building products and to take advantage of traditional relationships they have already established with builders through lumber yard channels that sell their other products. About 12 percent of builders, however, deal directly with the manufacturer's distribution center, avoiding the more circuitous and costly two-step distribution process.

CUSTOMERS

Customers and/or users of the shingle product near the end of the distribution chain are either the roofing subcontractors (or contractors) and the home builders (frequently referred to as general contractors). In either case, builders exercise responsibility for deciding on price, general style, and budget subject to the general requirements agreed to with the consumer or home buyer. For example, the builders help narrow down the choice for consumers, particularly in regard to the level of warranty desired, generally 20, 30, or 40 years (see detailed discussion in section on warranties). Once the builders make the basic choice in this manner, they or the roofing contractors will make more detailed cost estimates and go to the roofing distributor or lumber yard to obtain the best possible price within the agreed budget and style. If the builder's contract with the roofing contractor is for labor and materials, the roofing contractor will bargain with the distributor and be the purchaser. On the other hand, builders may prefer to buy materials and leave only the installation to the roofing subcontractors. The method of purchase and, therefore, the type of customer varies by tradition or individual circumstance rather than following any guiding principle or rule.

Roofing manufacturers tend to focus their sales effort on roofing contractors and traditionally do not deal directly with the builder, according to one builder. As noted above, a significant portion of the builders deal with lumber yards and are one step removed from the manufacturer. Manufacturer's have attempted to influence the builder indirectly by advertising their products to the consumer on the expectation that homeowners or potential home buyers would exert their influence and pull the product through the market. Attempts to influence the builder's purchasing decision by appealing to the consumer has been reenforced by the increasing popularity of home centers which also cater to the same market and use mass media advertising. Some, however, believe that this strategy is changing and that manufacturers are beginning to direct their marketing efforts to builders. Indeed, manufacturers employ regional salesmen that are responsible for working with distributors and retailers explaining the product line, setting up displays, acting as technical representative, and helping with claims. These salesmen work with builders as well as roofing contractors to pull sales through the market.

IMPLICATIONS: ADVANTAGES AND DISADVANTAGES OF DISTRIBUTION CHANNELS

Each supply chain or channel has distinct advantages and disadvantages that have implications for the commercialization of a PV-shingle module.

Specialty Roofing Suppliers or One-Steppers

Roofing suppliers handle a variety of competing products and therefore serve as one source where a roofer or builder can compare prices, colors, and styles of a large variety of roofing products and obtain the quantities they want. This type of supplier is therefore more likely to handle specialized items. In maintaining an inventory at the local level, arranging for transportation to the site, offering credit, doing the billing, explaining the value of different products, and giving technical advice, they perform essential services that a more centralized manufacturer would find inefficient, difficult, and costly to provide. Moreover, dealing directly with both the manufacturer and customers -- the roofers or builders -- they eliminate an extra step in the distribution chain that might add margin to the product thereby raising the cost of the product to the ultimate consumer, the home owner. The one exception to this is when the suppliers become distributors to lumber yards in a two-stage distribution chain.

On the other hand, manufacturers have less control over the sale of their product in this method of distribution and can never be sure of the extent to which the roofing suppliers are fairly representing or promoting their products in comparison to competing products. Nor can they always be assured of the technical competency of these distributors in explaining their products or giving advice on their installation, which can be important in avoiding claims. This is the reason for the expensive sales force maintained by manufacturers. In one sense these suppliers are really small, one-stop specialty retailers, since they give no special discounts to small contractors in the roofing trade for purchasing products from them, offering the same price to general customers such as builders. Price therefore does not tend to guarantee the loyalty of a small roofing contractor to a particular supplier. Instead, loyalty is maintained in arranging terms of credit, offering sufficient quantities, variety, and handling quantities of orders expeditiously and efficiently. The suppliers, however, do offer discounts to larger roofing contractors or general contractors who buy in big volumes.

Given the roofing distributor's capacity to carry a large variety of more specialized products, they are more likely than other channels to handle a special line such as a PV-shingle module. Handling the PV module, however, may be quite different from stocking it. Given the high cost and the specialized nature of the PV module, it would most likely be attractive only to a very small niche market of high-end custom homes, contributing to a very low product turnover. Distributors would therefore be unlikely to stock the product on the premises, but would probably have to order it on demand from the manufacturer as a special item. Such special orders would add to the cost of the product, since some of the advantages of local distributor in assuming the manufacturer's transportation costs and carrying inventory would be negated. Furthermore, the specialized roofing supplier might not be the best channel to reach the high-income custom market which is more likely be served by a small builder through a lumber yard or a manufacturer's center, rather than a roofing contractor and a roofing supply house.

Lumber Yards

Lumber yards are intermediate between the specialized roofing supplier and the home center. Like the home centers, they offer convenient one-stop shopping for the builder, but with a narrower range of products. Lumber yards that obtain product from roofing distributors or manufacturers' centers add a step and, therefore, costs in distributing the product. Although they carry a variety of products in addition to roofing, they do not carry the assortment of shingles offered by the more specialized roofing distributors. On the other hand, since their other building product lines are not as broad as that of the home centers, they are likely to stock a wider variety of roofing products than home centers. Unlike the larger home centers and despite the extra cost they may add in distributing product, they have been able to capitalize on the sale of the basic lumber commodity to reach out to small builders who predominate in the industry and establish a more personal relationship and trust based on the greater flexibility they can provide on terms and conditions of sale. The are more likely to provide competent technical advice on roofing than the home center, but are less adept in this regard than the specialized roofing contractors. In general, given the competitive pressures, the lumber yard is less inclined to stock or special order a specialized, high-priced item such as a PV module and even less equipped to offer technical advice on its installation.

Home Centers

The home centers are generalists that function as both distributor and retailer. They focus on popular-priced roofing products produced in high volume for quick turnover. They are not suited to serve specialized, high-priced, niche custom house markets that might be interested in a PV-shingle module and would contribute to low turnover in inventory.

Manufacturer's Centers

The extent to which manufacturers' centers rely on lumber yards to retail their roofing products, they have some of the same advantages and disadvantages in distribution as lumber yards, but they have added advantages that cannot be duplicated by other roofing product channels. In some cases, they also act as one-steppers and share some of their advantages of a one-stepper. For example, the 12 percent of builders who purchase directly from manufacturers' distribution centers not only avoid the circuitous two-step distribution process, but some may have more direct access to the high-end market than typical roofing contractors who deal with roofing suppliers. Moreover, the "deep pockets" of integrated manufacturers and their singular focus on one product line to the exclusion of competing products may indicate that they would be more able and willing to assume the risk in marketing the PV-shingle product and assure adequate technical and sales support. The manufacturers' centers offer manufacturers decentralized distribution, but at less ubiquitous locations than lumber yards. Consequently, they could provide a less risky, more economical, intermediate, and convenient distribution point for stocking the PV-module, reducing the expense involved in special ordering from the lumber yard. The PV-shingle module would have the advantage of sharing the channel with complimentary building products of a large integrated producer and add to the competitive advantage of the manufacturer's product line, since at the integrated module's current stage of development, it has very little competition.

SUMMARY

Given that PV-shingles are high-cost, specialized products serving a small niche market, two of the available channels appear to be most suitable for their distribution. Roofing distributors carry a wide assortment of roofing shingles including the more expensive roofing shingles for the high-end market. Some of the more aggressive distributors may be willing to sell the PV- shingles on special order rather than carry them in stock. Manufacturers' centers, on the other hand, carry variety only within their own product line, but have more financial resources to invest in riskier products and good relationships with builders who have a better chance of reaching high-end markets. As a result, they may be willing to stock them at their centers, thereby lowering the cost of distribution.

None of the available channels have the capability to advise builders or roofers on the amount of modules needed or their installation. Roofers would have to be trained to install and handle the modules. Instructions would have to be detailed but simple. A manufacturer's representative and/or an architect would have to assist in defining the square footage and the placement of the modules based on orientation and the customer's desires with regard to applications served by the PV (See Figure 1).

CHAPTER II
PV-METAL ROOF MARKET AND DISTRIBUTION

BACKGROUND

Metal roof manufacturers, often called roll-formers, receive metal in coated coils and cut and form it to a particular length to produce roof panels and details for metal roofs. Under a single billing system, roll-formers purchase bare steel, metal-coated and painted, from one of the large steel mills. In this system of payment the roll-former chooses a coater from a list provided by the mill who sends the steel to the selected coater for painting, who then ships it to the roll-former. The price of the raw material, metal coating, and painting is consolidated in one bill. Choice of coater is based on the experience, quality and location of the coater. For example, certain coaters are closer to the manufacturer and its shipping lanes, allowing it to back haul[3]. Based on customer demand, the manufacturers specify to the steel mill the sheet metal's attributes in terms of the desired thickness or gauge of the steel, the tensile strength (grade E -D), metallic coating (galvanized, aluminum, or galvalume) and type paint or coating (polyester, siliconized polyester, flouropolymer - Kynar or Hylar 5000). PV-Metal-coated steel is shipped directly to coil coaters who clean and degrease, prime, dry apply a finish paint coat, dry, put on a top-coat, and recoil the metal for shipment to the manufacturers. Manufacturers may market as many as 15 colors, some of which they may stock in inventory while they special order others.

The base sheet metal for roofing is bonded with a thin layer of corrosion-resistant metal at high temperatures over 1,300 F. The galvanized metal coating for roof panels is a pure a zinc coating usually designated as G-60 and G-90, equal to .60 and .90 ounces of zinc per square foot, respectively.[4] Zinc is water soluble and slowly oxidizes to protect the base metal. Its life depends on its thickness and its exposure to moisture. Although unpainted galvanized roofs on steep roofs in dry climates can last as long as 30 years, low-slope roofs in moist climates may corrode in only five years. A pure aluminum coating on steel, commonly designated as aluminized or Type II, is inert, providing better protection than a galvanized coating, it is typically warranted in normal climates against corrosion for 20 years in slopes as low as 1/4 in 12. A aluminum-zinc alloy coating, called galvalume, combines the advantages of both zinc and aluminum and is better than either one. Its typical designation of AZ-55 indicates a coating of 55 ounces per square foot, composed of 55 percent aluminum and 45 percent zinc, which can last longer than its usual warranted life of 20 years. A later section of this report on warranties discusses the implications of these characteristics in more detail.

All roof paints are composed of pigment, solvent, and resin. The solvent is the medium that carries pigment to the panel surface. The pigment consists of particles of color suspended in the resin which acts as a binder protecting it from moisture and air pollution. A paint finish is

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[3]Rather than have a truck return empty after delivery of its load, it is to the firm's economic advantage to pick up another load near the point delivery to be transported back to the point of origination.

[4] The discussion that follows in this section is based, in part, on Rob Haddock, "Low-Cost Metal Roofing", *The Journal of Light Construction*, June, 1992, pp. 19 - 22.

usually warranted against chipping, cracking, blistering, peeling, fading, and chalking for different periods of time depending on the quality of the paint used. A good paint properly applied on a

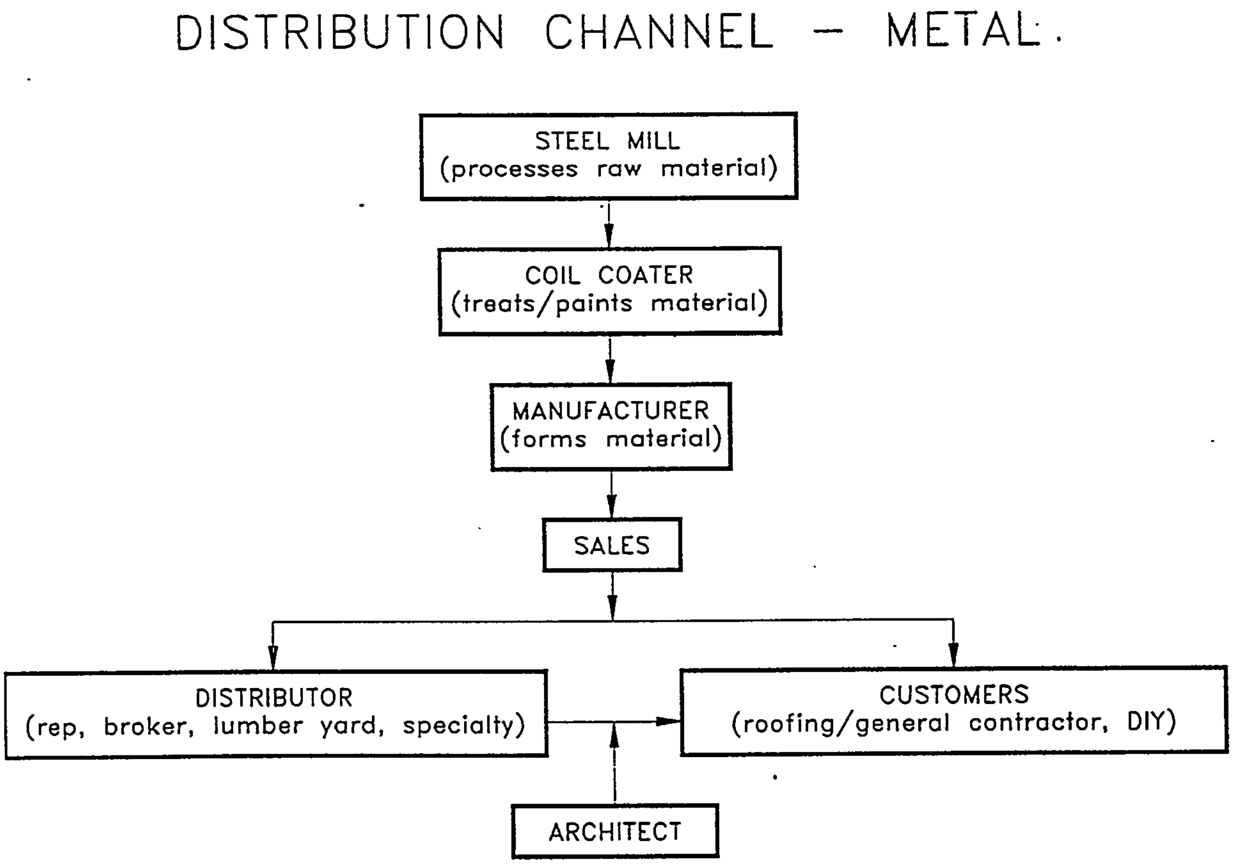

Figure 3
Metal Roofing Distribution Channel

metal panel will last (retain its color) for 30 years or more without cracking, blistering or peeling. Some colors, notably those that are red or are closer to primary values fade more rapidly than others. Also, more expensive inorganic pigments are less likely to fade. Chalking occurs when exposure to ultraviolet light degrades the resin, turning it into powder which accelerates fading. All pigments fade somewhat. As a result, warranties are always conditional and will not cover fade beyond a certain level or period of time.

Paints can be classified according to their resins which give them their different weathering characteristics. Inexpensive polyester resins are available in almost all colors, but their gloss and color does not last very long and they are usually not warranted for gloss retention, fade, and chalk. Silicon-modified polyester resins, consisting of different blends of polyester and silicon, are more expensive than polyester but perform better, especially with higher silicon content. Some grades have 20-year warranties. Flouropolymers, commonly known as Kynar or Hylar, are the most expensive of the resins and chemically their composition is close to teflon. They normally have 20-year warranties against excessive fade and chalk. A later section of this report contains a more detailed discussion of paint finish warranties.

THE RESIDENTIAL AND COMMERCIAL MARKET

The metal roofing industry is still largely oriented to commercial building. Unlike PV-shingle roofing, considerable difference exists in the channels of distribution between commercial and residential buildings. The distribution of commercial roofs is largely direct, from manufacturer to roofing subcontractor and to a lesser extent to builder-contractors. The intermediaries that do exist are largely salesmen, not retailers or wholesalers with stocks. On the other hand, dealers who carry an inventory of the manufacturer's product are much more common for the smaller residential segment of the industry, largely because of the dispersed locations of the residential customer base. Because the residential market is small and in its infancy, many lines of distribution are tentative. As a result, a larger number of alternative channels are available to the residential customer and distribution is much more complex (See Figure 3).

According to one roll-former, metal roofing has been slow to penetrate the residential market because the more demanding home buyer has a poor image of metal roofing based on appearance and such problems as "oil canning" that has sometimes occurred in agricultural and industrial metal roofs. Also, costs of metal roofs are high in comparison to residential roofs. Metal roofing is now installed in packages of 29 to 30 squares by sheet metal workers whose labor rate of about $25 per hour is not competitive with that of shingle roofers. Training of residential roofers so that they are capable of installing and making cost estimates for metal roofs is a problem inhibiting the commercialization of metal roofs in the residential market and will also affect the commercialization of PV-metal roof modules. In this regard, Wierton Steel has donated a building to the American Iron and Steel Institute to train residential roofing contractors in the installation of metal roofs. Other metal roof manufacturers have specialized trainers on their staff to conduct seminars directed to residential roofers.

DISTRIBUTION

Commercial Roofing

The manufacturer or roll-former distributes most metal roofs for commercial buildings, about 95 percent according to one estimate, directly to a roofing contractors and builder-general contractors or a design-build firms. Roofing contractors generally predominate since they can be trusted to make an accurate estimate or "cut-list" and can properly handle product installation, avoiding claim-related problems with waterproofing.

The principal intermediary between the manufacturer and the contractors are salesmen acting as company employees, sales representatives, or brokers. Company salesmen who have assigned territories or customer segments make formal and informal arrangements with roofing contractors, generally following every step of the procurement. Sales representatives own their company, work on commission, and have a contract with the manufacturer that gives them exclusive rights to represent a manufacturer's line. Brokers deal with any manufacturer's line and sell directly to a roofing contractor or builder.

The salesmen frequently cultivate, and obtain much of their business from architects and builder-general contractors. Architects often have special relationships with builder-contractor firms, specifying for them the seam height, width, color of metal roofs and determining whether the roof is in conformance with regulations. The contractors, either roofers or the builders, however, make the actual purchase, not the architect. A small portion of roll-formers distribute through regional dealers who have the capability to do estimates and put together packages for the contractors which include insulation as well as roof decks. Some roofing contractors informally function as dealers, uncovering jobs and doing "take-offs", based on unit prices provided by the manufacturer. A much smaller portion of roofing contractors have a formal agreement with the manufacturers under which they pay for a dealership and in return get sales and advertising support.

Residential Roofing

In the residential market, the metal manufacturers must serve a large variety of decentralized customers and therefore rely much more on middlemen in a two-stage distribution chain than is the practice in the commercial segment of the market. The architect is not a major decision maker in the residential market. Salesmen on the payroll of roll-formers rather than sales representatives or brokers cater to the home market. Some roofing contractors that install PV-shingle and bituminous roofing also do metal roofing for the commercial market, although the degree of specialization and expertise in metal roofing varies.

Manufacturers' salesmen largely reach the small home builder or residential roofing contractor through a lumber yard or retailer and a wholesale distributor or dealer. Wholesalers sell to retailers such as lumber yards, and are differentiated from them in that they tend to focus their sales and offer special discounts to specialized trades purchasing large volumes, such as the roofing contractors. The advantage of this two-stage distribution system is that dealers or distributors and retailers can more efficiently serve 15 to 20 small customers that exist within a 100-mile radius, while the manufacturers can avoid costly shipping to end-users in scattered locations.

For a variety of reasons, some manufacturers serving the residential market prefer to sell directly to roofing contractors. Some firms, in serving the upscale home market, believe that commercial roofing contractors have the expertise necessary to do a proper installation. In other cases, salesmen sell directly to the roofing contractor or builders in areas where dealers do not have a strong presence. In regions where they have good representation, however, they refer customers back to their dealer. Also, a few firms more oriented to the residential sector have created their own retail outlets or distributors that employ trained installers. These retailers or distributors cater exclusively to roofing contractors, builders, and DIY's in the residential market, in areas of the nation where roll-formers do not have good distribution. McElroy Metal, Inc., for example, has created 25 retail outlets called Metal Mart, that primarily promote residential metal roofing to contractors and the DIY market.

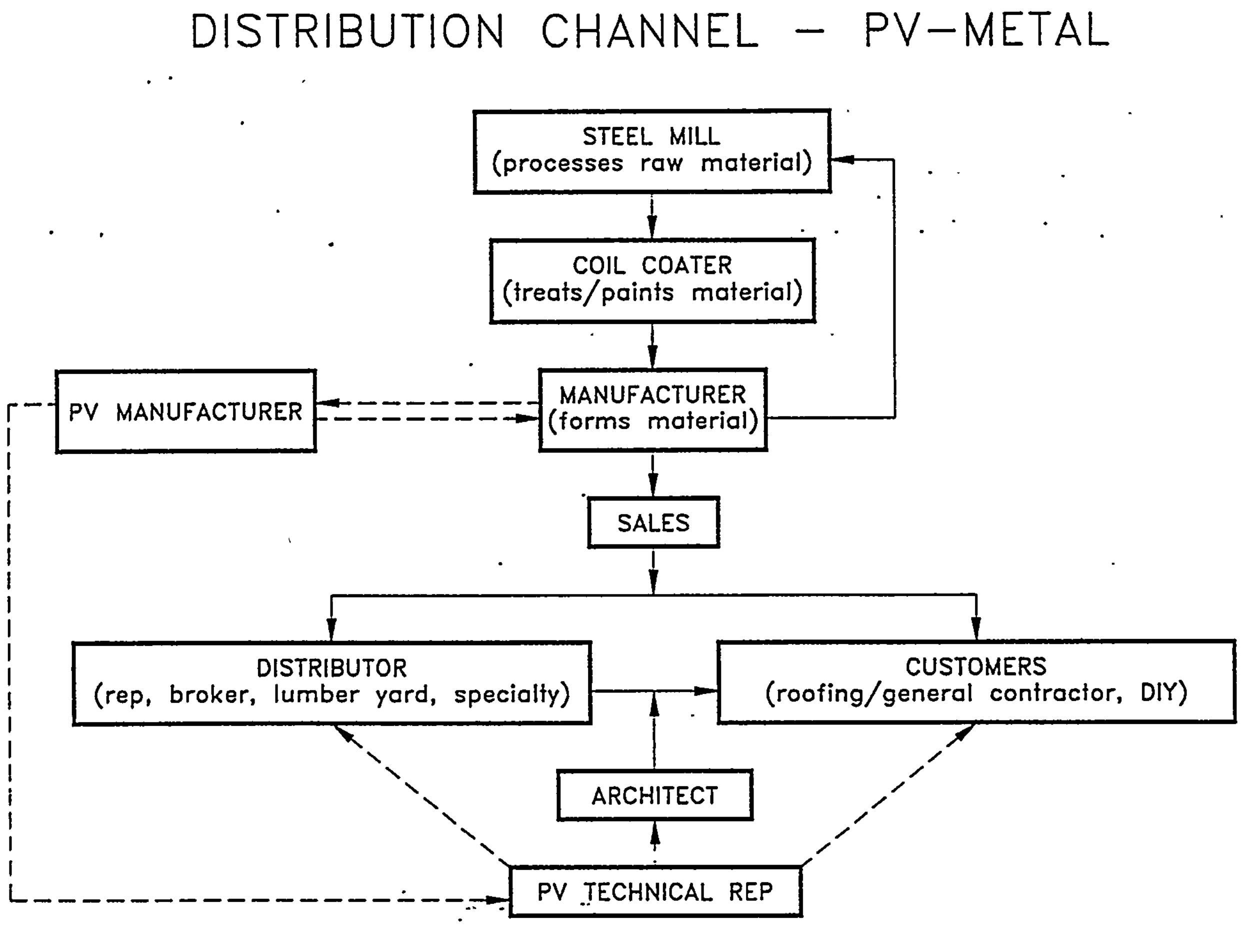

Figure 4
Potential PV-Metal Roof Distribution Channel

A few manufacturers sell to large discount retailers or home centers who carry light gauge steel products as well as shingles, serving the low-end of the residential market.

IMPLICATIONS: ADVANTAGES AND DISADVANTAGES OF DISTRIBUTION CHANNELS

Commercial Market

Regional dealers or wholesalers play only a minor role in the commercial market for metal roofing because the manufacturers deal directly with roofing contractors in a one-step distribution process. Manufacturers' representatives depend on long standing relationships with roofing contractors and architects who, in turn, are allied to builder contractors. They have little motivation to deal with small niche markets that might be interested in a PV-metal roof module.

Architects and company salesmen, on the other hand, play a prominent role in providing technical support which would be necessary in marketing a specialized product such as a PV module. The company salesmen's mission is to develop all aspects of the commercial market for their respective companies. Once they are trained in the details of the PV module application and installation, they could have a potential role in supporting the distribution of the PV module by arranging formal contracts with an aggressive roofing contractors to represent and install the PV product. Architects, similarly trained, could provide technical advice and technical support in computing the required square footage of modules based on the applications desired. Some may be architects who have been traditionally tied to commercial general contractors or design-build firms and have received special training in PV applications, while others might come from PV design-build firms.

Residential Market

The channels of distribution for metal roofing in the emerging residential market are still experimental and tentative and have yet to evolve into a definitive pattern. Although the two-stage distribution chain at first appears more circuitous and expensive, it has clear advantages in reaching the dispersed residential market.

The wholesale distributor that specializes in a wide variety of metal roofing and allied metal products is less important in serving larger industrial, agricultural, and commercial clients, since most manufacturer's already serve this market directly through sales representatives and their salesmen. They do have advantages, however, in acting as a clearinghouse for the residential market for experienced commercial metal roofing contractors who want to gain entre into the decentralized residential market. They should also have good potential to represent the integrated PV metal roof module.

Lumber yard retail outlets oriented to residential market, on the other hand, tend to appeal to the roofing contractors who focus on shingle and flat bituminous roofing for residential and light commercial roofing clients. They only incidentally indulge in metal roofing and are less experienced in its application and installation. Lumber yards have the advantage in that they have traditionally served these markets and already carry some metal roofing, but they do not have the expertise and resources to advise or train roofers inexperienced in its application and this would therefore be a disadvantage in selling and supporting a specialized PV-metal roof module.

Although manufacturers' retail outlets specialized to serve retail markets now largely serve remote areas, they may be the wave of the future in serving the residential market. Concentrating on their own product line, they have the financial resources and motivation to provide the focus and support necessary to exclusively serve the residential market. For example, some already operate with trained metal roof installers on their staff. They have flexibility in their dual role within the distribution chain as both wholesaler and retailer to reach residential roofing contractors and home builders. They are more likely to be sensitive to the competitive edge offered by new innovations and therefore might assume the risk and expense of stocking or promoting a PV-metal roof module. Alternatively, they could partner with a PV design-build firm to promote integrated PV in homes.

SUMMARY

A greater potential exists for integrated PV-metal roof panels in the commercial market than the residential market. Commercial clients are better able to bear the high costs associated with metal roofing and integrated PV. Metal roofing already has a small but significant foothold in the commercial market and has the support of an efficient one-step distribution system with experienced architects and contracting firms who could facilitate the implementation of integrated PV-metal roof modules. Once a partnership between a PV manufacturer and a roll-former is established for production, the roll-former through its company salesmen can seek out aggressive roofing contractors and architects who, once trained in the application and installation of the integrated PV panels , could promote PV among commercial customers. Alternatively, an architect with an assist from a PV design-build firm could help provide the complete package, including the BOS components.

The two step distribution pattern offers clear advantages in reaching the dispersed residential market. Training residential roof contractors in the design, take-offs, and installation of metal roofing is a formidable barrier to the commercialization of integrated of PV-metal roof panels. Such training is necessary to reduce some of the high costs of metal roofing which, when combined with the high cost of the PV modules can be prohibitive in the cost-sensitive home building industry. The problem of PV module design for a metal roof is compounded by the absence of architects serving the single-family residential market and the support of a PV design-build firm is more essential than in the commercial market. A two-step distribution system for metal roofs focussing exclusively on the residential market that employs trained installers with the support of an architect or a PV design-build firm is probably necessary for further penetration of the market (See Figure No. 4).

It is assumed that a system would eventually evolve that focusses exclusively on the residential market. Regional dealers would employ trained metal roof installers for the residential market who, in turn, would provide support to lumber yard retail outlets. In this scenario, the PV design-build firm would support the regional distributors in the application and installation of integrated PV-metal panels when special ordered by the local lumber yard.

CHAPTER III
WARRANTIES

ASPHALT ROOFING SHINGLES

Warranties on asphalt shingles commonly range from 20 to 40 years against leaking when installed properly. Provisions include a customary 5 year warranty against blow-off in wind gusts ranging from 54 to 120 mph. Most warranties specify a period in which they cover 100 of percent replacement cost, including labor. The duration ranges from the one to ten years.

After the 100 percent coverage period expires, most manufactures are liable only for a replacement cost prorated according to the number of years left in the warranty for the shingle material only. Unlike metal roofing, higher quality asphalt shingle warranties are generally transferrable for a fee, to at least the first subsequent owner, if transferred within ten years after installation. Fungus resistant shingles sold in humid climates are warranted against color change due to algae growth, usually for a period of 5 or 10 years.

A number of exceptions exist for manufacturer liability. Installations that do not conform to the instructions on each bundle packaging invalidates the warranty. Wind blow-off warranties are not valid if it can be determined that proper sealing had not taken place. Further, exposure to conditions that will adversely affect the performance of the shingle limits manufacturer liability. Table 1 shows various manufacturers, their products, and warranty specifications.

Table 1
ASPHALT SHINGLE WARRANTIES

MANUFACTURER	Warranty Period (years)	100% Replacement Period	Remedy	Transfer to Subsequent Owners?	5 Year Wind Resistance (MPH)	Additions/ Exclusions
Georgia Pacific (Summit)	30 & 40	5 years	1, 4	yes	54	A, B, C, D
Georgia Pacific (Tough Glass Plus & Premium-25)	25	3 years	1, 4	yes	54	A, B, C, D
Georgia Pacific (all others)	20 & 25	1 year	1, 4	no	54	A, B, C, D
Owens Corning	20, 25, 30 & 40	1 year	1, 2, 4	no	60	A, C, D
Atlas Roofing Corporation (StormMaster LM)	40	5 years	1, 2, 4, 5	yes	120	A, B, C, D, E
Atlas Roofing Corporation (StormMaster ST)	30	3 years	1, 2, 4, 5	yes	120	A, B, C, D, E
Atlas Roofing Corporation (Pinnacle & Pinnacle Plus, BriarWood)	30 & 40	5 years	1, 2, 4, 5	yes	54	A, B, C, D, E
Atlas Roofing Corporation (all others)	20 & 25	3 years	1, 2, 4, 5	yes	54	A, B, C, D, E
IKO Manufacturing (Dynasty)	40	7 years	1, 2, 3, 5	yes	60	C, D, E, F, M, J
IKO Manufacturing (Chateau Glass Ultra, Cambridge & Cambridge Ultra, Renaissance XL, Aristocrat, and Imperial Gentry 25)	25 & 30	5 years	1, 2, 3, 5	yes	60	B, C, D, E, F, J
IKO Manufacturing (all others)	20	3 years	1, 2, 3, 5	yes	60	B, C, D, E, F, J
CertainTeed Corporation (Grand Manor Shangle)	40	10 years	1, 3, 5	yes	60	A, C, D, E, F, H, K
CertainTeed Corporation (Carriage House Shangle)	35	7 years	1, 3, 5	yes	60	A, C, D, E, F, H, L
CertainTeed Corporation (Hallmark, Horizon, & Independence Shangle, Custom Sealdon 30, Master Slab, XT 25, Sealdon 25, and Fungusbuster 25)	25 & 30	5 years	1, 2, 3, 5	yes	60	A, B, C, D, E, F, I
CertainTeed Corporation (CertainTeed 20 and Solid Slab)	20	3 years	1, 2, 3, 5	yes	60	A, B, C, D, E, F, I
Elk Corporation (Capstone)	30	10 years	1, 2, 3, 5	yes	60	A, B, C, D, E, F, J
Elk Corporation (Presitque series)	25, 30, & 40	0	2, 3, 5	yes	60	A, B, C, D, E, F, J

REMEDY NOTES:

(1) During 100% coverage period, the manufacturer shall pay the total replacement cost of labor and materials.
(2) Does not include cost of tear-off and disposal of existing shingles.
(3) After 100% coverage period, the manufacturer shall pay a prorated replacement cost of materials only.
(4) After 100% coverage period, the manufacturer shall pay a prorated replacement cost of roof labor and materials.
(5) Wind resistance warranty includes only material costs.

ADDITION/EXCLUSION NOTES:

(A) Does not warrant against blow-off when proper shingle sealing does not take place.
Implications of installation cost on an annual prorated basis.
(B) Fungus resistant versions are warranted for 5 years against discoloration due to algae growth for material cost only.
(C) Does not warrant against any exposure that will adversely affect the performance of the shingle.
(D) Warrant is negated if alterations are made after installations.
(E) Warranty may be transferred to only one subsequent owner.
(F) Warranty may be transferred only within 10 years of installation.
(G) Only one claim may be filed against a building.
(H) Lifetime warranty extends only to original purchaser.
(I) 100% replacement warranty is terminated upon transfer.
(J) Warranty transfer fee applies.
(K) Wind resistance warranty extends for the first 10 years.
(L) Wind resistance warranty extends for the first 7 years.
(M) Discoloration due to algae growth is warranted against for 10 years including materials and installation cost on an annual prorated basis.

IMPLICATIONS OF WARRANTIES FOR BUILDING INTEGRATED PHOTOVOLTAIC MODULES

The warranty length may be considerably shorter for a standard shingle than the expected life of an integrated PV-shingle. Asphalt shingle warranties contain provisions that limit manufacturer liability in most non-standard applications, for example, incomplete sealing and its effects on other components of the building. Manufacturers assume that some color change will occur during the life of asphalt shingles and most are either ambiguous or do not warrant against it. The many implications warranty stipulations and conditions have for the design and installation of an integrated PV-shingle products are explained in more detail below.

Length of Warranty

The mechanical life expectancy of the integrated PV-shingle is expected to be longer than 30 years. Warranties for fiberglass asphalt shingles are comparable and can extend over the 30 years, while architectural shingles with random/unevenly spaced tabs dominate the product offering in the 30 to 40 year range. Conventional three tab shingles, however, have warranties that generally range from 20 to 30 years. The life of the 3-tab asphalt shingle may therefore expire before that of the PV-shingle.

Color or Fade

Since discoloration is assumed to occur, asphalt shingle manufacturers generally are vague or do not warrant against color fade. Consequently, initial color selection for the integrated PV-shingle should not be considered critical since fade rates between the asphalt roofing shingle and the PV-shingle will differ, resulting in differentials in color over the long term. The PV-shingle manufacturer, however, should attempt to develop a design, texture, and color complimentary to the range of shades likely to occur in an asphalt shingle over its useful life.

Sealing

Proper sealing should be provided against the effects of high winds. Roofing warranties against wind blow-off are only valid where individual components of the roof covering are adequately sealed to each other. Wherever an asphalt shingle and PV-shingle interface, manual sealing with a suitable adhesive may be required.

After-The-Fact Alterations and Installations

Warranties state that no alterations or equipment alterations should occur after initial installation. Alterations to a roof after initial installation will release the manufacturer of liability for all shingles affected. A retrofit installation of the PV-shingle modules could thus nullify the warranty on shingles that cover the rest of the roof. Manufacturers also do not warrant against damage to equipment caused by their shingles. If for any reason the shingles on the roof adjacent to the PV module shingles should have a negative impact on the modules, such damage will not be covered by a warranty.

Runoff

Shingle runoff could affect the light transmittance of the PV-shingle modules. Some warranties state that temporary discoloration of PV-shingles in the form of a yellow stain or a chalky film may occur within the first six months after installation. The yellow stain is said to occur "due to transfer of backing materials."[5] Further, if a roof uses zinc granules embedded in the shingle surface as a fungus resistant agent, it is likely to leave white stains on other shingles. The ability of the PV-shingle module surface to transmit light may thus be affected, depending on the interaction between the PV-shingle superstrate material. Other materials contained in asphalt shingles, i.e., asphalt and filler materials could possibly leave a film on the PV-shingle module.

Roof Retrofit

The normal procedure in replacing the first layer of shingles is simply to cover them with a second layer without prior removal. In replacement of a roof covering that contains integrated PV-shingles, however, roofing materials will likely have to be removed and tear-off and re-installation of the PV-shingles may be required. Wire connections and methods of PV-shingle attachment and placement should, if possible, minimize the negative effects of re-installation and facilitate ease of retrofit.

METAL ROOFING: PAINT AND SUBSTRATE WARRANTIES

Warranties on most metal roofing products tend to be shorter and contain a greater number of exclusions than warranties for asphalt shingles because of the corrosive nature of metals and the tendency for paints to deteriorate under ultraviolet (UV) radiation. Caution must also be exercised in installing metal roofing to assure the paint and metal do not come in contact with substances that affect its performance. Warranties for metal roofing with a factory paint finish come frequently in two parts--a weathertightness warranty against the substrate leaking and a finish coating warranty against paint chipping, cracking, peeling, excessive color change (fading,) and chalking. The substrate warranty is often superseded by the paint warranty. Alternatively, the entire panel can be protected under a single warranty. Warranties are traditionally not transferrable and warranty periods are typically 20 years. They differ, however, in allowable remedies and paint fade and chalk rates, depending on materials used.

Paint Finish Warranties

Polyester and Silicon Modified Polyester Paint Finishes

Polyester-based paint is a less expensive factory-applied finish for metal roofing. These paints are available in a wide variety of colors but are not as durable in terms of color retention. They have a tendency to fade in a non-uniform manner and are found more often on agricultural and industrial buildings. Polyester painted metal roof panels do not usually warrant against excessive fading or chalking. Silicon modified polyesters (SMPs) have much better color retention qualities due to the addition of silicon to the paint formulation. More expensive and durable, they cost

[5] Atlas Roofing Corporation Limited PV-Shingle Warranty.

from $0.06 to $0.12 more per square foot than polyesters. Fade rates are determined by a method identical to that of fluoropolymers, but chalking rates are determined by ASTM #D4214 on a score of from 10 to 1, with 10 the most favorable. Other warranty provisions are similar to fluoropolymers. Table. No. 2 that follows represents warranties for metal roof panels with polyester and silicon modified polyester-based paint finishes.

Table 2
POLYESTER OR SILICON MODIFIED POLYESTER (SMP) PAINT FINISH WARRANTIES

	WARRANTY PERIOD (YEARS)	REMEDY	FADE RATE (MAXIMUM NBS UNITS)	MAXIMUM CHALK RATING	WARRANTS AGAINST	EXCLUSIONS
ATAS ALUMINUM (POLYESTER)	20	REPAINT OR REPLACE, LIMITED TO COST OF MATERIALS	NONE	NONE	CRACK, CHECK, OR PEEL	(1)
PV-METAL SALES MFG. CORP. (SMP)	20	REPAINT OR REPLACE, COST OF LABOR & MATERIALS	7	6	CRACK, CHECK, OR PEEL	(2)
VICWEST STEEL (SMP, 0-45 DEGREES FROM VERTICAL)	20	REPAINT OR REPLACE, LIMITED TO COST OF MATERIALS	5 (ASTM D2244-85	6 (ASTM D4214-82)	CRACK, CHECK, PEEL, OR FLAKE	(3)
VICWEST STEEL (SMP, 45-85 DEGREES FROM VERTICAL)	20	REPAINT OR REPLACE, LIMITED TO COST OF MATERIALS	7 (LATEST ASTM D2244)	6 (ASTM D4214-82)	CRACK, CHECK, PEEL, OR FLAKE	(4)

EXCLUSIONS:

(1) Any repair, refinishing, or replacement negates warranty.
(2) Contact with foreign substances and failure of conversion coating material negate warranty.
(3) Contact with harmful chemical solids, liquids, or gases negates warranty.
(4) Same as (3).

Flouropolymer Paint Finishes

Fluoropolymers are resins with a chemical formulation similar to Teflon. They are available under the trade names Kynar and Hylar, technologies that are licensed to a number of producers. Fluoropolymers, among the most expensive and most durable paints available on metal roofing, range from $0.15 to $0.25 more per square foot than polyesters. Fade rates for fluoropolymers are measured and rated according to the American Society of Testing Materials (ASTM) #D659 from 1 to 10 National Bureau of Standards (NBS) units, with 1 being the most favorable score. Chalk rates for fluoropolymers are determined by ASTM #D659 and rated from 10 to 1, with 10 being the most favorable score. Actual fade and chalk rates depend on paint color with some colors performing better than others. Warranties, however, state only a maximum allowable rate. Warranties also guarantee the paint finish for a specified period against chipping, cracking, checking, or otherwise exposing the metal surface beneath the paint. Remedy for paint failure can result in repainting (not necessarily with the same paint) or replacing the faulty panels, or providing new panels, but does not include the labor for installation or award monetary damages equal to the full replacement value. Table No. 3 that follows represents paint warranties for metal roof panels finished with fluoropolymers.

Table 3
FLOUROPOLYMER PAINT FINISH WARRANTIES

	WARRANTY PERIOD (YEARS)	REMEDY	FADE RATE (MAXIMUM NBS UNITS)	MAXIMUM CHALK RATING	WARRANTS AGAINST	EXCLU SIONS
PETERSON ALUMINUM	20	REPAINT OR REPLACE, COST OF MATERIALS & LABOR	5	8 (ASTM D659-44)	CRACK, CHECK, OR PEEL	(1)
ATAS ALUMINUM	20	REPAINT OR REPLACE, LIMITED TO COST OF MATERIALS	5	8 (ASTM D659-80)	CRACK, CHECK, OR PEEL	(2)
PV-METAL SALES MFG. CORP.	20	REPAINT OR REPLACE, COST OF MATERIALS & LABOR	5	8	CRACK, CHECK, PEEL, OR FLAKE	(3)
FABRAL-ALCAN	20	REPAINT OR REPLACE, COST OF MATERIALS & LABOR	5 (LATEST ASTM D2244)	8 (MOST RECENT ASTM D659)	CRACK, CHECK, OR PEEL	(4)

EXCLUSIONS:

(1) Warranty excludes damage caused by contact with foreign substances that cause corrosion.
(2) Any repair, refinishing, or replacement of panels negates warranty.
(3) Contact with foreign substances and failure of conversion coating material negate warranty.
(4) Warranty applies only where normal materials, methods, and workmanship are used.

WARRANTIES FOR METAL ROOF SUBSTRATES

Three common metal roof substrates are solid aluminum panels, zinc-galvanized coated steel panels, and zinc-aluminum coated steel panels. Each is considered corrosion resistant, but they are still subject to failure when subjected to aggressive conditions. Consequently, special care should be taken that they are installed only where shielded against potential corrosives, such as pressure treated wood, runoff from copper, cement, or PVC gutters, location near some chemical plants, pencil marks, salt spray, and any other substance not compatible with the metal or its coating. Like paint warranties, substrate warranties exclude damage resulting from any contact with corrosives. When no weathertightness warranty is expressly given, warranties for substrates may be superseded by the finish warranty or combined into a single warranty for the entire panel.

Aluminum Substrate Weathertightness Warranty

Solid aluminum roofing can be more durable than ordinary zinc-galvanized steel roofing. It is affected negatively by strong alkalis and should be protected from wet cement and metals such as lead and copper. Since aluminum's coefficient of expansion is double that of steel panels, special care must be taken during installation and fastening so that minimal damage will occur from thermal movements. An aluminum panel will expand and contract 1/2 inch over a 30 foot panel in many climates. Aluminum substrate warranties can also be superseded by paint warranties, since corrosive elements must first permeate the painted finish to begin their corrosive action on the substrate. The degree of pitch in a roof can influence the extent of water runoff. Low pitch roofs can be conducive to stagnant water, increasing the possibility of damage to the substrate. Some manufacturers limit the aluminum substrate warranty to installations where roof pitch is greater than 12 degrees. Table No. 4 that follows represents aluminum substrate weathertightness warranties.

Table 4
ALUMINUM SUBSTRATE WEATHERTIGHTNESS WARRANTIES

	WARRANTY PERIOD (YEARS)	REMEDY	WARRANTS AGAINST	EXCLUSIONS
PETERSON ALUMINUM	20	REPAIR OR REPLACE, COST OF LABOR & MATERIALS	SUBSTRATE WARRANTY IS SUPERSEDED BY PAINT WARRANTY. COVERS AGAINST ROOF FAILURE.	(1)
ATAS ALUMINUM	10 OR 20	REPAIR OR REPLACE, COST OF LABOR & MATERIALS	COVERS AGAINST LEAKS. ROOFING CONTRACTOR SUPPLIES FIRST 2 YEARS OF COVERAGE. 20 YEAR WARRANTY IS AVAILABLE AT EXTRA CHARGE.	(2)
FABRAL-ALCAN	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	LEAKAGE AS A RESULT OF CORROSION--FIRST 10 YEARS NON-PRORATED REPAIRS, LAST 10 YEARS ARE PRORATED	(3)

EXCLUSIONS:

(1) Warranty excludes damage caused by contact with foreign substances that cause corrosion.
(2) Warranty does not apply to panels that come in contact with corrosive elements or those that have been altered without prior written permission from manufacturer.
(3) Requires proper isolation against dissimilar metals.

Zinc-Aluminum Coated Steel Weathertightness Warranty

Zinc-aluminum alloy coated steel, frequently called by its trade name "Galvalume," is more durable and more expensive than galvanized steel roofing and some warranties allow a pitch of 2.5 degrees which is more favorable than either zinc coated steel or aluminum roofing. Galvalume roofing is sold with or without a factory finish and is warranted up to 20 years against leakage due to rust or corrosion. Table No. 5 that follows represents substrate weathertightness warranties for zinc-aluminum coated steel roofing.

Table 5
ZINC-ALUMINUM COATED STEEL WEATHERTIGHTNESS WARRANTIES

	WARRANTY PERIOD (YEARS)	REMEDY	WARRANTS AGAINST	EXCLUSIONS
PV-METAL SALES MANUFACTURING CORP.	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	RUPTURE, FAIL STRUCTURALLY, OR PERFORATION	(1)
FABRAL-ALCAN	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	LEAKS, PERFORATIONS, OR STRUCTURAL FAILURE	(2)
VICWEST STEEL	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	RUPTURE, STRUCTURAL FAILURE, OR PERFORATION	(3)

EXCLUSIONS:

(1) Warranty excludes damage from contact with corrosives, failure to remove debris from panel surface, and installation in a manner that would inhibit free water run-off.
(2) Does not warrant against installation where free evaporation of water or dampness on panels is inhibited or contact with corrosives.
(3) Warranty does not apply for panels altered or moved after initial installation.

Zinc Coated Galvanized Steel Weathertightness Warranty

Galvanized steel roofing consists of a base steel sheet coated with a layer of zinc. When exposed to the elements, zinc continues to oxidize to coat and protect the base steel. Some manufacturers limit their liability for zinc coated galvanized steel panels to pitches greater than 14 degrees. The warranty for factory finished galvanized steel is often superseded by the finish warranty. Table No. 6 that follows represents the weathertightness warranties for zinc coated steel roofing.

Table 6 ZINC COATED GALVANIZED STEEL WEATHERTIGHTNESS WARRANTIES				
	WARRANTY PERIOD (YEARS)	REMEDY	WARRANTS AGAINST	EXCLUSIONS
PETERSON ALUMINUM	20	REPAIR OR REPLACE, COST OF MATERIALS & LABOR	SUBSTRATE WARRANTY IS SUPERSEDED BY PAINT WARRANTY.	(1)
FABRAL-ALCAN	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	ROOF LEAKS RESULTING FROM PERFORATIONS CAUSED BY RUST OR CORROSION	(2)
PV-METAL SALES MANUFACTURING CORP.	20	REPAIR OR REPLACE, COST OF LABOR & MATERIALS	SUBSTRATE WARRANTY IS SUPERSEDED BY PAINT WARRANTY.	(3)
VICWEST STEEL	20	REPAIR OR REPLACE, LIMITED TO COST OF MATERIALS	SUBSTRATE WARRANTY IS SUPERSEDED BY PAINT WARRANTY.	(4)

EXCLUSIONS:

(1) Warranty excludes damage caused by contact with foreign substances that cause corrosion.
(2) Leaks due to failure to insulate against contact with dissimilar metals are not covered by the warranty.
(3) Warranty excludes damage caused by failure of conversion coating material and contact with foreign substances.
(4) Warranty does not cover damage resulting from contact with harmful chemical solids, liquids, or gases.

WARRANTY IMPLICATIONS FOR INTEGRATED PHOTOVOLTAIC USING FACTORY-FINISHED METAL ROOF PANELS

Alteration of a metal roof panel to include the integration of PV cells has many implications for the performance of the manufacturer's warranty. The long-term weathertightness of the substrate and painted finish performance are affected by the chemical composition of the PV cells and lamination materials, the rate of thermal expansion, the roof pitch, and the ease of moisture runoff and evaporation which are discussed in more detail below.

Coefficient of Expansion

All materials will expand and contract when exposed to a wide range of temperatures. Heat radiating from the sun can raise the roof temperature to over 180 degrees F, while the night time winter temperatures in many U.S. locations can drop to -40 degrees F, a potentially 220 degree variation for any given roof panel. Aluminum has a coefficient of expansion of 0.0000129 inches per degree for every inch of panel. A 30 foot aluminum panel will therefore expand and contract one inch over the length of the panel with a 220 degree temperature change. Steel has a coefficient of expansion of 0.0000067, roughly half that of aluminum[6]. Further, expansion and contraction of the roof will cause bowing across the panel's width. The PV cells should also be able to withstand repeated bowing without becoming detached from the metal roofing panel. Materials too rigid to bow may increase the tension on other roof panels and fasteners. Consequently, improperly designed integrated PV-metal roof panels may not perform as typical metal roof pass might be expected.

Permeability of Glazing Laminate

Most warranties do not cover panels whose design or other damage does not allow free water runoff or evaporation. The lamination of the PV cells to the metal roof panel therefore should not hold water in any of its seams exposed to the elements.

Corrosive Elements from Glazing Laminate and Adhesives

All finish and weatherability warranties of metal roofing panels do not cover damage resulting from contact with corrosives, manufactured chemicals, dissimilar metals, corrosive gases, and "aggressive" atmospheric conditions. Integrated PV-metal roof panels should be composed only of materials that are not potentially harmful to paint or substrate. The chemical composition of the adhesives and lamination used in the PV-metal roof should not leech, or off-gas any substance incompatible with the paint or substrate.

Alterations and Non-Standard Installation Practices

Most manufacturers will honor their metal roof warranties only where "normal materials, methods, and workmanship" are used during installation. Alterations to panels or use of non-standard attachment methods may negate the warranty. A prior written agreement of terms and conditions will therefore probably have to be negotiated with manufacturers before they will honor any warranty on a integrated metal roof PV panel. Alternatively, the PV manufacturer may need to offer its own weathertightness warranty.

Color Performance

Fade and chalking rates of metal roof paint varies with exposure to UV rays. Some warranties contain clauses that indemnify themselves against uneven fading due to positioning that alters the light pattern striking the panel. Laminates with UV protection or glazing that concentrates sunlight may cause uneven fading or chalking, negating any color performance warranty. Since painted PV-metal roofing colors will change over time, resulting in uneven fade rates or differentials in color that contribute to the unsightly appearance of the roof, the integrated PV-metal roof panel should be designed either to minimize differentials in color due to fade rate or to eliminate the exposed painted surface entirely.

[6] Op.Cit, "Low-Cost Metal Roofing" p.22

Testing for Chalking and Fade Rate

Performing chalk and fade rate tests (ASTM D4214, D659, and D2244) require the painted surface to be exposed. When covered by a glazing laminate, the manufacturer will likely not honor the color performance portion of the warranty unless prior written permission is obtained.

Roof Pitch

Warranties vary for minimum roof pitch requirements for warranty performance. Fabral-Alcan, for example, requires installation with at least 14 degrees pitch for honoring the galvanized steel substrate warranty, 12 degrees for the aluminum substrate warranty, and 2.5 degrees for the zinc-aluminum coated steel warranty. Similarly, VicWest Steel decreases the fade and chalk rating from 5 and 8 to 6 and 7, respectively, when panel installation of PV-metal roof at a pitch of less than 45 degrees. In some latitudes the roof pitch required for maximum solar power gain may exclude the entire roof from the warranty or may increase the maximum allowable fade and chalk rates of the finish. Further, water ponding behind ice, snow, leaves, or other obstructions will more likely result in roof leaks on shallow roofs that use water shedding installation detailing. Design of integrated PV-metal roof panels should be able to accommodate watertight detailed installation, especially in areas where water ponding is likely.

Inspections

Warranties against substrate material defects may require frequent inspection of the metal roof for early detection of failures. Building owners with integrated metal roof PV panels may not be able to visually inspect for substrate corrosion beneath the PV lamination and may negate any weathertightness warranty, unless prior written consent is obtained from the manufacturer.

APPENDIX “C”

APS MARKET SIZE ASSESSMENT

APPENDIX "C"

A P S

PHOTOVOLTAIC ROOFING PRODUCT

MARKET SIZE ASSESSMENT

PV: BONUS

JUNE 1995

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U.S. Department of Energy
National Renewable Energy Laboratory
Research and Development Directed at
Building Opportunities in the U.S. for Photovoltaics
Number DE-FC02-93-CH10571

Disclaimers

The research contained in this report was supported, in part, by an award from the U.S. Department of Energy (DOE), award Number DE-FC02-93-CH10571. Such support does not constitute an endorsement by DOE of the views expressed herein.

PHOTOVOLTAIC ROOFING PRODUCT MARKET ASSESSMENT

U.S. Department of Energy
National Renewable Energy Laboratory
Research and Development Directed at
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PV: BONUS

JUNE 1995

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1.0 Introduction

The purpose of the PV: BONUS program is "... to develop a U.S. photovoltaic (PV) buildings industry based on the delivery of reliable, cost-effective PV products ...". PV: BONUS is designed to create the infrastructure needed to commercialize the use of PV in the building construction industry.

The Roofing Sector of the U.S. Building Construction Industry has $17 billion in annual sales and uses approximately $8 billion in roofing product materials.

The U.S. Department of Energy's PV:BONUS program has provided support leading to the development of dual purpose (photovoltaic power generation and roofing) building products. ECD's PV roofing products can displace traditional:

- *Flat roofing products (66% of the market),*
- *Shingles (25% market share), or,*
- *Metal roofing (4% share).*

ECD's products can also be distributed through existing distribution channels.

ECD products have the potential to improve utilization of resources and significantly increase value added in the U.S construction industry. Commercialization of ECD's product would achieve these ends through:

- *Production of significant quantities of electric energy,*
- *Reduction in consumption of fossil fuels,*
- *Creation of domestic employment, and*
- *Improvement in environmental quality and related quality of life.*

An early step in the commercialization of a product is the identification and evaluation of the size of the potential market. The initial screening of end user sectors, product markets, market share, potential competitors, prospective trade allies and barriers to market penetration is intended to lay the foundation for more detailed market analysis and *research directed toward the development of specific marketing strategies and tactics.*

The purpose of this study was to lay the foundation for more detailed business planning efforts through:

- *Evaluation of the size of the potential market for integrated PV Roofing Products,*
- *Estimation of the acceptance of the product within the market and the related long term attainable market share.*

2.0 Summary of Results

The Roofing sector of the construction industry has annual sales of $17 billion.[1] The Roofing Materials fraction of the market aggregates slightly less than half of the total or approximately $8 billion annually.[2]

ECD has developed an integrated PV Roofing product that can be configured to displace traditional roofing product configurations. ECD's PV Roofing products can be configured to displace traditional roofing materials representing more than 90% of new and retro-fit installations:

- Flat Roofing Products representing 66% of the market[3]
- Shingle Roofing products with a 25% share of the market, and
- Metal roofing products - 4% share of the market.

[1] National Roofing Contractors Association, Annual Market Survey
[2] Based on value added by Roofing contractors
[3] Market share based on revenues

The roofing footage stock for U.S. Residential and Commercial buildings is approximately 150 billion square feet [4]. Of this stock, 16 billion square feet or 11% were found to represent technically feasible applications of PV Roofing. [5] Of this technically feasible stock, 186 million square feet or 1.2% were preliminarily found likely to accept the utilization of PV Roofing Products over the next twenty years (i.e. an average attainable market of 9 million square feet per year in sales).

The incremental target price was found to be at the upper most limit of commercial pricing, however, PV Roofing Products were projected to:

- Penetrate roofing markets at the target incremental price, $2,290 per kilowatt (kW).

[4] Based on Residential and Commercial floor square footage stocks adjusted for multi-story structures and typical roof slopes.
[5] Based on sizing of the PV constrained by customer daytime electric load (ie no storage or back feed to the utility) and building screens (see *infra*)

- Achieve long term market share as large as of 3-5.5% (.05%-.1% of square footage) of the $8 billion roofing products market over a twenty year time horizon.

Figures 2-1 and 2-2 show Technically Feasible and Economically Attainable estimates for PV Roofing Products.

Expected market penetration at the target price was concentrated in California, Arizona, Nevada and Hawaii , with these geographic areas comprising 90% of projected sales. The market penetration in this region was driven by high levels of insolation and the retail price of electricity.

Initial penetration opportunities were found in both the residential and commercial consuming sectors. Potential residential markets were constrained by low coincidence between daytime electric consumption and insolation. Commercial customers were found to have significantly higher energy consumption intensity and coincidence of consumption with insolation, resulting in larger technically feasible markets.

Significant industry structural barriers to product acceptance and market penetration were identified. These barriers included:

- Lack of expertise and among the contractors likely to sell the product,
- Installation requirements necessitating more than just the roofing trade to complete a product installation,
- High cost of gaining product acceptance
- Development of competition, and,
- Unavailable or insufficient utility and governmental incentives.

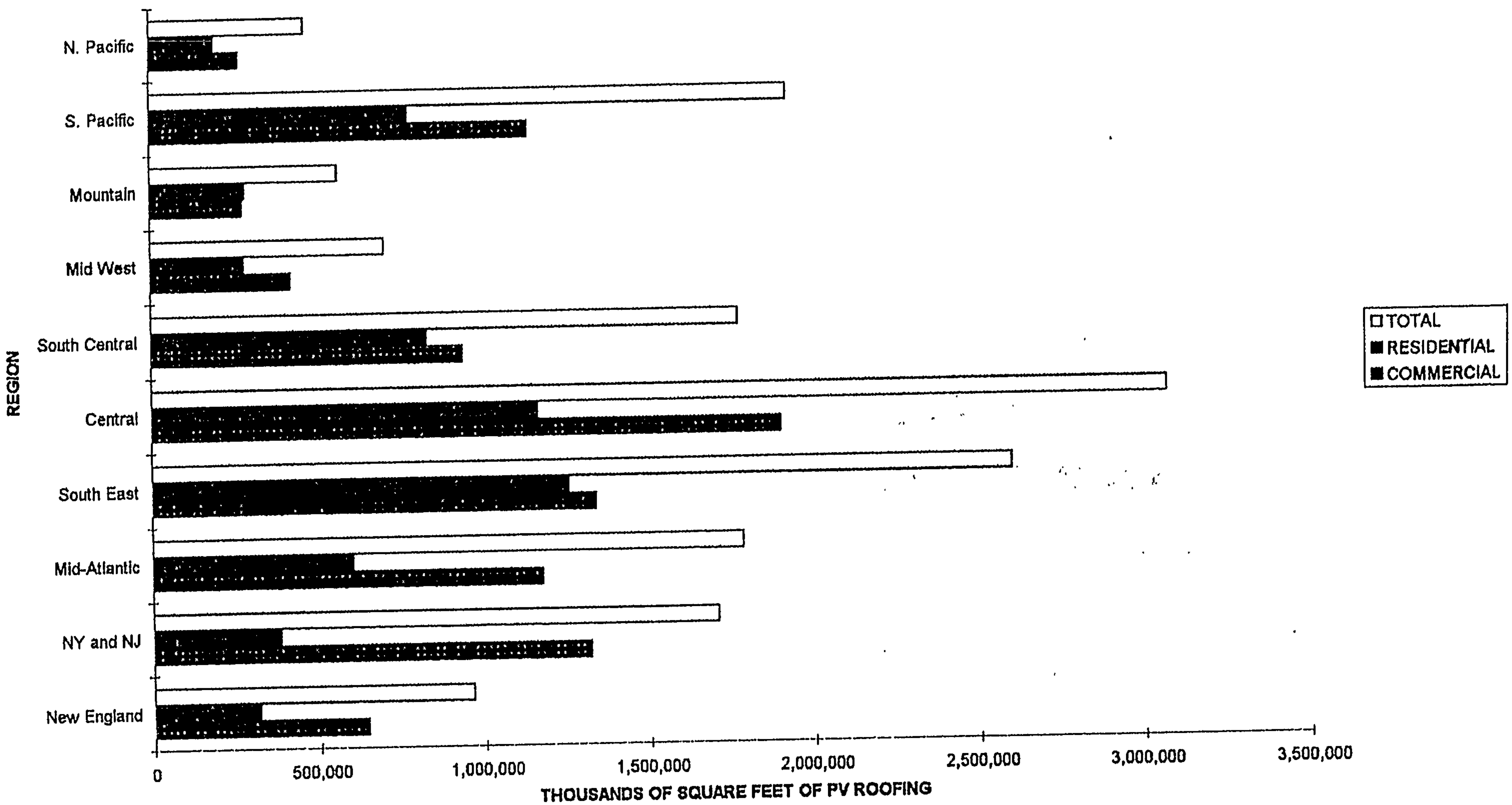
The use of the PV Roofing Product as an electric utility demand side management ("DSM") tool was shown to significantly effect the products overall penetration of the market. DSM incentives were found to almost double the expected market penetration.

The level of DSM benefits, supporting utility incentives, was demonstrated to vary significantly by geographic area. DSM related benefits varied by geographic area due to two factors:

1. Level of insolation, and
2. Coincidence of solar insolation with utility peak loads.

The market for PV Roofing products, as modeled, was asymmetrically responsive to price. Reductions in product pricing resulted in order of magnitude increases in projected market sizes. Very little commercial market for the product was found at prices exceeding $3,000 /kW.

FIGURE 2-1
TECHNICALLY FEASIBLE MARKET



3.0 Methodology

The study methodology is the organization of information to estimate the interactions of market forces affecting commercialization of PV Roofing Products. The methodology was developed to provide reliable, intuitively reasonable estimates of market size and penetration. Table 3-1 presents a Flow Chart of the study methodology.

The market estimation techniques used in this study are similar, although more detailed, to the methods used in earlier studies of potential markets for PV. [6]

3.1 Overview of Methodology

The forecast methodology was developed to provide reliable estimates of market size and segmentation with sufficient flexibility to evaluate alternative pricing scenarios and sensitivities. Specifically, the objectives of the forecast were:

[6] see A.D. Little, Photovoltaic Market Potential

TABLE 2-2:
ECONOMICALLY ATTAINABLE MARKET

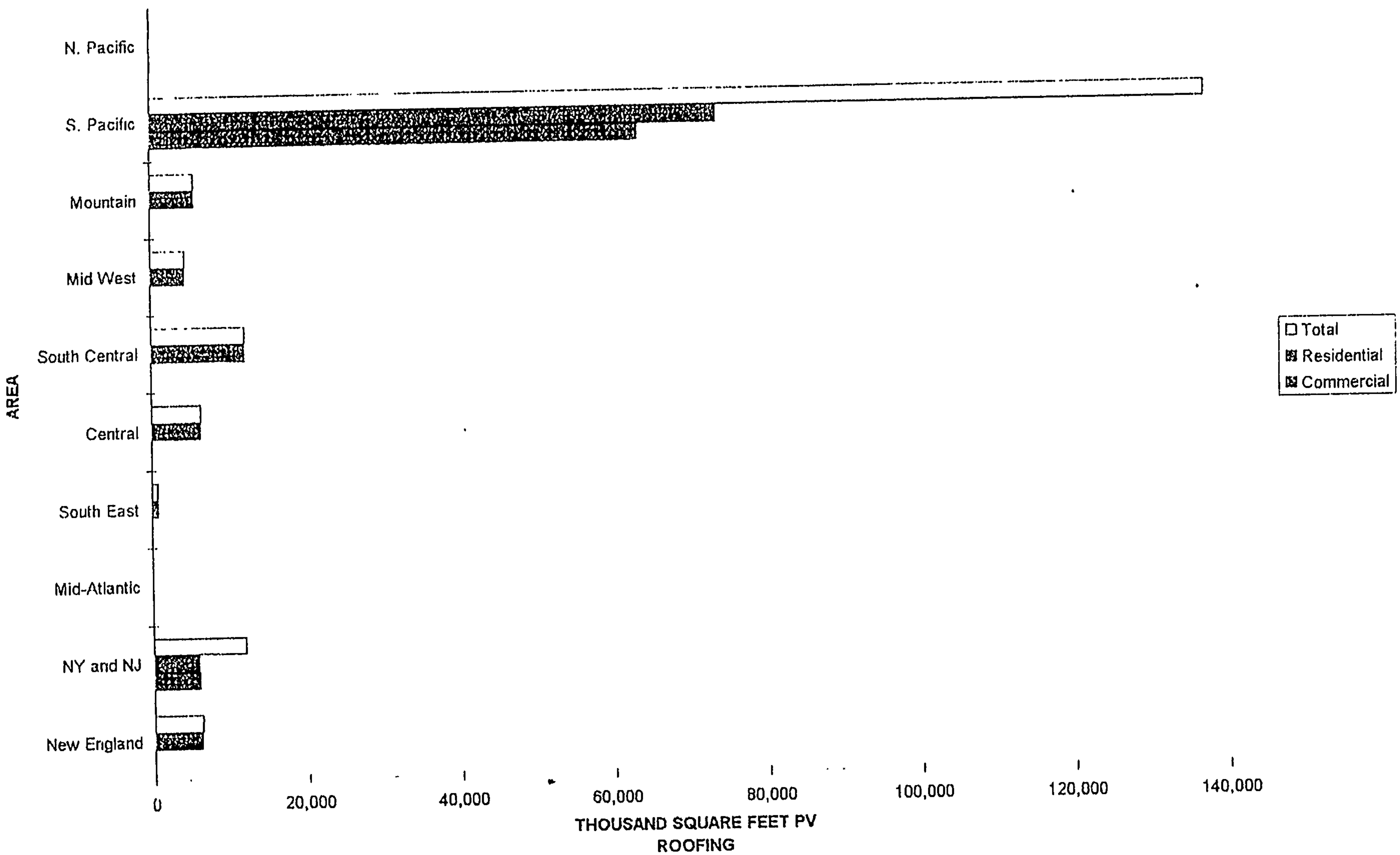
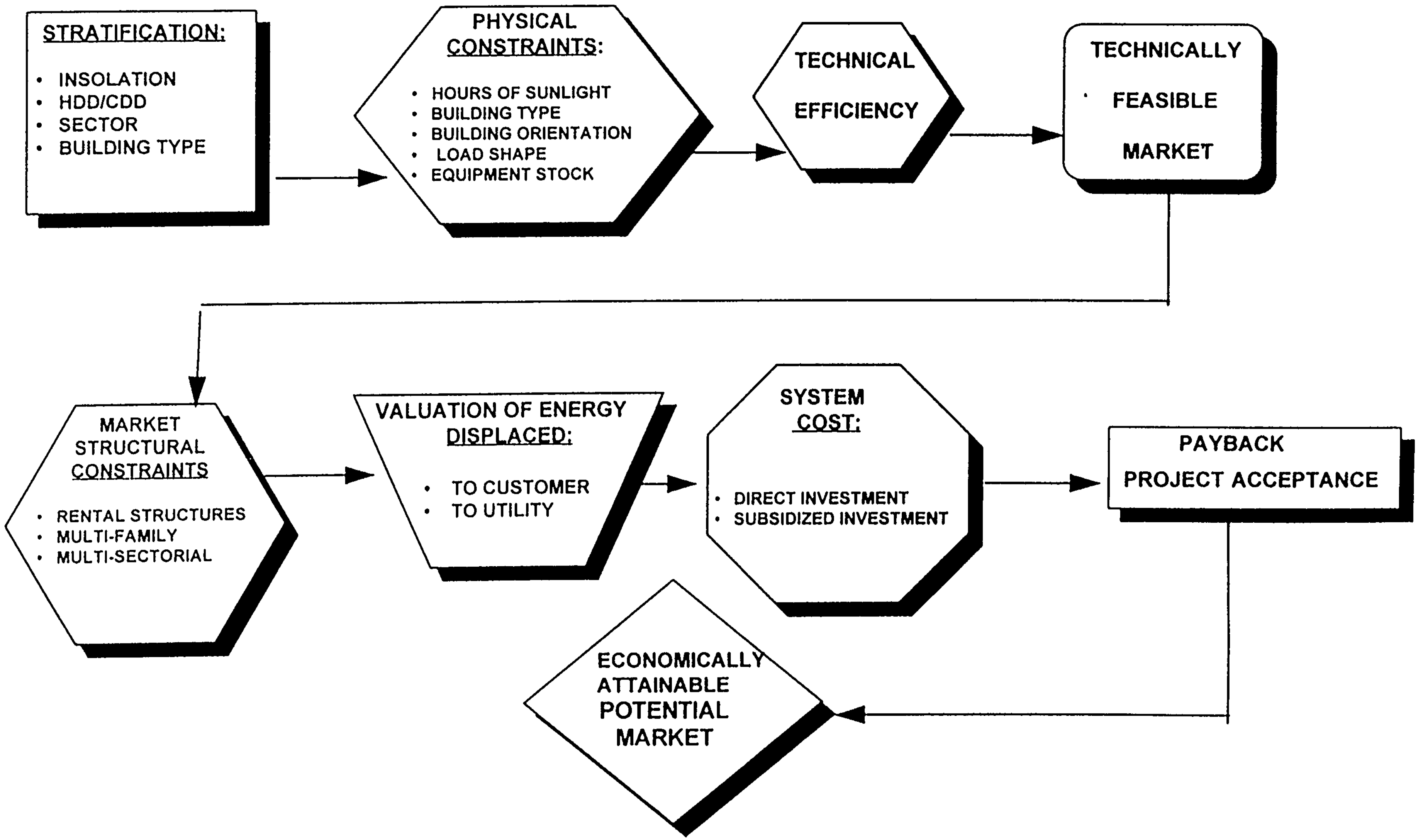


TABLE 3-1: FLOW CHART FOR ASSESSING MARKET SIZE



- Estimate the size of the market for PV Roofing Products
- Project the penetration of PV Roofing Products within the Roofing Market at the target price
- Preliminarily identify initial penetration opportunities
- Estimate the potential electric utility DSM impact of PV Roofing Products

Market estimates were made for the product in new and retro-fit application. The size of the potential market for the PV Roofing Product was measured in:

- MWp,
- Square footage of product, and
- Sales revenues.

The estimated market size represents the ultimate penetration of the new and replacement roofing market over a twenty year time horizon.

The forecast methodology had three major elements:

1. Segmentation and stratification of markets,

2. Estimate of Technically feasible market size, and

3. Estimate of the Economically Attainable market size (i.e. likely market penetration)

Markets were segmented and stratified to provide higher levels of forecast accuracy, and insight into initial target markets. Diurnal usage characteristics and available insolation support stratification because the technical and economic decisions faced by product consumers are significantly affected by these parameters.

The technically feasible market size was defined as:

The maximum potential market that could be achieved by the product in a roof-top stand alone configuration.

The technically feasible market was determined to be the lesser of :

1. Electrical loads occurring during daytime hours,

   or,

2. The output of the PV Roofing product using all

   available roof top area.

The economically attainable market was defined as:

The expected penetration of the technically feasible market based on customer response to economic criteria.

The economically attainable market represents the expected long term market penetration of the product. The economically attainable market was forecast under two scenarios:

- Incremental projected product pricing targeted by the manufacturer (ECD), and

- Incremental projected product pricing reduced by a hypothetical DSM incentive equal to the value of archetypal utility avoided costs.

3.2 Segmentation and Stratification of the Market

The market for the PV Roofing Product was segmented and stratified to :

- Improve the accuracy of the Technically Feasible market size estimate,
- Increase the reliability of penetration estimates for the product by better modeling purchase decision making among differing types of customers, geographic/climatic areas and building types,
- Identify potential target markets

The U. S. was segmented into ten regions :

1. New England - Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island and Vermont.

2. New York & New Jersey,

3. Middle Atlantic - District of Columbia, Delaware, Maryland, Pennsylvania, Virginia, West Virginia.

4. Southeast - Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee.

5. Midwest - Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

6. South Central - Arkansas, Louisiana, New Mexico, Oklahoma, Texas

7. Central - Iowa, Kansas, Missouri, Nebraska

8. Mountain - Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming

9. South Pacific - Arizona, California, Hawaii, Nevada

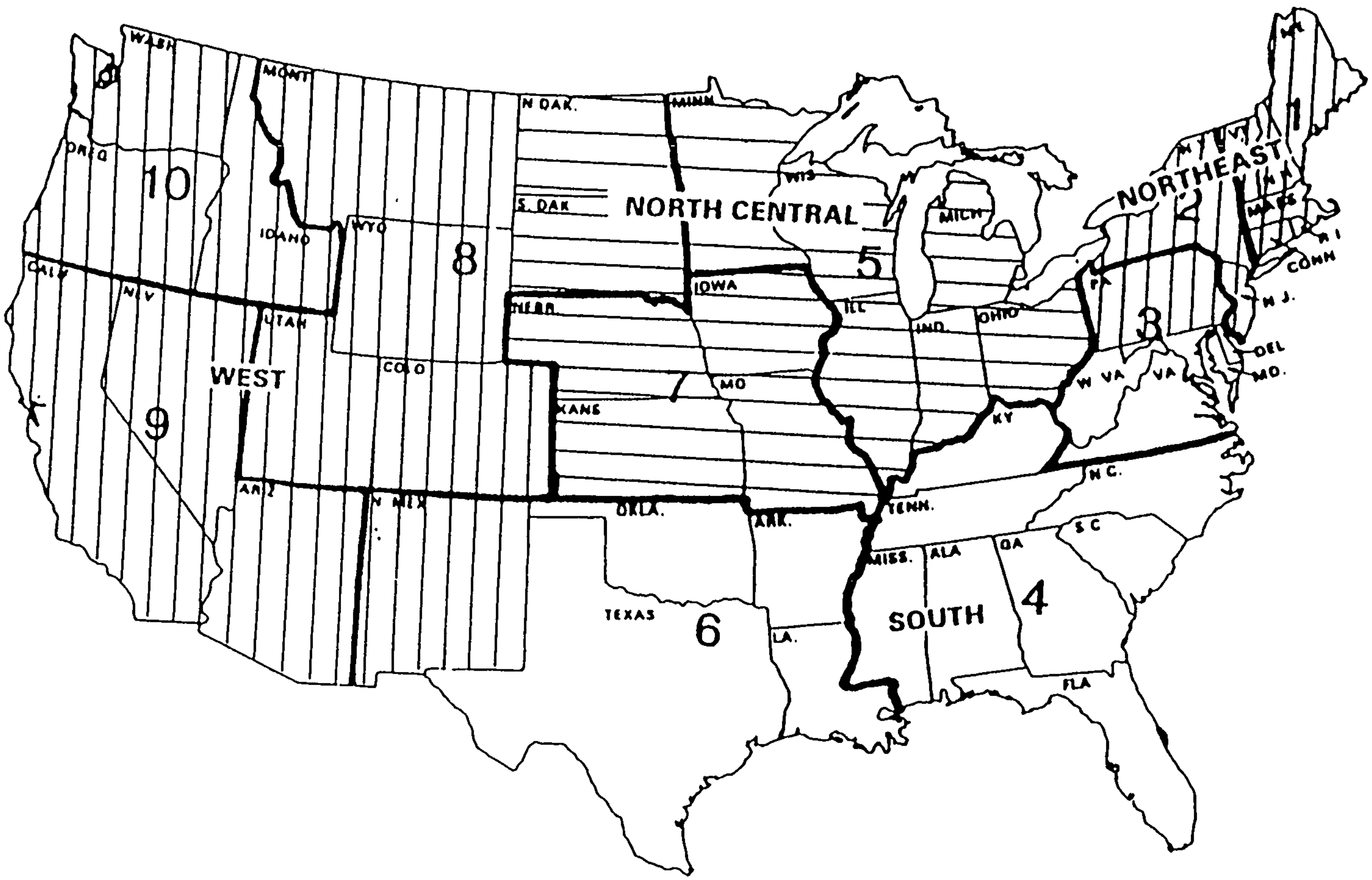
10. North Pacific - Alaska, Idaho, Oregon, Washington

The criteria used to evaluate the geographic segmentation of the market were:

- Insolation,
- Heating and cooling degree days
- Size of the building stock
- Availability of data

Geographic segmentation was made using U.S. Department of Energy (DOE) Regions because of the ready availability of data, the relative homogeneity of climatic and insolation characteristics and the ability to integrate census region data with DOE region information. Figure 3-2 compares Census and DOE regions.

Table 3-2 DOE AND CENSUS REGIONS



Note: DOE Regions are Numbered
Census Regions are Cross Hatched

Insolation, building stock, electric cost and electric saturation data were then compiled for each region.[7,8,9] The product market in each of the ten regions was further stratified by type of consumer (residential or commercial). The commercial strata were further segmented among ten building types[8]:

1. Office,
2. Restaurants,
3. Retail Establishments,
4. Grocery Stores,
5. Warehouse (including refrigerated warehouses),
6. Education - Elementary/Secondary Schools and Colleges/Universities,
7. Health Care Facilities - Hospitals, Clinics, Nursing Homes
8. Hotels
9. Assembly - auditoriums, arenas, churches

[7] Sandia National Laboratory, PV Form (Version 3.3)
[8] Energy Information Administration, Office of Markets and End Use, Commercial Buildings Energy Consumption Survey

10. Miscellaneous - Parking Garages, Public Order/Safety and Vacant structures.

3.3 Technically Feasible Market

Archetypal consumption patterns for each geographic area and building stratum were developed using primary and secondary data sources.

Residential consumption estimates were based on the development of regional archetypal building envelopes based on typical housing size and electric end use intensity.[9] Annual consumption was then projected using an engineering simulation analysis over typical meteorological year weather data for each geographic region.[10]

Commercial consumption estimates were based on estimates of daytime end use consumption intensity per square foot of building space for each geographic region

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9 Energy Information Administration, Housing Characteristics.
10 A.D. Little, EPRI Simplified Program for Residential Energy

for each building type.[11] Lighting and water heating end use intensities were used as a proxy for actual load shape data. The footage stock for each building type within each region was based on Commercial Building Energy Consumption Survey estimates.[12] Total daytime consumption was then estimated for each building type within each geographic area by multiplying the building square footage stock by the end use consumption intensity. Estimated electric consumption was adjusted to reflect actual end-use market shares of electric.

Roof area available for the PV roofing product was estimated based on the average floor stock, number of stories and the typical roof pitch for each building type[13]. Roof area available for installation was reduced for building orientation and roof penetrations. The electric output of the PV roofing material was then simulated based upon the average efficiency of the product in converting

[11] Electric Power Research Institute, The COMMEND Planning System: National and Regional Data and Analysis
[12] Ibid
[13] American Society of Heating, Air Conditioning and Refrigeration Engineers, Fundamentals

solar insolation into electric energy in each geographic area for each building stratum.

An estimate of the technically feasible market size for the product was made for each strata. The lesser of the estimated electric consumption or the maximum PV output was used to estimate the Technically Feasible market size.

3.4 Economically Attainable Market

The Economically Attainable Market represents the fraction of consumers with technically feasible installations who would elect to purchase the product. The Economically Attainable market was estimated in five steps.

First, the building stock was screened to eliminate consumers likely to be largely unresponsive to economic decision making criteria or for whom the economic impact of product installation was likely to be negligible. These screens included[14]:

[14] U.S. Bureau of the Census, Statistical Abstract of the United States (113 th Edition)

- Rented Buildings
- Multi-family Buildings
- Condominium and Cooperatively owned Buildings
- Structures Higher than three Stories
- Vacant structures

Second, typical residential and commercial electricity costs for each building type within each geographic area were compiled. [15]

Third, the annual cost saving attributable to installation of the product was estimated. The cost savings estimate was projected assuming electric price escalators equivalent to approximately 2% per year. The resulting estimates were then averaged for the first five years to yield the expected annual benefit level.

[15] Casazza, Schultz & Associates, Electric Rate Book

Fourth, the target incremental product cost, $2,290 per kilowatt or approximately $25 per square foot of roofing product was then applied to the available roof stock, in each strata and market segment, to yield the total cost (or revenues) assuming 100% market penetration. Applicable state and federal tax credits were compiled, and applied as reductions in the first cost of the installation.[16] [17] [18]

Fifth, the fraction of consumers in each strata and within each market segment who would elect to purchase the product given an economic decision indicated by the payback developed in the first three steps was estimated. The penetration estimate was principally based on project acceptance schedules compiled over a wide range of long lived energy projects across seven customer types and market segments.[19] [20] The project acceptance schedules reflect the fraction of consumers electing to pursue a given

[16] Commerce Clearing House, Multistate Corporate Income Tax Guide

[17] Commerce Clearing House, State Tax Guide

[18] Commerce Clearing House, Standard Federal Tax Reports

[19] Arizona Public Service Company, Market Penetration Rates, (an update of an earlier study based on approximately 500 energy projects reported in the trade press)

[20] Synergic Resources Corporation, Market Penetration Seminar, April 1990

long term energy investment at a given level of economic benefits.

Additional penetration estimates for the PV Roofing Product were made using simulated utility incentives. Incentives were treated as a reduction in the first cost of the product to obtain estimates of market penetration.

The utility incentive level was predicated on simulated archetypal avoided capacity and energy costs. Avoided capacity and energy costs were based on a natural gas fired combustion turbine costing $500 per kilowatt (kW) with a heat rate of 12,000 Btu/kwh.[21]

Avoided energy and capacity costs were projected over a twenty year time horizon assuming a 5% annual escalation in fuel costs.[22] A coincidence factor representing the coincidence of insolation and utility peak loads was applied to avoided capacity streams to reflect the utility demand

[21] Based on a General Electric Frame 7 Model EA Turbine with water injection for NOx control

[22] Based on American Gas Institute and Gas Research Institute 1993 Wellhead natural gas price forecasts

side benefit in each of the ten geographic areas. [23] The future costs were discounted using a 10% discount rate, with the net present value thus determined used as the basis for the utility incentive.

[23] Robert H. Williams and Gregory Terzian, A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology

4.0 Key Assumptions

Several key assumptions were made to produce the market size projection that significantly effect the magnitude and reliability of the estimate:

- Cost of the Product
- Configuration of the Product
- Distribution Channels for the Product
- Competition

4.1 Cost of the Product

The assumed incremental installed cost of the product, \$2,290 per kW (\$25/ ft^2), is substantially below current product costs. Higher product costs would translate into a smaller economically attainable market.

Additionally assumed was:

The incremental cost of the PV Roofing Product is the same across all configurations of roofing displaced.

There is significant variability in the cost and physical characteristics of roofing products. On average, roofing products cost \$1.10/ft^2 (installed) so a 1 kW PV Roofing application producing 10 W/ft^2 would displace \$110 in traditional roofing costs, or less than half the initial ECD projection.

4.2 Product Configuration

Four types of product configuration were assumed applicable for the PV Roofing Product. If the product were unable to be effectively configured or priced to meet the needs of these markets then the estimated market potential would be reduced. Table 4-1 summarizes the current market for various roofing product types.

First, a flat roofing product configuration, for use in built up, single ply and other similar flat or low pitch applications. This product configuration accounts for almost 90% of the commercial market and approximately

TABLE 4-1: ROOFING INDUSTRY REVENUES

By type of roofing installation

($ - billions)

	COMMERCIAL			
	NEW	RE-ROOF	TOTAL	%
BUILT-UP ROOF	0.83	3.15	3.98	30.2%
EPDM	0.93	2.42	3.35	25.4%
CSPE	0.07	0.21	0.28	2.1%
PVC	0.10	0.32	0.42	3.2%
OTHER SINGLE PLIES	0.06	0.22	0.28	2.1%
SPRAYED POLYURETHANE FOAM	0.04	0.12	0.16	1.2%
LIQUID APPLIED	0.01	0.06	0.07	0.5%
METAL - STRUCTURAL	0.04	0.11	0.15	1.1%
METAL ARCHITECTURAL	0.13	0.25	0.38	2.9%
MODIFIED BITUMEN	0.23	1.14	1.37	10.4%
MODIFIED BITUMEN	0.34	1.33	1.67	12.7%
TILE	0.04	0.16	0.20	1.5%
ASPHALT SHINGLES	0.17	0.61	0.78	5.9%
OTHER	0.01	0.10	0.11	0.8%
	3.00	10.20	13.20	100.0%

	RESIDENTIAL			
	NEW	RE-ROOF	TOTAL	%
FIBERGLASS ASPHALT SHINGLE	0.36	1.96	2.32	51.6%
ORGANIC ASPHALT SHINGLE	0.08	0.50	0.58	12.9%
CEMENT BASED SHINGLE	0.01	0.03	0.04	0.9%
WOOD SHINGLES/SHAKES	0.02	0.12	0.14	3.1%
CLAY TILE	0.01	0.06	0.07	1.6%
CONCRETE TILE	0.02	0.09	0.11	2.4%
SLATE	0.02	0.10	0.12	2.7%
COMPOSITE/SYNTHETIC	0.01	0.01	0.02	0.4%
METAL	0.03	0.16	0.19	4.2%
BUILT-UP ROOF	0.04	0.23	0.27	6.0%
MODIFIED BITUMEN	0.03	0.21	0.24	5.3%
SINGLE PLY	0.06	0.32	0.38	8.4%
OTHER	0.01	0.01	0.02	0.4%
	0.70	3.80	4.50	100.0%

15% of the residential market. Overall, this product configuration represents approximately two-thirds of roofing market installations.

Second, a product configured to displace metal roofing products. This configuration accounts for approximately 4% of residential and commercial roofing markets.

Third, a shingle replacement product configuration. This type of product presently represents 70% of the residential roofing market and 6% of the commercial roofing market. Overall, shingles represent approximately 25% of roofing sales.

Fourth, the product was assumed usable in recovery roofing applications. Recovery roofing (re-roofing over a pre-existing roof) represents approximately 25% of the roofing market (33% of the retro-fit roofing market). The technical feasibility of the use of PV Roofing products in this application has yet to be demonstrated. The inability of the product to be configured to meet the needs of this market could significantly impact the potential market for PV Roofing.

4.3 Distribution Channels

The market penetration projection assumes that distribution channels exist to market, install and support the product. Since installation of the product could require several different trades, distribution channels for the product could be problematic during developmental phases.

Existing distribution channels are concentrated within trade contractors. Roofing contractors do not typically employ electricians nor do electrical contractors typically employ roofers. Consequently, use of existing distribution channels to market the product will be pose significant organizational, communication and logistic hurdles. Additionally, if there is no or little initial demand for the product, it could be difficult to induce wholesalers to stock the product. If the product is not stocked then it may be difficult to get roofers to sell the product.

The solutions to gaining acceptance of the product could pose significant barriers to entry due to the high costs of potential solutions such as :

- Regional and/or national advertising
- Financing wholesaler inventories
- Expedited delivery from central or regional warehouses

There is a level of expertise needed to appropriately size the PV installation that generally does not exist among roofing contractors. Inappropriately sized installations could obviate the economics of the installation, diminish quality of electrical service to both the customer installing the PV Roofing product as well as other electric consumers in close proximity to the PV installation. [24]

Currently there are approximately 26,000 roofing contractors in the U.S. The average roofing contractor employs seven construction workers. The large number of

[24] An oversized system will backfeed the utility grid with the potential to disrupt service to nearby customers due to harmonic distortion .

firms, with each having a relatively small number of employees implies high cost of marketing and training. Figures 4-1 and 4-2 provide pertinent demographic information about roofing contractors.

Additionally, architects, engineers, general contractors and the public would have to become sufficiently aware of the product to specify its use. Adequately trained roofing and/or electrical contractors could then submit bids for product installation in new and retro-fit applications.

4.4 Competition

The estimate of market size reflects the market for all PV Roofing products. There is no guarantee that competitors will not penetrate a significant fraction of the market to the exclusion of ECD's product.

Alternative or new photovoltaic and other solar products could also displace penetration of ECD's PV Roofing Product. These competing products could be more readily

FIGURE 4-1: SIZE DISTRIBUTION OF ROOFING FIRMS

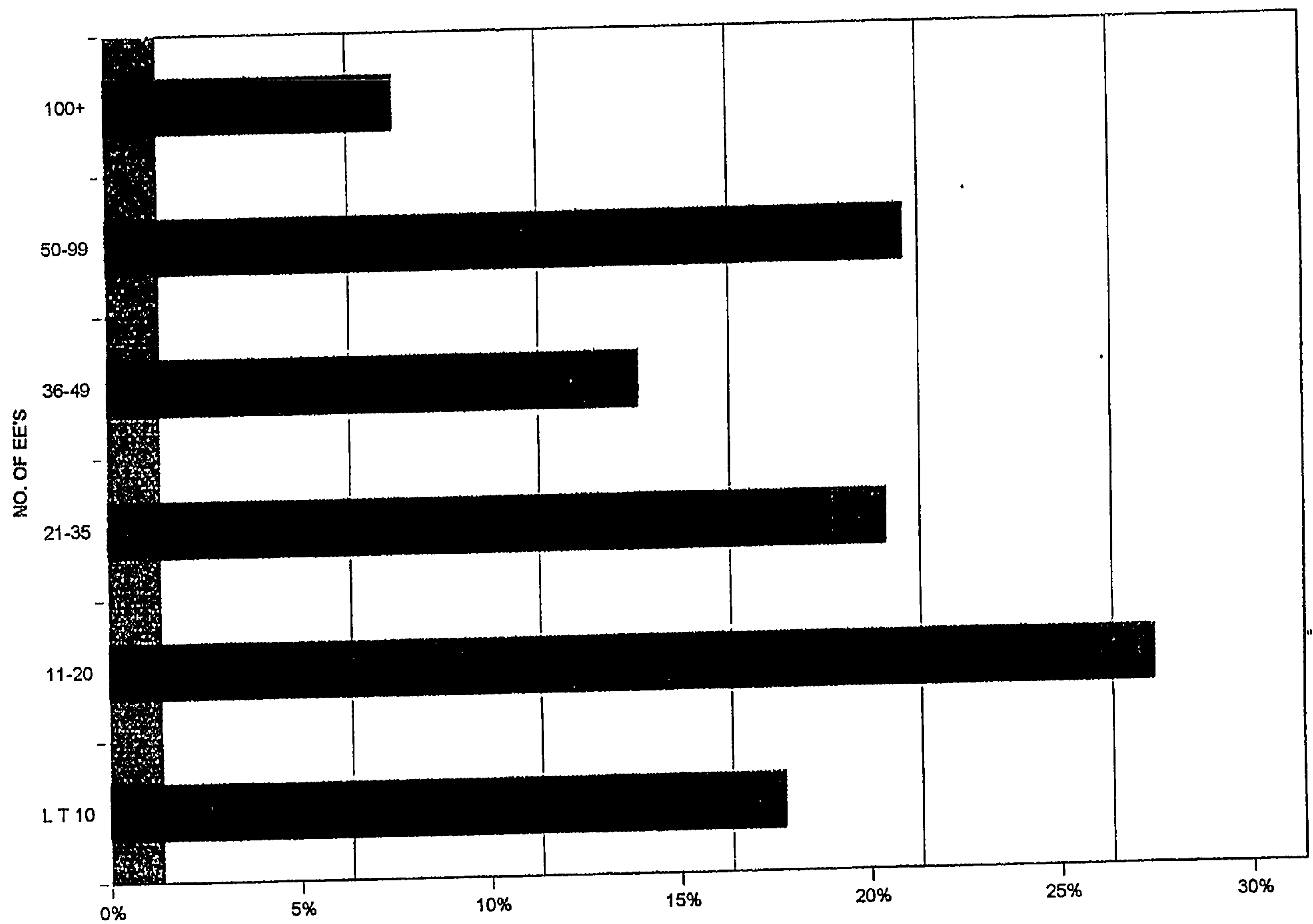
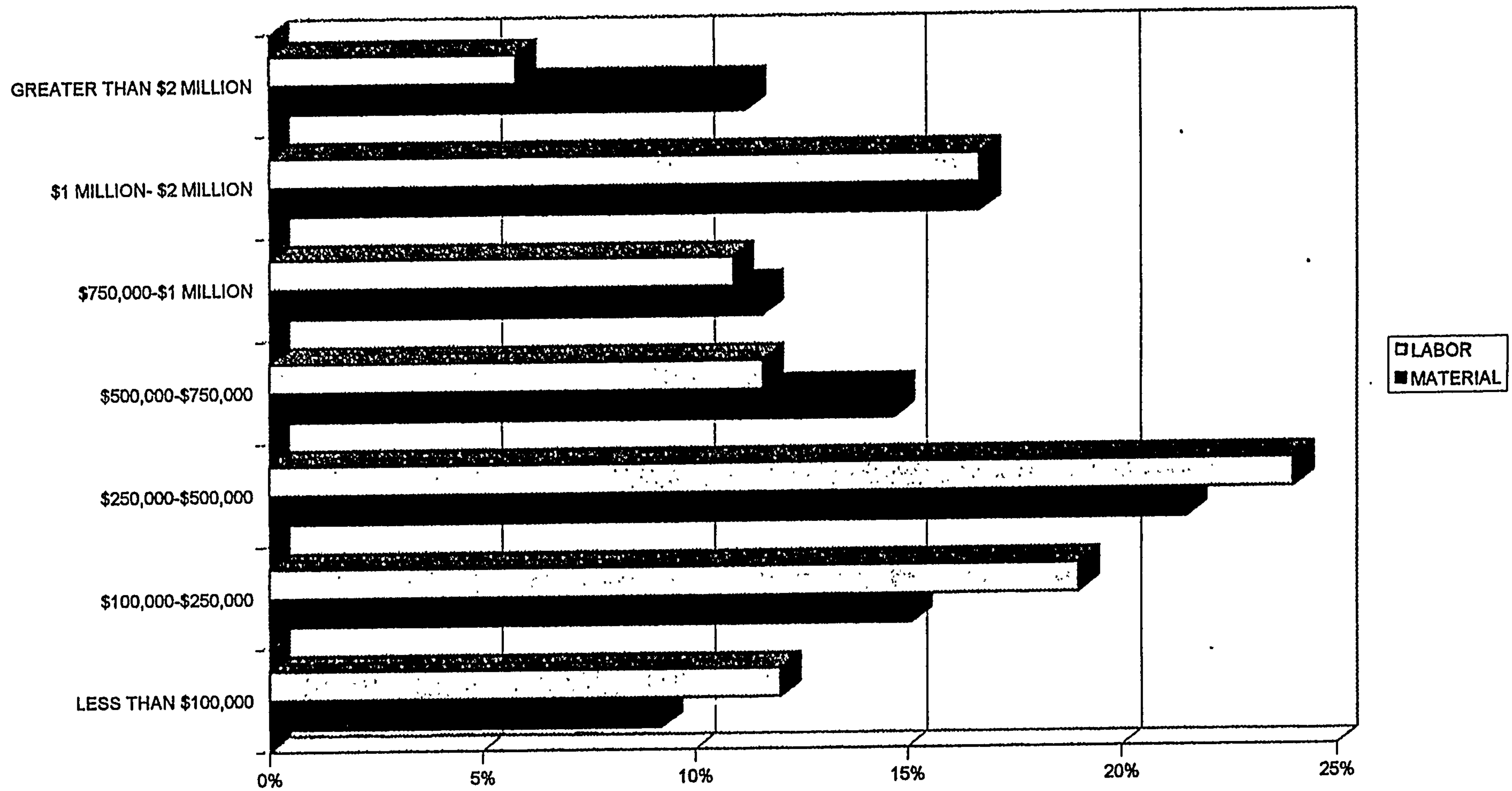


FIGURE 4-2: ROOFING CONTRACTOR ANNUAL EXPENSES



produced and installed at lower prices than the ECD product once distribution channels have been established.

Additionally, other competitive products could have non-performance based product differentiation and attributes (color, shape etc.) that could be preferred by customers.

4.5 DSM Valuation

The assumed use of electric utility Demand Side Management (DSM) incentives was shown to significantly stimulate product demand. The level of incentives was based on estimated archetypal avoided costs which did not include administrative costs or free ridership.

The programmatic subsidization of PV roofing products is an independent decision that would have to made by each of the approximately 200 major electric utilities in the U.S. The actual level of subsidization would vary, based on the local load, generating resources, fuel, environmental, regulatory and climatic profiles faced by each individual utility.

There are presently a number of proposals to restructure the electric utility industry which could significantly impact utility resource based DSM programs and related DSM incentives. This study assumes continuation of existing DSM subsidization and promotion of PV by utilities.

5.0 Discussion of Results

Three estimates of market potential were developed:

1. A Technically Feasible estimate reflective of the maximum feasible quantity of product installation regardless of costs,

2. An Economically Attainable estimate indicative of the likely penetration of the market given the expected financial benefits attributable to product installation, and,

3. Third, an Economically Attainable estimate including use of utility DSM incentives as a reduction in consumer first cost.

5.1 Technically Feasible Market Size

The Technically Feasible Market for the PV roofing product was estimated to be 15.6 billion square feet or approximately 11% of total U.S. residential and commercial roof stock. The saturation of technically feasible roof stock with PV could displace the equivalent of 147,535 MW of electric non-coincidental demand. The commercial market represented 9.5 billion square feet or 61% of all technically feasible applications of the product. The Technically Feasible Market is summarized in Table 5-1.

Geographically, the Central and South Central regions had the largest technically feasible market for the PV Roofing Product in both the Residential and Commercial sectors. Almost 6 billion square feet, or 37%, of technically feasible market opportunities were concentrated in these regions, as shown on Table 5-1.

Four building types comprised almost two-thirds of technically feasible product markets:

- Office buildings represent one-third or 3 billion square feet of technically feasible markets.

TABLE 5-1: TECHNICALLY FEASIBLE MARKET

Commercial and Residential Customers

	MW Billing Demand			Square Feet of Product (000)		
	Commercial	Residential	Total	Commercial	Residential	Total
New England	5,922	3073	8,995	647,841	320140	967,981
NY and NJ	12,657	3718	16,375	1,323,961	387320	1,711,281
Mid-Atlantic	11,001	5821	16,822	1,180,462	606329	1,786,791
South East	12,676	12104	24,780	1,341,356	1260806	2,602,162
Central	17,448	11198	28,646	1,902,763	1166485	3,069,248
South Central	8,951	7996	16,947	941,797	832962	1,774,759
Mid West	3,983	2709	6,692	423,569	282179	705,748
Mountain	2,584	2763	5,347	280,239	287835	568,074
S. Pacific	10,946	7493	18,439	1,142,039	780548	1,922,587
N. Pacific	2,602	1890	4,492	270,069	196891	466,960
	88,770	58,765	147,535	9,454,096	6,121,495	15,575,591

Figure 5-1 (a)

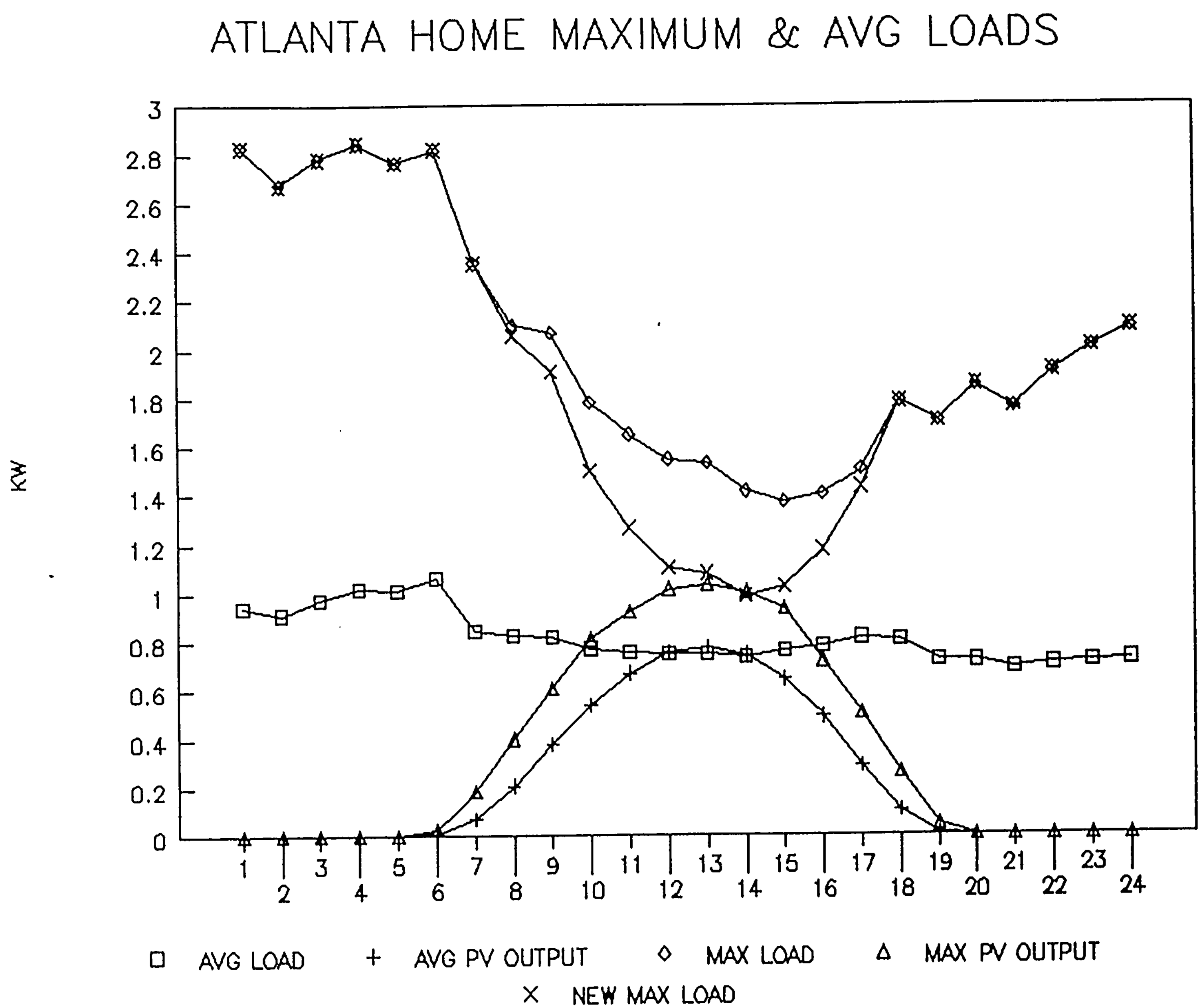

ATLANTA HOME MAXIMUM & AVG LOADS
KW
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
AVG LOAD
AVG PV OUTPUT
MAX LOAD
MAX PV OUTPUT
NEW MAX LOAD

Figure 5-1 (b)

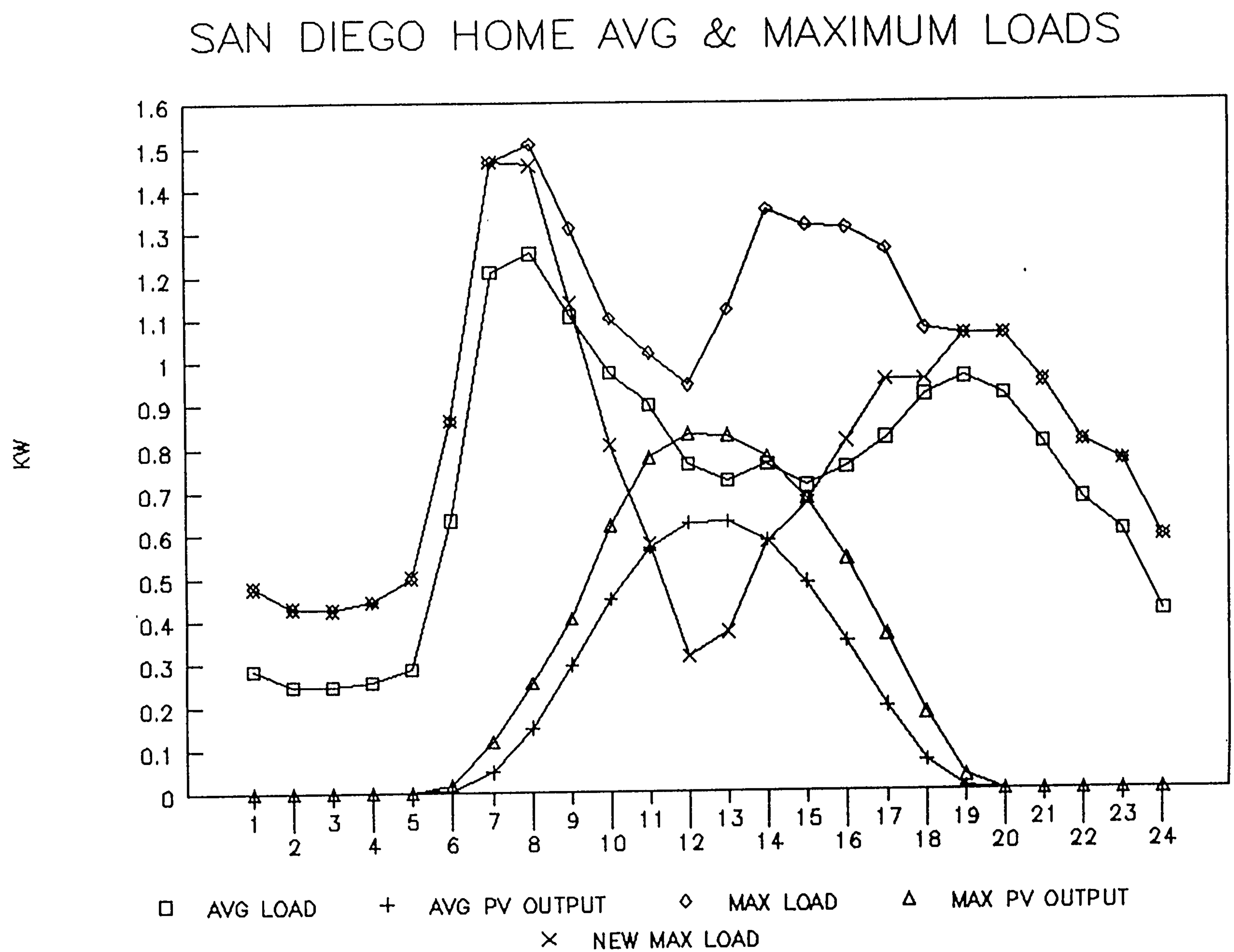

SAN DIEGO HOME AVG & MAXIMUM LOADS
KW
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
AVG LOAD
AVG PV OUTPUT
MAX LOAD
MAX PV OUTPUT
NEW MAX LOAD

Figure 5-1 (c)

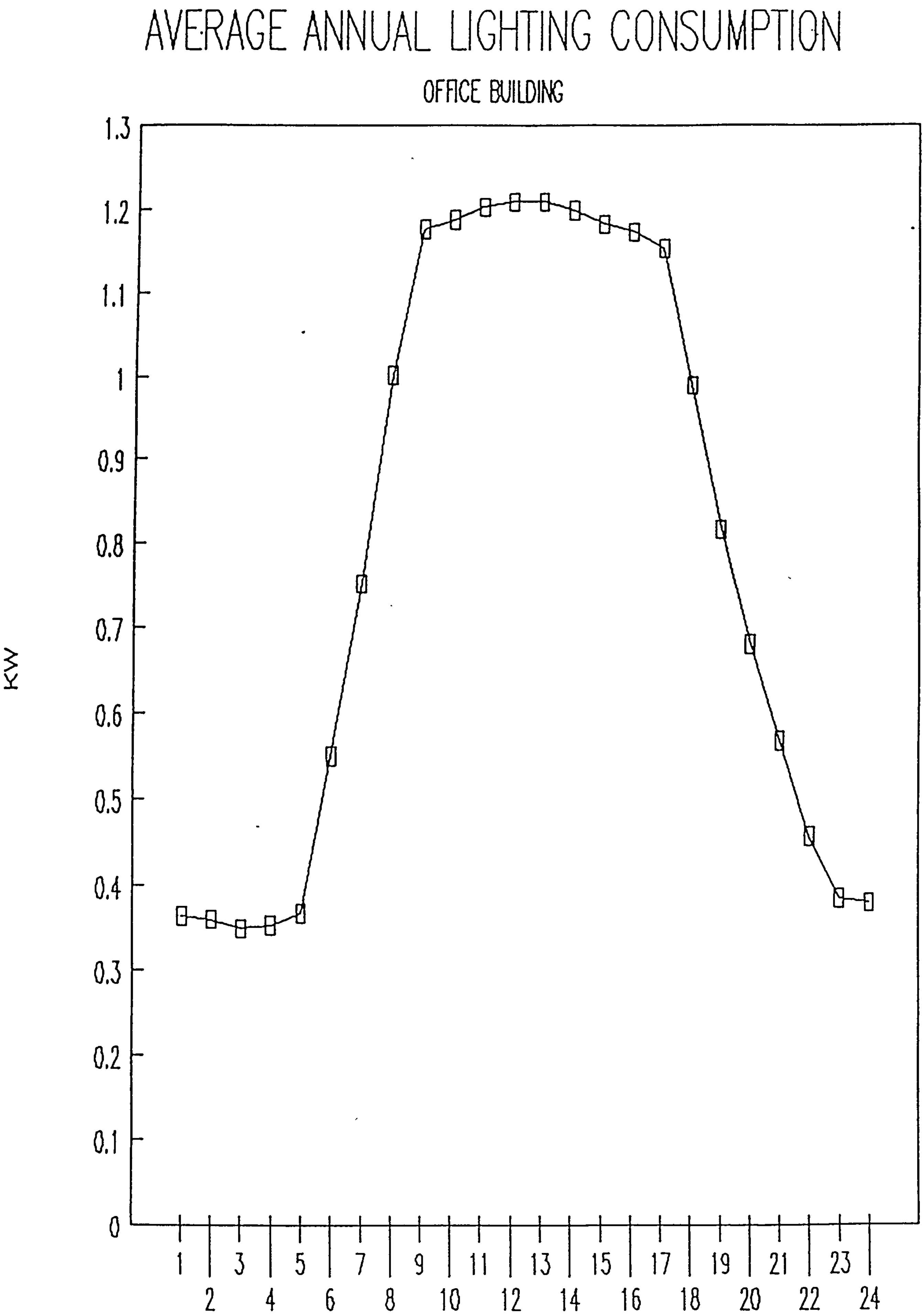

AVERAGE ANNUAL LIGHTING CONSUMPTION
OFFICE BUILDING
KW
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 5-1 (d)

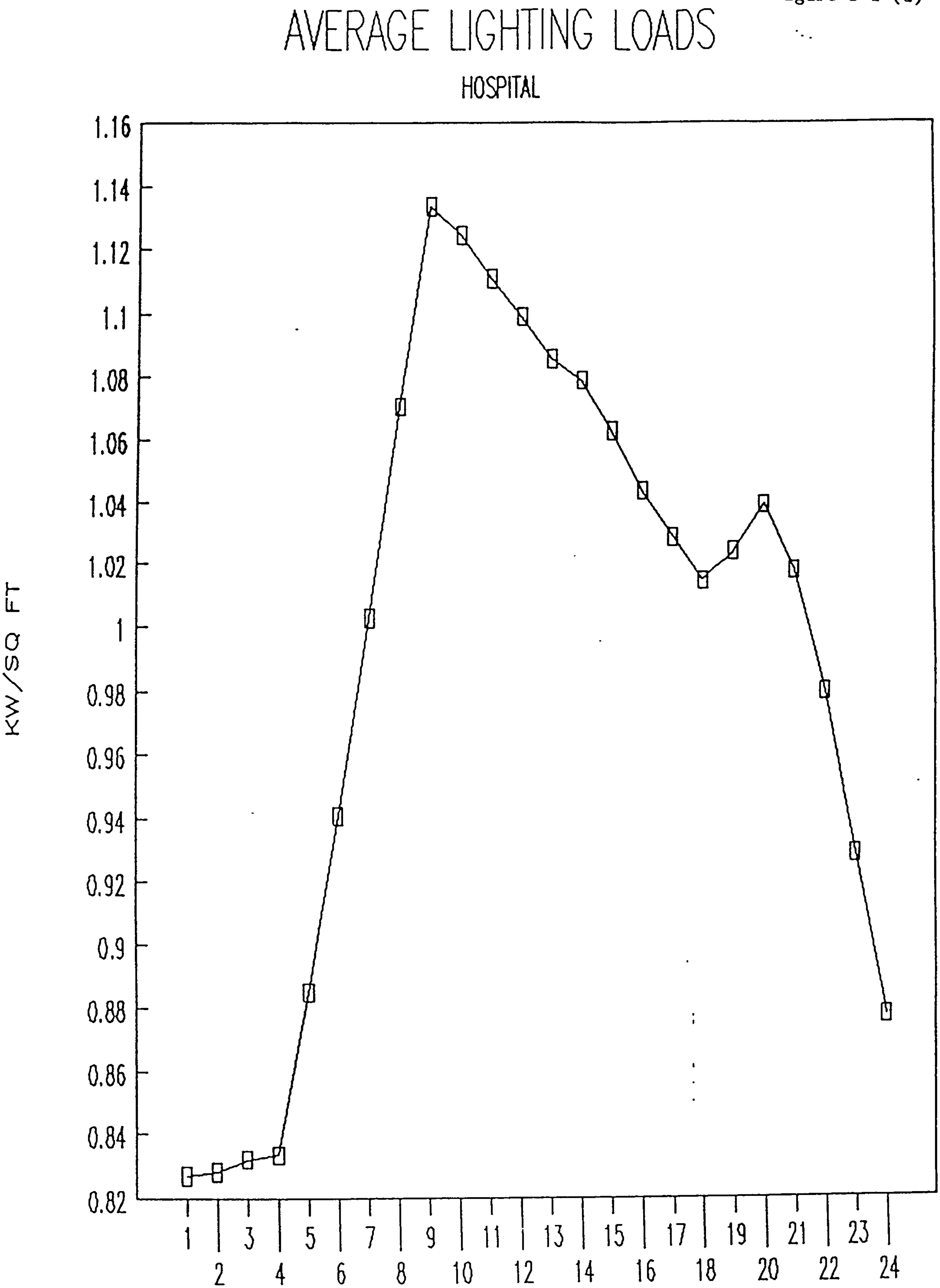

AVERAGE LIGHTING LOADS
HOSPITAL
KW/SQ FT
1.16
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 5-1 (e)

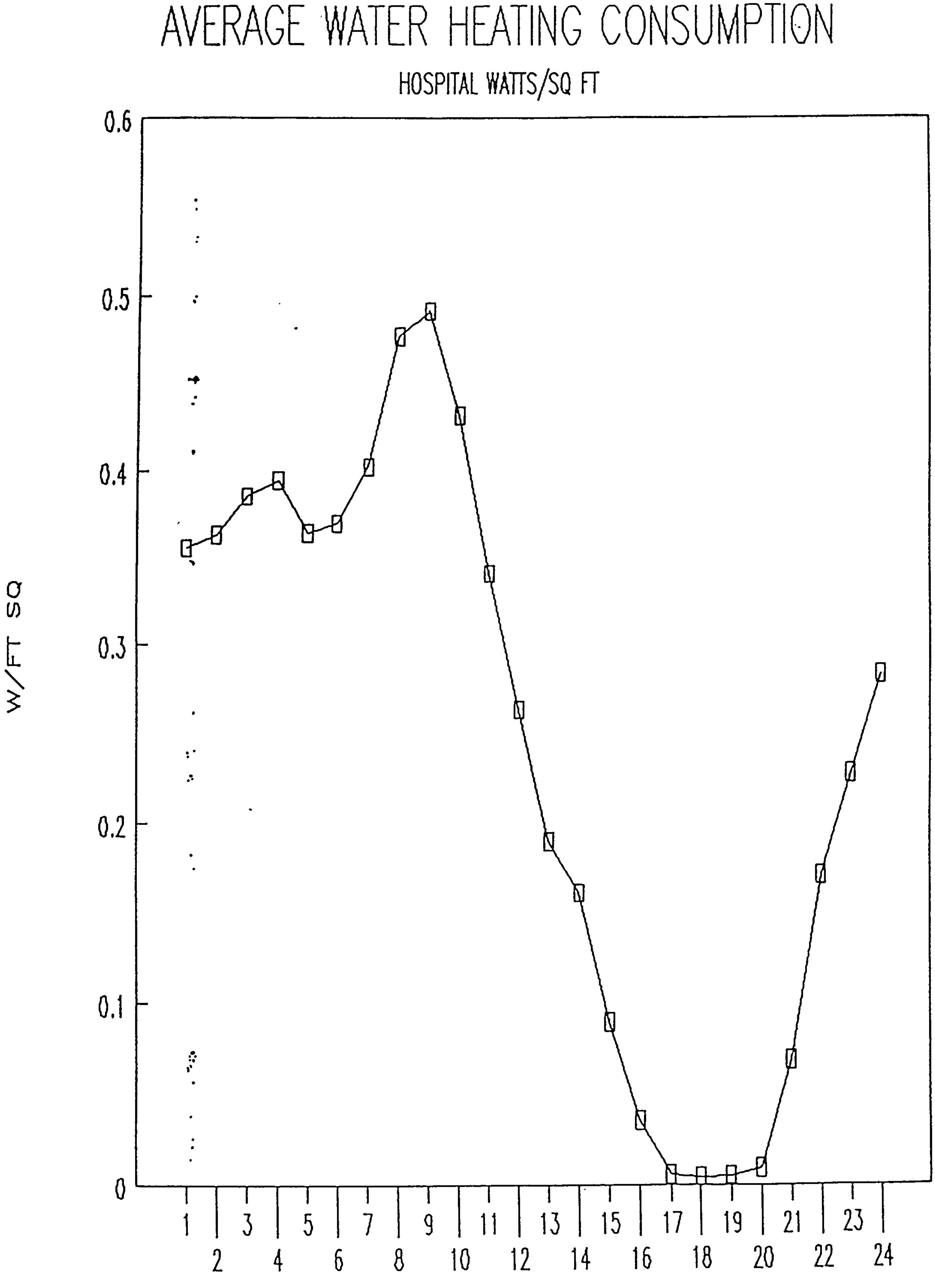
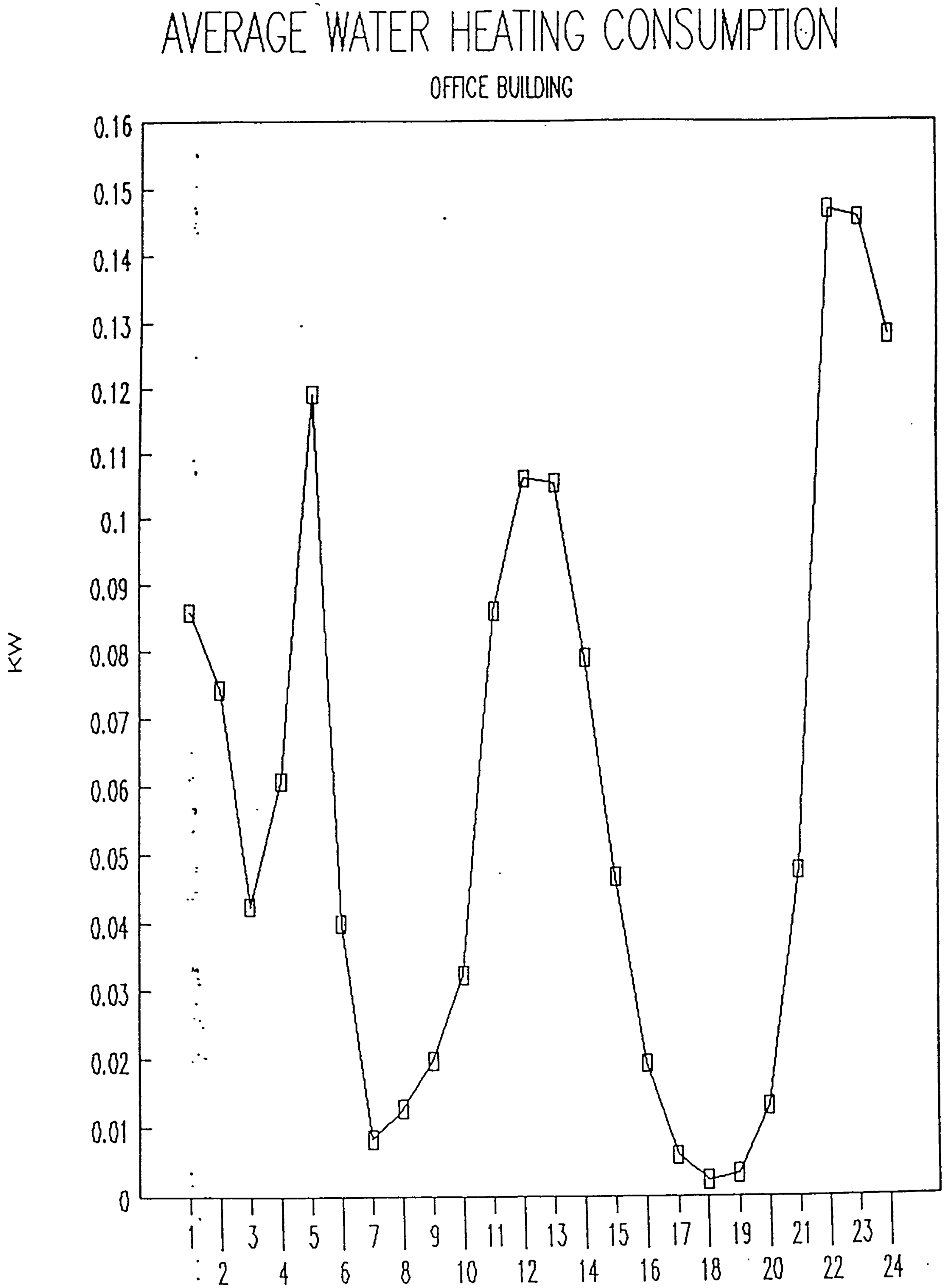

AVERAGE WATER HEATING CONSUMPTION
HOSPITAL WATTS/SQ FT
W/FT SQ
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 5-1 (f)


AVERAGE WATER HEATING CONSUMPTION
OFFICE BUILDING
KW
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

- Warehouses comprise 14% or 1.3 billion square feet of technically feasible product markets.
- Government buildings (Schools, Public Assembly Facilities) represent 11% of the technically feasible product market.
- Restaurants comprising 12% of technically feasible square footage.

Table 5-2 summarizes Technically Feasible commercial markets by geographic region and commercial building type.

Commercial customers were able to use 94% of available solar electric energy. Available roof space constrained the size of the commercial market. The commercial loads and consumption characteristics were found to be large enough and have a sufficient level of coincidence with insolation to support a photovoltaic system using all available roof space. Figure 5-1 illustrates typical commercial and residential building consumption patterns. Figure 5-2

TABLE 5-2: MAXIMUM TECHNICALLY FEASIBLE MARKET

MW of Billing Demand

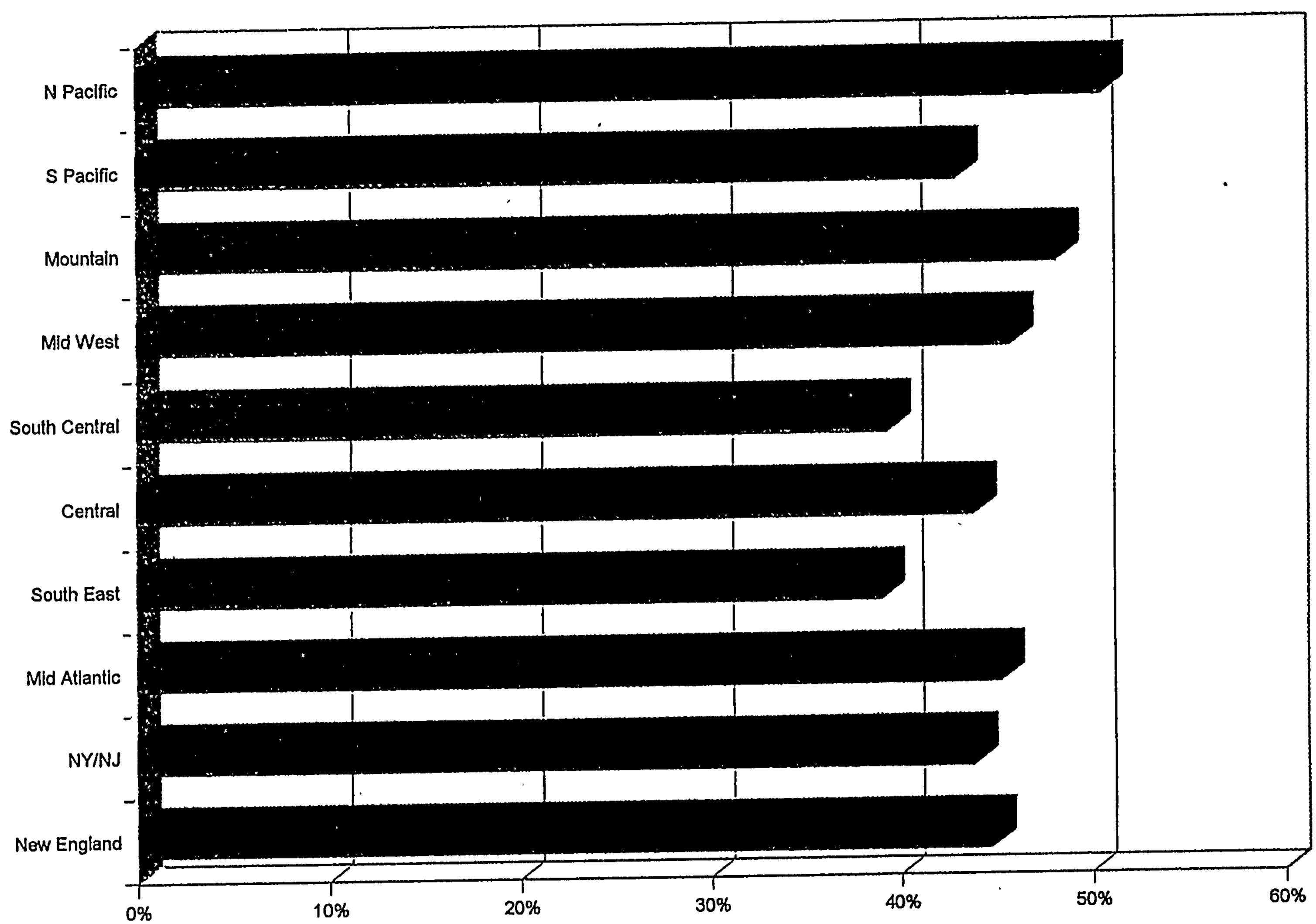
	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	5,922	1,953	746	128	178	687	211	405	92	355	1,167
NY and NJ	12,657	4,126	1,464	310	373	1,622	343	880	129	638	2,771
Mid-Atlantic	11,001	3,635	1,312	234	303	1,302	399	798	124	909	1,985
South East	12,676	4,031	1,655	287	314	1,813	379	891	147	848	2,310
Central	17,448	5,246	2,169	360	573	2,437	918	1,224	209	1,293	3,020
South Central	8,951	2,713	1,074	213	236	1,349	340	609	110	625	1,683
Mid West	3,983	1,138	458	68	107	557	199	217	46	465	728
Mountain	2,584	932	298	39	73	352	138	167	40	147	398
S. Pacific	10,946	4,066	1,390	240	381	1,557	473	1,052	143	590	1,054
N. Pacific	2,602	546	314	58	84	425	143	206	51	275	500
	88,770	28,387	10,881	1,937	2,621	12,100	3,543	6,449	1,091	6,146	15,614

MAXIMUM TECHNICALLY FEASIBLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	647,841	213,647	81,623	14,007	19,421	75,155	23,131	44,289	10,105	38,841	127,622
NY and NJ	1,323,961	431,313	153,170	32,424	39,003	169,695	35,854	92,032	13,555	66,769	290,147
Mid-Atlantic	1,180,462	389,217	140,780	25,123	32,563	139,641	42,828	85,849	13,260	97,679	213,523
South East	1,341,356	427,312	174,956	30,345	33,247	192,045	39,966	94,534	15,601	89,077	244,272
Central	1,902,763	572,136	236,532	39,241	62,483	265,757	99,982	133,519	22,724	141,066	329,323
South Central	941,797	285,510	113,031	22,426	24,803	141,691	35,829	64,092	11,617	65,861	176,936
Mid West	423,569	120,704	48,784	7,223	11,356	59,327	21,238	23,063	4,902	49,467	77,506
Mountain	280,239	101,132	32,327	4,266	7,941	38,132	14,973	18,047	4,304	15,971	43,147
S. Pacific	1,142,039	424,144	145,012	25,061	39,745	162,394	49,354	109,787	14,879	61,567	110,094
N. Pacific	270,069	56,751	32,590	6,032	8,734	44,134	14,833	21,337	5,276	28,550	51,830
	9,454,096	3,021,866	1,158,805	206,147	279,296	1,287,972	377,989	686,549	116,224	654,849	1,664,400

Figure 5-2: Lighting & Water Loads as a % of Total Commercial Loads



shows the fraction of total consumption represented by commercial lighting and water heating.

Residential customers were capable of using only 60% of the available insolation (after taking into account the orientation of the roof, roof penetrations, geographic location). Technically feasible residential markets were constrained by day time usage and hourly consumption patterns. Residential electric energy consumption patterns had relatively low coincidence with insolation, limiting potential stand alone product configurations.

Residential customers also had significant variability in sizing of PV applications across geographic areas. Areas of the country with moderate climates and relatively small housing unit size (e.g. California) were found capable of using 1 kW in PV Roofing product. Other areas of the country with larger houses and less moderate climate (e.g. Atlanta, Phoenix) were capable of using 2 kW in PV roofing product. Colder climatic areas such as the Mid-West and North East generally had insufficient day time

TABLE 5-3: TECHNICALLY FEASIBLE MARKET

Residential

	MAX $ Sales ($-000)	MAX Sq Ft of Product (000)	MW Billing Demand
New England	$7,853,442	320,157	3,074
NY and NJ	$9,501,455	387,340	3,718
Mid-Atlantic	$14,874,012	606,360	5,821
South East	$30,929,145	1,260,870	12,104
Central	$28,615,337	1,166,545	11,199
South Central	$20,433,587	833,004	7,997
Mid West	$6,922,214	282,194	2,709
Mountain	$7,060,940	287,849	2,763
S. Pacific	$19,147,818	780,588	7,494
N. Pacific	$4,830,035	196,903	1,890
	$150,167,986	6,121,809	58,769

loads to support PV roofing in the absence of electric heating and/or air-conditioning. Residential Technically Feasible Market is estimated on Table 5-3.

5.2 Economically Attainable Market

The Economically Attainable Market, summarized in Table 5-4, was estimated to be 186 million square feet of product sales over a 20 year time horizon. The economically attainable market represents twelve one-hundredths of a percent (.12%) of the existing total U.S. roof-stock or 1.2% of the technically feasible roof stock footage. An annual sales level averaging approximately 9 million square feet per year (89 MW) or $225 million in annual sales revenue was hypothesized to develop in response to the target incremental price of $2,290/kW.

The simple paybacks for each region, shown on Figure 5-3 represent the tails of the project acceptance curves shown in

TABLE 5-4: EXPECTED MARKET PENETRATION

Commercial and Residential Customers

	MW Billing Demand			Square Feet of Product (000)		
	Commercial	Residential	Total	Commercial	Residential	Total
New England	1	61	62	141	6,327	6,468
NY and NJ	54	58	112	6,125	6,029	12,154
Mid-Atlantic	0	0	0	0	0	0
South East	0	9	9	0	893	893
Central	0	63	63	1	6,570	6,571
South Central	0	117	117	21	12,197	12,218
Mid West	0	45	45	0	4,637	4,637
Mountain	0	56	56	0	5,780	5,780
S. Pacific	508	707	1,215	63,415	73,629	137,044
N. Pacific	2	0	2	230	0	230
	565	1,114	1,680	69,933	116,062	185,995

FIGURE 5-3: AVERAGE COMMERCIAL PAYBACK

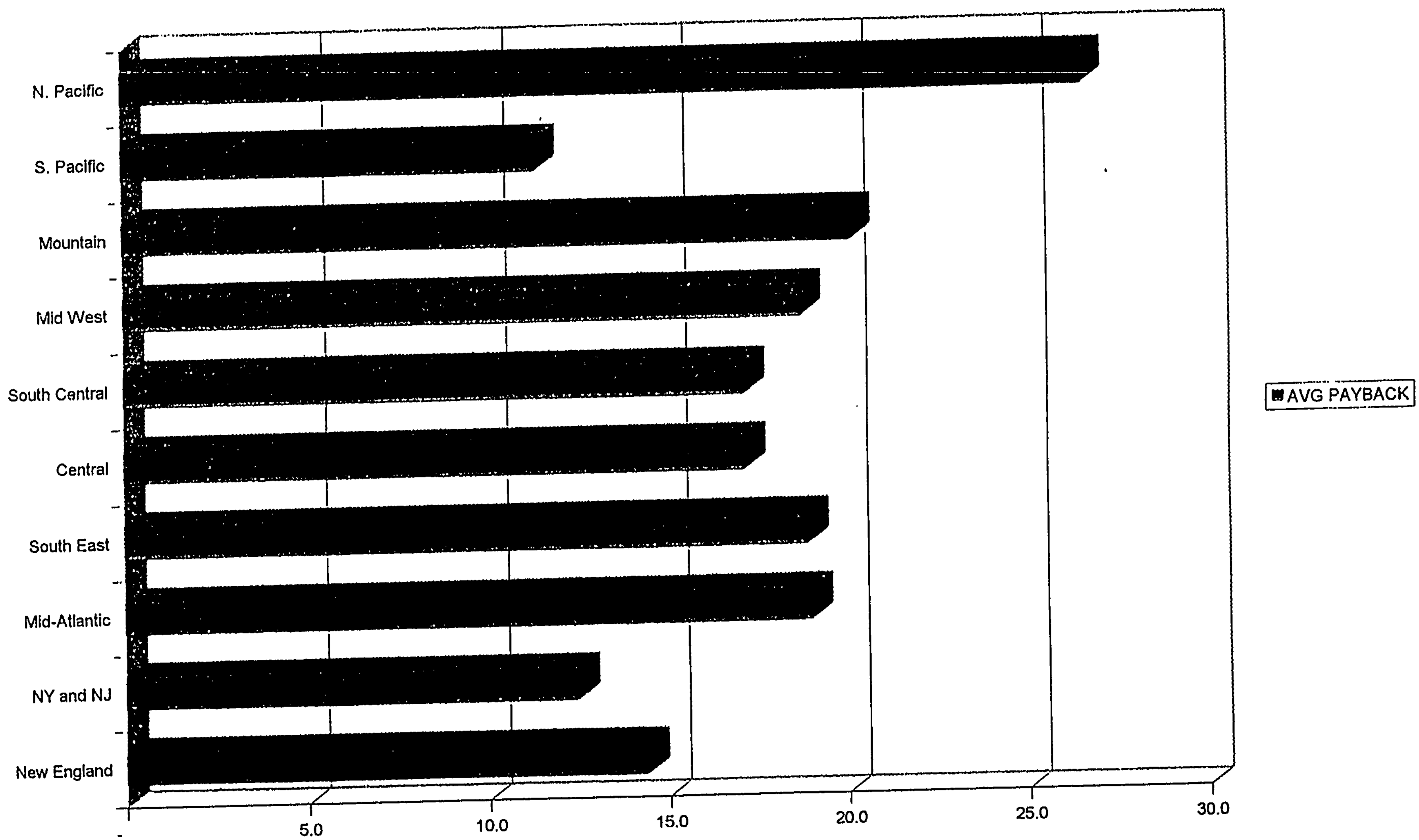


FIGURE 5-4: PROJECT ACCEPTANCE RATES

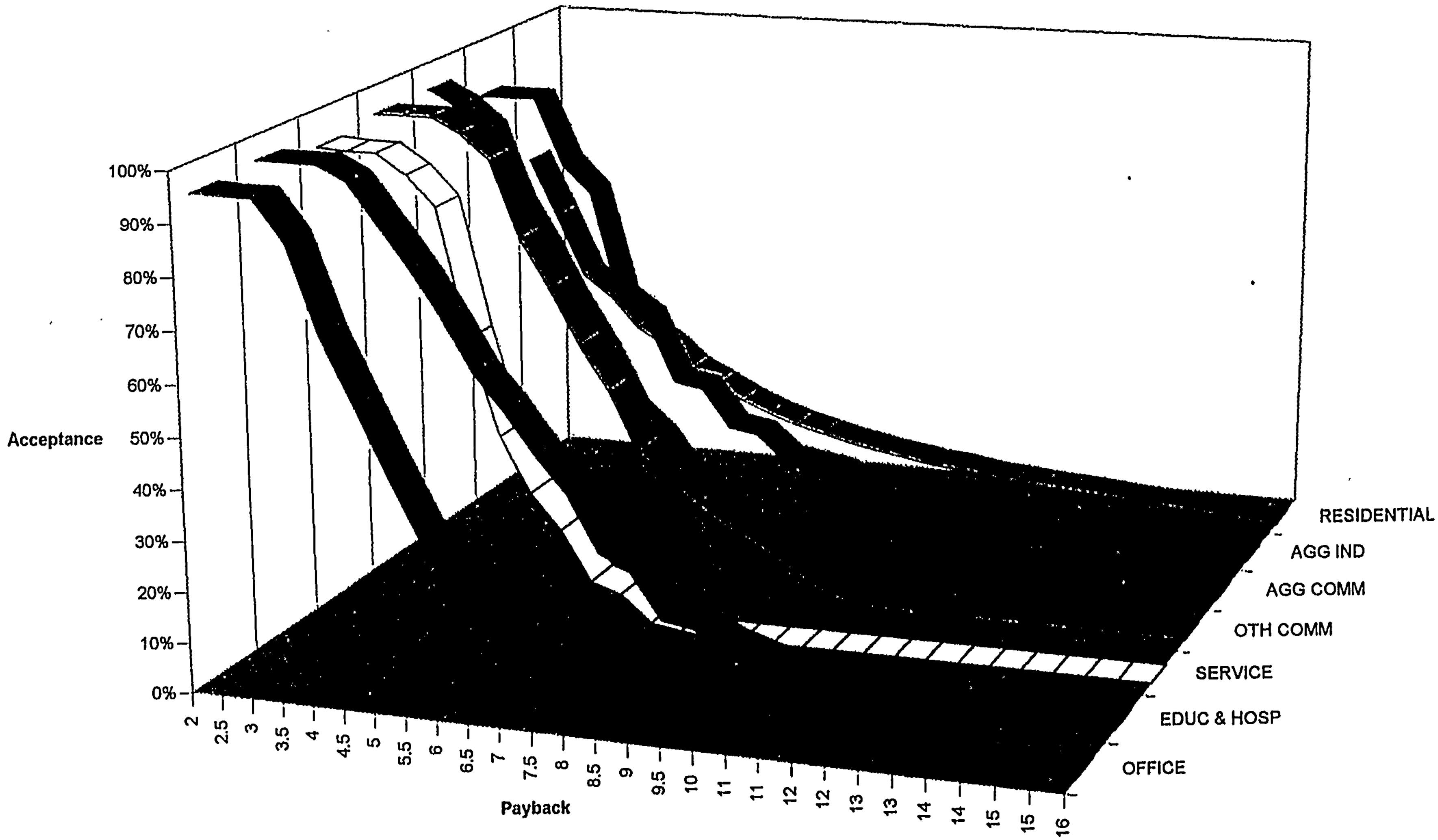


Figure 5-4. This indicates that the target incremental sales price is at the outermost limit of commercialization.

The wholesale market for roofing materials aggregates approximately $8 billion annually in the U.S., so the maximum attainable long term market share for PV Roofing products represents 2.8% of current sales revenues.[25]

Residential customers account for 116 million square feet of the total expected market penetration or 62%. Commercial customers comprise 70 million square feet of anticipated market penetration or 38%.

The projected sectoral penetration levels reflect higher relative penetration in the commercial sector as compared to the residential sector. The total roof stock and annual additions to the stock are approximately two-thirds residential housing and one-third commercial building construction measured on a square footage basis. So the

[25] Market share based on unit volume would be significantly lower

TABLE 5-5: EXPECTED MARKET PENETRATION

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	1	0	0	0	0	0	0	1	0	0	0
NY and NJ	54	1	0	0	0	2	9	24	0	18	0
Mid-Atlantic	0	0	0	0	0	0	0	0	0	0	0
South East	0	0	0	0	0	0	0	0	0	0	0
Central	0	0	0	0	0	0	0	0	0	0	0
South Central	0	0	0	0	0	0	0	0	0	0	0
Mid West	0	0	0	0	0	0	0	0	0	0	0
Mountain	0	0	0	0	0	0	0	0	0	0	0
S. Pacific	508	72	1	24	0	156	54	119	14	67	0
N. Pacific	2	0	0	0	0	0	0	0	0	0	0
	565	73	1	24	0	159	63	144	14	86	0

EXPECTED PENETRATION OF ECONOMICALLY ATTAINABLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	141	1	0	0	0	1	27	61	0	48	0
NY and NJ	6,125	87	0	48	0	235	919	2,490	21	1,895	0
Mid-Atlantic	0	0	0	0	0	0	0	0	0	0	0
South East	0	0	0	0	0	0	0	0	0	0	0
Central	1	0	0	0	0	0	0	0	0	0	0
South Central	21	0	0	0	0	0	6	7	0	7	0
Mid West	0	0	0	0	0	0	0	0	0	0	0
Mountain	0	0	0	0	0	0	0	0	0	0	0
S. Pacific	63,415	7,551	74	2,487	20	16,320	5,618	12,452	1,483	6,965	0
N. Pacific	230	19	1	3	0	39	52	16	6	31	0
	69,933	7,657	75	2,538	21	16,595	6,623	15,027	1,509	8,946	0

TABLE 5-6: EXPECTED PENETRATION OF MARKET

$ 000 Sales Revenue

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	$3,469	$23	$0	$6	$0	$33	$662	$1,505	$3	$1,176	$0
NY and NJ	$150,246	$2,123	$0	$1,166	$0	$5,771	$22,553	$61,076	$516	$46,488	$0
Mid-Atlantic	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
South East	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Central	$22	$0	$0	$0	$0	$0	$6	$8	$0	$7	$0
South Central	$513	$3	$0	$1	$0	$3	$155	$184	$1	$161	$0
Mid West	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Mountain	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
S. Pacific	$1,555,565	$185,220	$1,803	$61,011	$499	$400,320	$137,808	$305,454	$36,369	$170,845	$0
N. Pacific	$5,652	$458	$27	$78	$7	$959	$1,266	$391	$139	$762	$0
	$1,715,467	$187,828	$1,830	$62,262	$506	$407,085	$162,450	$368,618	$37,027	$219,440	$0

TABLE 5-7: EXPECTED MARKET PENETRATION
Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$155,202	6,327	60.7
NY and NJ	$147,909	6,030	57.9
Mid-Atlantic	$0	0	0.0
South East	$21,911	893	8.6
Central	$161,170	6,570	63.1
South Central	$299,196	12,197	117.1
Mid West	$113,750	4,637	44.5
Mountain	$141,793	5,780	55.5
S. Pacific	$1,806,217	73,633	706.9
N. Pacific	$0	0	0.0
	$2,847,148	116,068	1,114.3

anticipated commercial penetration as a fraction of the total is about 15% higher than the commercial fraction of the building stock.[26]

Commercial and Residential expected market penetration is shown on Table 5-5, Table 5-6 and Table 5-7.

Seventy-four percent of expected total market (residential and commercial) penetration was projected to occur in the South Pacific states (California, Arizona, Nevada, Hawaii). The fraction of total PV Roofing Product anticipated market penetration concentrated in the South Pacific states represented 90% of national penetration for Commercial strata and 63% of national penetration for Residential consumers.

The concentration in the region occurred due to two factors:

1. High levels of insolation, and ,

[26] Rental residential property represents 35% of residential construction, resulting in 49% commercial decision makers and 51% residential home owner decision makers.

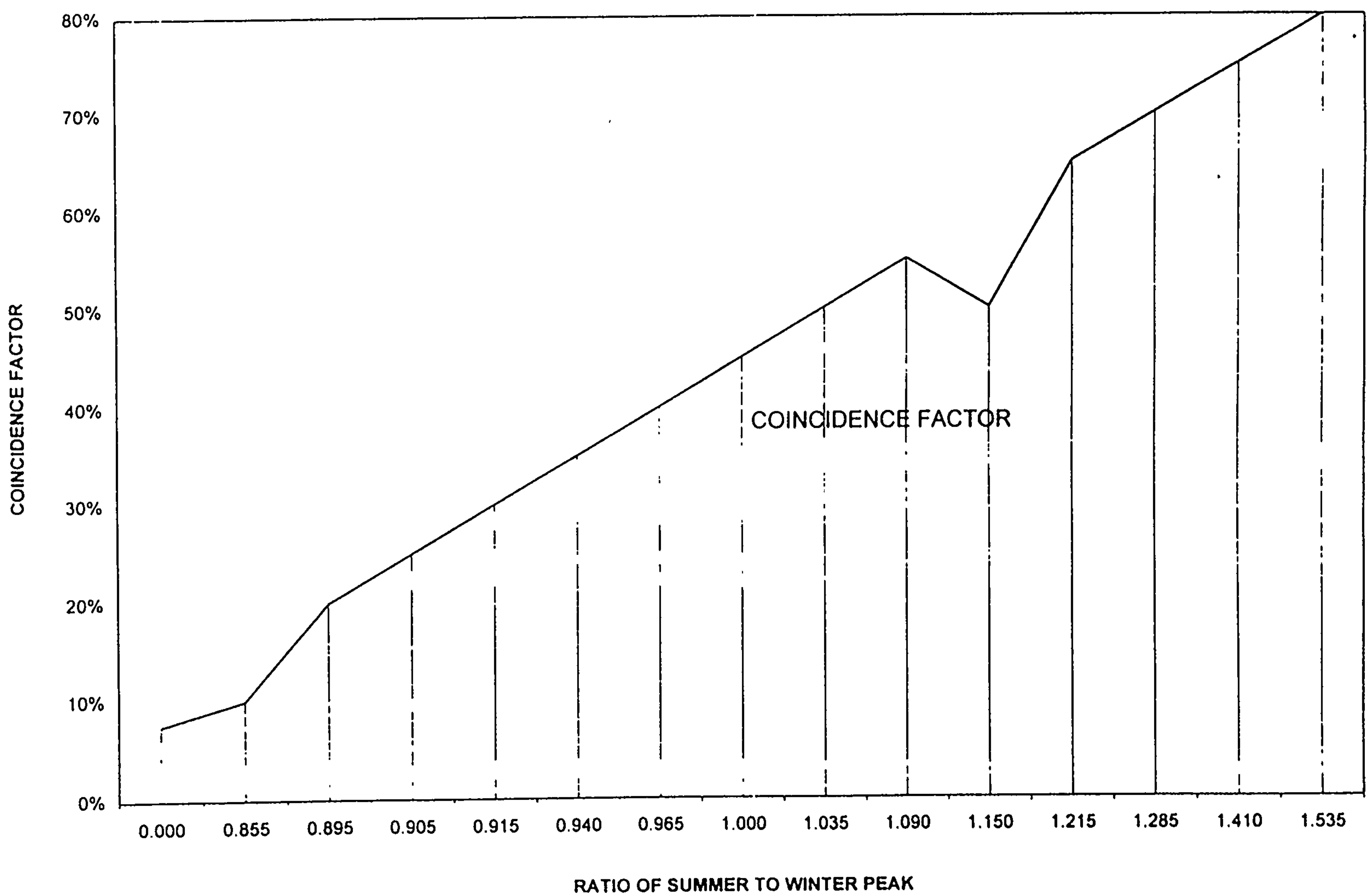
2. Relatively high residential and commercial electric prices.

Warehouse buildings (including refrigerated warehouses) and health care facilities (less than three stories) represented over half of the expected market penetration. These facilities had higher modeled project acceptance rates at the tail of commercial acceptance which translated into increased market penetration.

5.3 Demand Side Management

The valuation of archetypal utility avoided costs ranged from $280 to $1,000 per kilowatt of non-coincidental PV output. The value of the solar resource as a utility DSM measure had significant variability due to levels of insolation and coincidence of insolation with utility peak loads. Figure 5-5 illustrates the relationship between utility peaks and solar coincidence. [22]

FIGURE 5-5: SOLAR COINCIDENCE WITH UTILITY PEAKS



The impact on PV market penetration of offering these values as DSM incentives was simulated. DSM subsidies were treated as a reduction in first cost.

DSM incentives had the effect of almost doubling the expected penetration of the market from a twenty year PV Roofing Industry attainable average annual sales level of $225 million to $465 million. The increased penetration represents a 5.5% share of the roofing market. Table 5-8 summarizes expected market penetration with DSM incentives.

The major growth in the market resulting from DSM incentives occurred in the commercial sector. The effect of DSM incentives in the commercial sector was a three-fold increase in the level of expected penetration. Twenty year commercial market penetration aggregated 224 million square feet of roofing product with DSM incentives compared to an expected penetration of 70 million square

TABLE 5-8: EXPECTED PENETRATION WITH DSM INCENTIVES

Commercial and Residential Customers

	MW Billing Demand			Square Feet of Product (000)		
	Commercial	Residential	Total	Commercial	Residential	Total
New England	57	89	146	6,204	9,261	15,465
NY and NJ	439	98	537	45,864	10,242	56,106
Mid-Atlantic	0	1	1	4	119	123
South East	1	60	61	152	6,202	6,354
Central	11	63	74	1,212	6,572	7,784
South Central	8	206	214	828	21,438	22,266
Mid West	0	55	55	1	5,781	5,782
Mountain	0	98	98	5	10,254	10,259
S. Pacific	1,625	898	2,523	169,490	93,570	263,060
N. Pacific	5	3	8	478	331	809
	2,145	1,571	3,716	224,238	163,770	388,008

feet without incentives. The effect on the residential sector was growth of 41% in the expected level of penetration.

The impact on the commercial sector was driven by several factors.

1. Commercial customers were modeled as more responsive to economic criteria than residential consumers because they have greater access to capital, and they generally have a lower cost of capital. As the economic attractiveness of a technology improves, commercial consumers will more readily adopt the new technology compared to residential consumers (i.e. product acceptance is more sensitive to project economics).

2. The economic benefits attributable to the product were generally better for commercial customers than for residential customers because:

- Commercial electric costs are often higher than residential electric costs,

- Commercial consumers can receive a 10% Federal income tax credit applicable to the purchase of the PV Roofing Product
- Commercial customers can use accelerated amortization provisions in the U.S. and state tax codes to offset or "shelter" increases in tax liability attributable to product savings.

Geographically the preponderance of projected growth in unit volume attributable to DSM incentives was expected to occur in the California, Arizona, Hawaii and Nevada region. On a percentage basis, markets in New York/New Jersey area grew eight-fold in response to DSM incentives, driven by the relatively high cost of electricity.

Seventy-nine percent of the unit volume impact of DSM incentives was projected to occur within four building strata: Offices, Warehouses, Health Care Facilities and Assembly Buildings.

These strata are generally more capital intensive than other commercial strata, have access to capital and tend to be more responsive to economic criteria than other commercial strata. Table 5-9 and 5-10 summarize geographic and building type estimates for market penetration in residential and commercial sectors.

Additionally, utility subsidization of PV Roofing could provide knowledge and information about products and performance and thereby overcome barriers to consumer acceptance. [27]

[27] David Berry, You've Got to Pay to Play: Photovoltaics and Transaction Costs, Electricity Journal, March 1995, pp 46-47

TABLE 5-9: MARKET PENETRATION WITH DSM INCENTIVES

Residential

	MW Billing Demand	Square Feet of product
New England	89	9,261
NY and NJ	98	10,242
Mid-Atlantic	1	119
South East	60	6,202
Central	63	6,572
South Central	206	21,438
Mid West	55	5,781
Mountain	98	10,254
S. Pacific	898	93,570
N. Pacific	3	331
	1,572	163,769

TABLE 5-10: EXPECTED PENETRATION WITH DSM INCENTIVE

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	56.7	3.5	-	1.8	-	9.4	8.3	18.2	0.9	14.6	-
NY and NJ	438.5	60.6	0.6	27.4	0.2	138.4	36.2	94.1	11.9	69.1	-
Mid-Atlantic	-	-	-	-	-	-	-	-	-	-	-
South East	1.4	-	-	-	-	-	0.2	0.5	-	0.7	-
Central	11.2	0.1	-	0.1	-	0.4	3.0	4.0	-	3.6	-
South Central	7.9	0.5	-	0.2	-	1.0	1.8	2.2	0.2	2.0	-
Mid West	-	-	-	-	-	-	-	-	-	-	-
Mountain	-	-	-	-	-	-	-	-	-	-	-
S. Pacific	1,624.6	415.8	83.8	51.8	23.0	335.8	153.5	340.3	30.4	190.2	-
N. Pacific	4.6	0.7	0.1	0.1	-	0.8	1.2	0.6	0.1	1.0	-
	2,144.9	481.2	84.5	81.4	23.2	485.8	204.2	459.9	43.5	281.2	-

EXPECTED PENETRATION WITH DSM INCENTIVE

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	6,203.6	378.8	0.4	193.6	0.1	1,029.1	912.8	1,990.6	101.1	1,597.1	-
NY and NJ	45,864.4	6,334.3	64.0	2,871.2	17.0	14,480.0	3,782.5	9,840.4	1,246.2	7,228.8	-
Mid-Atlantic	3.9	-	-	-	-	-	0.7	1.5	-	1.7	-
South East	151.7	0.8	-	0.3	-	1.5	26.4	50.9	0.1	71.7	-
Central	1,212.4	7.6	-	6.1	-	47.7	321.5	434.1	2.9	392.5	-
South Central	828.0	49.5	-	18.2	-	101.2	190.0	234.8	18.8	215.5	-
Mid West	0.6	-	-	-	-	-	0.1	0.2	-	0.3	-
Mountain	5.2	-	-	-	-	0.1	1.6	2.2	-	1.3	-
S. Pacific	169,490.1	43,380.9	8,745.0	5,404.7	2,398.5	35,027.6	16,018.2	35,508.5	3,177.2	19,829.5	-
N. Pacific	478.4	75.0	13.9	6.5	3.7	78.9	122.1	61.7	11.4	105.2	-
	224,238.3	50,226.9	8,823.3	8,500.6	2,419.3	50,766.1	21,375.9	48,124.9	4,557.7	29,443.6	-

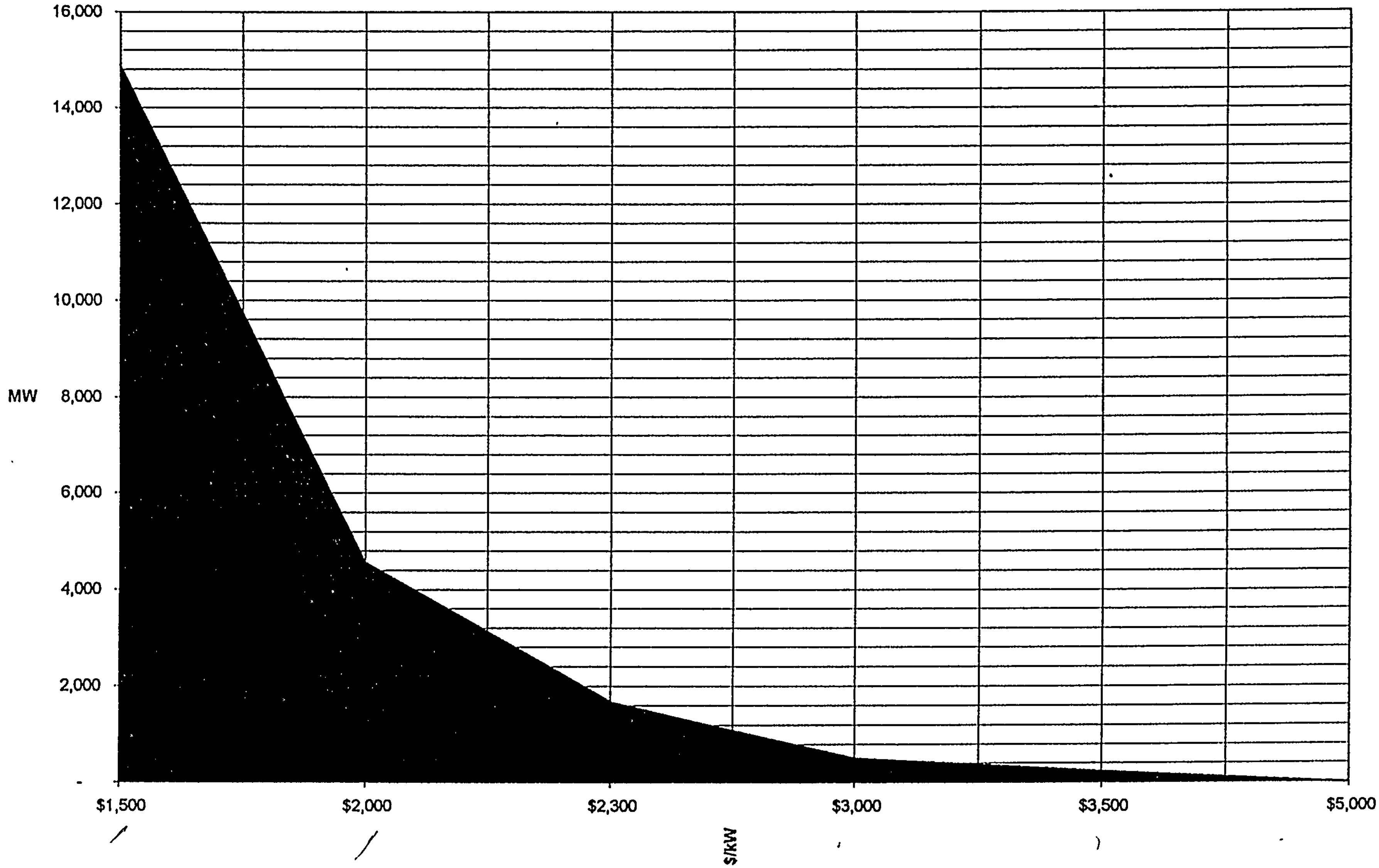
6.0 Sensitivity Analysis

An extensive evaluation of the potential effect on market size of high and lower product prices was made. Evaluations of market size were made at $5,000/kW (118% higher price), $3,000 /kW (30% higher price) , $3,500/ kW (65% higher price) , $2,000 /kW (13% lower price) and $1,500 / kW (35% lower price). Figure 6-1 summarizes the impact of higher and lower prices on the PV Roofing Product market size.

The target incremental product price, $2,290, provides levels of economic benefits to residential and commercial customers that were at the "tail end" of their respective project acceptance decision making criteria. So, one would expect greater sensitivity to price decreases than to price increases due to the shape of the project acceptance curves used.

At $5,000/kW there is no commercial market for PV Roofing products absent significant (ie one-third or more of cost) subsidization by utilities or government. Tables 6-16

FIGURE 6-1: 20 YEAR MARKET PENETRATION AT DIFFERENT PRICES



and 6-17 show the market erosion attributable to a 118% higher price of $5,000/kW.

A 30% increase in the PV Roofing price to $3,000/ kW reduced the residential market size 56% and the commercial market size 94%. An increase in price to $3,500 /kW essentially eliminated both residential and commercial markets. Small residential and commercial markets aggregating 240.5 MW over 20 year of penetration, or an annual average of 10-12 MW were projected to exist at a $3,500/kW market price. Tables 6-5, 6-6 and 6-7 show the estimated 20 year market size for residential and commercial customers at $3,500/kW.

As the price of the PV Roofing Product declines two factors work to dramatically increase market penetration.

First, the rate of acceptance among customers in geographic areas of initial penetration (California, Arizona, Hawaii and Nevada) would significantly increase. Penetration rates in areas of initial penetration would increase rapidly due to the implicit elasticity of demand illustrated by the project acceptance rates shown on Figure 5-4.

Second, areas of the U.S. not initially penetrated by the product would experience improved economics due to lower product cost (including DSM subsidies). The improvement in project economics would initiate penetration of these markets.

A 13% lower price, $2,000 / kW had the effect of increasing the projected residential market size 123% and the commercial market 268% (see Tables 6-8, 6-9, 6-10 and 6-11. A 35% lower price increased projected residential penetration by 431% and commercial penetration fourteen fold as show in Tables 6-12, 6-13, 6-14 and 6-15.

The project acceptance curves shown in Figure 5-4 depict greater price responsiveness among commercial customers when compared to similar expected project acceptance rates among residential consumers.

Commercial customers, generally, are more responsiveness to price than residential consumers for a several reasons:

1. Access to capital,
2. Cost of Capital,
3. Longer term investment horizon,
4. Availability of federal tax credits,
5. Deductibility of capital consumption and interest expenses.

TABLE 6-1: EXPECTED 20 YEAR MARKET PENETRATION @ $3,000/kW

	MW DEMAND			Sq Ft of PRODUCT		
	COMMERCIAL	RESIDENTIAL	TOTAL	COMMERCIAL	RESIDENTIAL	TOTAL
New England	-	-	-	-	-	-
NY and NJ	0.040	-	0.04	4.00	-	4.00
Mid-Atlantic	-	-	-	-	-	-
South East	-	-	-	-	-	-
Central	-	-	-	-	-	-
South Central	-	18.30	18.30	-	1,906.28	1,906.28
Mid West	-	16.51	16.51	-	1,719.57	1,719.57
Mountain	-	-	-	-	-	-
S. Pacific	19.540	451.98	471.52	2,038.39	47,081.32	49,119.71
N. Pacific	-	-	-	-	-	-
	19.580	486.79	506.37	2,042.39	50,707.17	52,749.56

TABLE 6-2: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $3,000/kW

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
NY and NJ	0.0382	0.0000	0.0000	0.0000	0.0000	0.0001	0.0066	0.0178	0.0000	0.0135	0.0002
Mid-Atlantic	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
South East	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Central	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
South Central	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mid West	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mountain	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S. Pacific	19.5377	0.1406	0.0000	0.1220	0.0000	0.8037	4.1465	9.1829	0.0730	5.0690	0.0000
N. Pacific	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	19.576	0.141	0.000	0.122	0.000	0.804	4.153	9.201	0.073	5.083	0.000

EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NY and NJ	4.0	0.0	0.0	0.0	0.0	0.0	0.7	1.9	0.0	1.4	0.0
Mid-Atlantic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mid West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. Pacific	2,038.4	14.7	0.0	12.7	0.0	83.8	432.6	958.2	7.6	528.6	0.0
N. Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2,042.4	14.7	0.0	12.7	0.0	83.8	433.3	960.0	7.6	530.0	0.0

TABLE 6-3: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $3,000/kW

$- 000 Sales Revenues

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	0	0	0	0	0	0	0	0	0	0	0
NY and NJ	125	0	0	0	0	0	21	58	0	44	0
Mid-Atlantic	0	0	0	0	0	0	0	0	0	0	0
South East	0	0	0	0	0	0	0	0	0	0	0
Central	0	0	0	0	0	0	0	0	0	0	0
South Central	0	0	0	0	0	0	0	0	0	0	0
Mid West	0	0	0	0	0	0	0	0	0	0	0
Mountain	0	0	0	0	0	0	0	0	0	0	0
S. Pacific	63,700	458	0	398	0	2,620	13,519	29,942	238	16,518	0
N. Pacific	0	0	0	0	0	0	0	0	0	0	0
	$63,825	$459	$0	$398	$0	$2,620	$13,541	$30,000	$238	$16,562	$0

TABLE 6-4: EXPECTED MARKET PENETRATION @ $3,000/kW

Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$0	0	0.000
NY and NJ	$0	0	0.000
Mid-Atlantic	$0	0	0.000
South East	$0	0	0.000
Central	$0	0	0.000
South Central	$61,256	1,906	18.300
Mid West	$55,256	1,720	16.508
Mountain	$0	0	0.000
S. Pacific	$1,512,896	47,081	451.981
N. Pacific	$0	0	0.000
	$1,629,408	50,707	486.789

TABLE 6-5: EXPECTED 20 YEAR MARKET PENETRATION @ $3,500/kW

	MW DEMAND			Sq Ft of PRODUCT		
	COMMERCIAL	RESIDENTIAL	TOTAL	COMMERCIAL	RESIDENTIAL	TOTAL
New England	-	-	-	-	-	-
NY and NJ	-	-	-	-	-	-
Mid-Atlantic	-	-	-	-	-	-
South East	-	-	-	-	-	-
Central	-	-	-	-	-	-
South Central	-	-	-	-	-	-
Mid West	-	6.74	6.74	-	701.79	701.79
Mountain	-	-	-	-	-	-
S. Pacific	0.186	233.59	233.77	19.37	24,332.02	24,351.39
N. Pacific	-	-	-	-	-	-
	0.186	240.32	240.51	19.37	25,033.81	25,053.18

TABLE 6-6: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $3,500 per kW

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NY and NJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mid-Atlantic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mid West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. Pacific	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
N. Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0

EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NY and NJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mid-Atlantic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mid West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mountain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. Pacific	19.4	0.0	0.0	0.0	0.0	0.1	4.3	9.6	0.0	5.3	0.0
N. Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19.4	0.0	0.0	0.0	0.0	0.1	4.3	9.6	0.0	5.3	0.0

TABLE 6-7: EXPECTED MARKET PENETRATION @ $3,500/kW

Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$0	0	0.000
NY and NJ	$0	0	0.000
Mid-Atlantic	$0	0	0.000
South East	$0	0	0.000
Central	$0	0	0.000
South Central	$0	0	0.000
Mid West	$26,310	702	6.737
Mountain	$0	0	0.000
S. Pacific	$912,190	24,332	233.587
N. Pacific	$0	0	0.000
	$938,500	25,034	240.325

TABLE 6-8: EXPECTED 20 YEAR MARKET PENETRATION @ $2,000/kW

	MW DEMAND			Sq Ft of PRODUCT		
	COMMERCIAL	RESIDENTIAL	TOTAL	COMMERCIAL	RESIDENTIAL	TOTAL
New England	33.330	118.07	151.40	3,646.40	12,299.27	15,945.67
NY and NJ	410.070	155.13	565.20	42,893.70	16,159.44	59,053.14
Mid-Atlantic	0.030	2.84	2.87	3.40	296.20	299.60
South East	0.210	54.64	54.85	22.60	5,692.18	5,714.78
Central	10.840	110.39	121.23	1,182.10	11,499.07	12,681.17
South Central	5.060	274.49	279.55	532.10	28,592.52	29,124.62
Mid West	-	75.94	75.94	0.40	7,909.91	7,910.31
Mountain	0.050	315.48	315.53	5.00	32,862.74	32,867.74
S. Pacific	1,616.330	1,351.76	2,968.09	168,634.00	140,808.41	309,442.41
N. Pacific	3.830	12.11	15.94	398.10	1,261.36	1,659.46
	2,079.750	2,470.86	4,550.61	217,317.80	257,381.10	474,698.90

TABLE 6-9: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $2,000/kW

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	33.33	0.79	0.00	0.57	0.00	3.01	5.76	12.77	0.29	10.13	0.00
NY and NJ	410.07	56.35	0.61	25.76	0.16	128.44	33.73	88.38	11.30	65.34	0.00
Mid-Atlantic	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00
South East	0.21	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.00	0.10	0.00
Central	10.84	0.07	0.00	0.05	0.00	0.43	2.89	3.88	0.03	3.49	0.00
South Central	5.06	0.11	0.00	0.06	0.00	0.32	1.34	1.65	0.06	1.52	0.00
Mid West	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.00
S. Pacific	1,616.33	408.50	83.21	51.36	22.99	335.83	153.53	340.31	30.44	190.16	0.00
N. Pacific	3.83	0.72	0.13	0.06	0.04	0.75	1.02	0.35	0.11	0.65	0.00
	2,079.75	466.54	83.95	77.86	23.19	468.79	198.33	447.43	42.23	271.42	0.01

EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	3,646.4	86.9	0.0	62.1	0.0	329.2	630.4	1,397.4	32.3	1,108.3	0.0
NY and NJ	42,893.7	5,890.3	63.6	2,697.4	16.9	13,433.5	3,522.5	9,238.7	1,185.0	6,837.1	0.0
Mid-Atlantic	3.4	0.0	0.0	0.0	0.0	0.0	0.6	1.3	0.0	1.5	0.0
South East	22.6	0.1	0.0	0.1	0.0	0.4	3.8	7.5	0.0	10.2	0.0
Central	1,182.1	7.5	0.0	6.0	0.0	47.2	314.7	423.5	2.8	380.4	0.0
South Central	532.1	11.4	0.0	6.1	0.0	33.9	141.7	173.1	6.3	160.2	0.0
Mid West	0.4	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.2	0.0
Mountain	5.0	0.0	0.0	0.0	0.0	0.1	1.4	2.2	0.0	1.1	0.0
S. Pacific	168,634.0	42,616.7	8,681.7	5,357.3	2,398.5	35,027.6	16,018.2	35,508.5	3,177.2	19,829.5	0.0
N. Pacific	398.1	74.8	13.9	6.4	3.7	78.4	105.8	35.8	11.4	67.9	0.0
	217,317.6	48,687.6	8,759.2	8,135.3	2,419.2	48,950.1	20,739.2	46,788.0	4,415.0	28,396.5	0.0

TABLE 6-10: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $2,000 /kW

$- 000 Sales Revenues

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	$75,966	$1,810	$1	$1,293	$0	$6,857	$13,133	$29,111	$672	$23,089	$0
NY and NJ	$893,618	$122,714	$1,324	$56,196	$352	$279,864	$73,386	$192,472	$24,688	$142,440	$0
Mid-Atlantic	$71	$0	$0	$0	$0	$0	$13	$26	$0	$32	$0
South East	$470	$2	$0	$1	$0	$8	$79	$156	$1	$212	$0
Central	$24,627	$156	$0	$125	$0	$983	$6,556	$8,822	$59	$7,924	$0
South Central	$11,085	$237	$0	$127	$0	$706	$2,952	$3,607	$131	$3,338	$0
Mid West	$9	$0	$0	$0	$0	$0	$2	$3	$0	$4	$0
Mountain	$104	$0	$0	$0	$0	$2	$30	$45	$0	$24	$0
S. Pacific	$3,513,207	$887,848	$180,870	$111,609	$49,970	$729,742	$333,712	$739,760	$66,191	$413,115	$0
N. Pacific	$8,293	$1,557	$290	$134	$78	$1,632	$2,203	$747	$237	$1,415	$0
	$4,527,450	$1,014,325	$182,484	$169,485	$50,399	$1,019,794	$432,066	$974,749	$91,978	$591,593	$0

TABLE 6-11: EXPECTED MARKET PENETRATION @ $2,000/kW

Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$263,481	12,299	118.073
NY and NJ	$346,175	16,159	155.131
Mid-Atlantic	$6,345	296	2.843
South East	$121,941	5,692	54.645
Central	$246,338	11,499	110.391
South Central	$612,522	28,593	274.488
Mid West	$169,450	7,910	75.935
Mountain	$704,000	32,863	315.482
S. Pacific	$3,016,461	140,808	1,351.761
N. Pacific	$27,022	1,261	12.109
	$5,513,734	257,381	2,470.859

TABLE 6-12: EXPECTED 20 YEAR MARKET PENETRATION @ $1,500/kW

	MW DEMAND			Sq Ft of PRODUCT		
	COMMERCIAL	RESIDENTIAL	TOTAL	COMMERCIAL	RESIDENTIAL	TOTAL
New England	583.700	263.49	847.19	63,854.00	27,447.30	91,301.30
NY and NJ	2,568.100	381.18	2,949.28	268,632.20	39,706.04	308,338.24
Mid-Atlantic	105.100	151.30	256.40	11,274.00	15,760.40	27,034.40
South East	236.100	382.20	618.30	24,982.20	39,812.29	64,794.49
Central	643.200	504.16	1,147.36	70,145.80	52,516.63	122,662.43
South Central	407.300	742.01	1,149.31	42,857.80	77,292.42	120,150.22
Mid West	42.500	245.48	287.98	4,516.10	25,570.91	30,087.01
Mountain	40.900	740.68	781.58	4,434.00	77,153.77	81,587.77
S. Pacific	4,268.000	2,456.95	6,724.95	445,290.80	255,931.87	701,222.67
N. Pacific	76.900	49.55	126.45	7,984.90	5,161.60	13,146.50
	8,971.800	5,916.99	14,888.79	943,971.80	616,353.22	1,560,325.02

TABLE 6-13: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $1,500/kW

MW of Billing Demand

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	583.7	96.6	6.7	18.6	1.7	100.1	36.8	74.3	12.4	62.8	0.0
NY and NJ	2,568.1	550.6	98.8	78.4	25.9	404.2	121.8	317.9	33.3	234.3	0.0
Mid-Atlantic	105.1	1.7	0.0	1.3	0.0	6.9	15.4	31.8	0.6	35.7	0.0
South East	236.1	9.9	0.0	6.2	0.0	36.8	22.9	54.6	3.2	53.5	0.0
Central	643.2	53.0	0.6	21.3	0.2	136.6	65.8	94.6	10.9	90.8	0.0
South Central	407.3	32.9	0.8	13.0	0.2	85.3	35.5	62.4	7.0	62.8	0.0
Mid West	42.5	0.6	0.0	0.4	0.0	3.1	7.7	8.9	0.3	17.4	0.0
Mountain	40.9	2.8	0.0	1.0	0.0	8.0	6.6	7.1	0.9	5.9	0.0
S. Pacific	4,268.0	1,271.4	343.2	113.7	95.1	734.7	260.5	577.7	66.6	324.5	0.0
N. Pacific	76.9	4.2	0.6	2.1	0.2	14.7	8.2	11.1	2.1	16.2	0.0
	8,971.8	2,023.7	450.6	255.8	123.3	1,530.6	581.2	1,240.3	137.2	904.0	0.0

EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET

000 Square Footage of Roofing Material

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	63,854.0	10,573.7	728.4	2,039.3	188.1	10,954.6	4,029.5	8,123.6	1,361.6	6,870.3	0.0
NY and NJ	268,632.2	57,550.5	10,330.9	8,209.5	2,715.7	42,281.5	12,718.9	33,238.0	3,489.4	24,517.5	0.0
Mid-Atlantic	11,274.0	177.0	0.1	137.1	0.0	744.6	1,649.0	3,415.8	68.4	3,831.0	0.0
South East	24,982.2	1,049.8	3.9	653.4	0.7	3,893.7	2,415.6	5,793.3	336.2	5,621.5	0.0
Central	70,145.8	5,779.2	62.3	2,323.0	16.5	14,894.2	7,170.0	10,324.5	1,189.7	9,903.4	0.0
South Central	42,857.8	3,458.5	83.6	1,364.0	19.6	8,963.3	3,744.6	6,562.1	742.0	6,624.8	0.0
Mid West	4,516.1	62.6	0.0	41.5	0.0	332.5	818.3	946.0	27.5	1,852.0	0.0
Mountain	4,434.0	303.2	0.8	104.7	0.2	868.4	717.4	764.7	92.9	644.4	0.0
S. Pacific	445,290.8	132,643.4	35,806.9	11,855.8	9,925.2	76,632.7	27,177.4	60,281.4	6,947.3	33,839.5	0.0
N. Pacific	7,984.9	433.4	58.7	214.8	15.8	1,531.3	854.8	1,147.0	214.5	1,677.8	0.0
	943,971.9	212,031.1	47,075.7	26,943.0	12,881.8	161,096.7	61,295.4	130,596.5	14,469.6	95,382.2	0.0

TABLE 6-14: EXPECTED PENETRATION ECONOMICALLY ATTAINABLE MARKET at $1,500/kW

$- 000 Sales Revenues

	TOTAL	Office	Restaurant	Retail	Grocery	W/H	Education	Health	Lodging	Assembly	Misc
New England	$1,566,338	$259,372	$17,868	$50,025	$4,613	$268,717	$98,844	$199,273	$33,401	$168,530	$0
NY and NJ	6,589,548	1,411,713	253,418	201,378	66,616	1,037,166	311,993	815,327	85,594	601,414	0
Mid-Atlantic	276,552	4,342	2	3,364	0	18,264	40,451	83,791	1,678	93,974	0
South East	612,814	25,752	95	16,028	18	95,511	59,255	142,109	8,246	137,895	0
Central	1,720,677	141,763	1,528	56,983	405	365,355	175,879	253,260	29,184	242,930	0
South Central	1,051,302	84,836	2,051	33,459	480	219,869	91,856	160,969	18,200	162,505	0
Mid West	110,781	1,535	1	1,017	0	8,155	20,073	23,206	675	45,430	0
Mountain	108,766	7,437	21	2,567	5	21,303	17,597	18,757	2,279	15,808	0
S. Pacific	10,922,984	3,253,742	878,344	290,822	243,466	1,879,800	666,661	1,478,702	170,417	830,083	0
N. Pacific	195,869	10,630	1,439	5,269	387	37,563	20,968	28,137	5,263	41,156	0
	$23,155,630	$5,201,123	$1,154,766	$660,912	$315,990	$3,951,702	$1,503,577	$3,203,531	$354,938	$2,339,726	$0

TABLE 6-15: EXPECTED MARKET PENETRATION @ $1,500/kW

Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$440,991	27,447	263.494
NY and NJ	$637,951	39,706	381.178
Mid-Atlantic	$253,220	15,760	151.300
South East	$639,658	39,812	382.198
Central	$843,776	52,517	504.160
South Central	$1,241,845	77,292	742.007
Mid West	$410,844	25,571	245.481
Mountain	$1,239,617	77,154	740.676
S. Pacific	$4,112,016	255,932	2,456.946
N. Pacific	$82,931	5,162	49.551
	$9,902,847	616,353	5,916.991

TABLE 6-16: EXPECTED MARKET PENETRATION @ $5,000/kW

Residential

	$000 Sales	Sq Ft of Product (000)	MW Billing Demand
New England	$0	0	0.000
NY and NJ	$0	0	0.000
Mid-Atlantic	$0	0	0.000
South East	$0	0	0.000
Central	$0	0	0.000
South Central	$0	0	0.000
Mid West	$0	0	0.000
Mountain	$0	0	0.000
S. Pacific	$0	0	0.000
N. Pacific	$0	0	0.000
	$0	0	0.000

Bibliography

1. A.D. Little, EPRI Simplified Program for Residential Energy, May 1986 (various software versions)

2. A.D. Little, Photovoltaic Market Potential, 1993

3. American Society of Heating, Air Conditioning and Refrigeration Engineers, Fundamentals, 1981

4. Arizona Public Service Company, Project Acceptance Rates, Unpublished, 1994

5. Arizona Public Service Company, Estimated Installed Costs of GE Frame 7 Turbine, Unpublished, 1993

6. David Berry, You've Got to Pay to Play: Photovoltaics and Transaction Costs, Electricity Journal, March 1995, pp 46-47

7. Casazza, Schultz & Associates, Electric Rate Book, 1993

8. Commerce Clearing House , Multistate Corporate Income Tax Guide, 1994
   , Standard Federal Tax Reports, 1992
   , State Tax Guide, 1992

9. Electric Power Research Institute, The COMMEND Planning System: National and Regional Data and Analysis, March 1986

10. Energy Information Administration, Office of Markets and End Use, Commercial Buildings Energy Consumption Survey, 1989

11. Energy Information Administration, Housing Characteristics, 1990

12. National Roofing Contractors Association, Annual Market Survey, 1994

13. Sandia National Laboratory, PV Form (Version 3.3)

14. Synergic Resources Company, Market Penetration Seminar, April 1990

15. U.S. Bureau of the Census, Statistical Abstract of the United States (113 th Edition), 1993

16. R.H. Williams and G. Terzian, A Benefit/Cost Analysis of Accelerated Development of Photovoltaic Technology, October 1993