JPL ENCAPSULATION TASK
SPRINGBORN LABORATORIES, INC.
P. Willis

JPL Encapsulation Task (Inception: 1975)

OVERALL GOAL: • PRODUCTION OF ELECTRICAL POWER FROM PHOTOVOLTAICS COMPETITIVE WITH COMMERCIAL POWER SOURCES • TARGET: $0.70 PER PEAK WATT (1980 DOLLARS)

WHY CAPSULATION?
• MECHANICAL SUPPORT — PREVENT CELL BREAKAGE
• THERMAL CONDUCTION — DISSIPATE HEAT
• ENVIRONMENTAL PROTECTION — PREVENT CORROSION
• PACKAGING / HANDLING — TRANSPORTATION AND FIELD DEPLOYMENT OF MODULES

Performance Requirements

• SERVICE LIFE 30 YEARS
• LIGHT TRANSMISSION TO SOLAR CELLS >90% OF INCIDENT
• LOSS IN MODULE POWER AFTER 30 YEARS <10% OF INITIAL
• PROCESSING AND FABRICATION AUTOMATED
• STRUCTURAL PERFORMANCE (INCLUDING HANDLING AND WEATHERING) NO FAILURES

• MUST CONFORM TO COST GOALS

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### PLENARY SESSIONS

**Encapsulation Cost Goals**

- \( \$0.70/W_{p_k} \times 10 \text{ W/ft}^2 = \$7.00/\text{ft}^2 \)

<table>
<thead>
<tr>
<th>Encapsulation System</th>
<th>Module Cost</th>
<th>$/m^2</th>
<th>$/ft^2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>14</td>
<td>1.40</td>
</tr>
</tbody>
</table>

- **1980 $**

- Cost now served as driver for selection of materials
- Need to redefine encapsulation requirements
  - What components are needed?
  - What must materials do?
- Does encapsulation package meet both cost and performance requirements?
**Early Encapsulation Systems**

**TWO SCHOOLS OF THOUGHT:**

A. POURABLE SYRUPS  
B. DRY FILM LAMINATION

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>APPROACHES</th>
<th>DEFICIENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SILICON LIQUIDS</td>
<td>MIXING AND PUMPING</td>
<td>UNPREDICTABLE ADHESION</td>
</tr>
<tr>
<td>VERY HIGH COST ($12/LB) (CASTING SYRUP)</td>
<td></td>
<td>LONG CURE TIMES</td>
</tr>
<tr>
<td>URETHANE LIQUIDS</td>
<td>MOISTURE SENSITIVE</td>
<td>YELLOWING WITH AGE</td>
</tr>
<tr>
<td>(CASTING SYRUP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POLYVINYL BUTYRAL (PVB) (LAMINATION FILM)</td>
<td>SPECIALIZED STORAGE</td>
<td>DIFFICULT PROCESS - AUTOCLAVE</td>
</tr>
<tr>
<td>SUBSTRATES:</td>
<td></td>
<td>LONG LAMINATION TIMES</td>
</tr>
<tr>
<td>FIBERGLASS, ALUMINUM</td>
<td></td>
<td>MODERATE COST</td>
</tr>
<tr>
<td>INDUSTRIAL PROCESSING</td>
<td>NOT CONSIDERED AT THIS TIME</td>
<td></td>
</tr>
</tbody>
</table>

- OVERALL PERFORMANCE QUESTIONABLE?  
- MAJOR OBJECTION: CANNOT MEET FSA COST GOALS
Module Construction Elements

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFACE (1) MATERIAL (2) TREATMENT</td>
<td>- LOW SOILING&lt;br&gt;- EASY CLEANING&lt;br&gt;- ANTIREFLECTIVE&lt;br&gt;- ABRASION RESISTANT</td>
</tr>
<tr>
<td>FRONT COVER</td>
<td>- UV SCREENING&lt;br&gt;- STRUCTURAL</td>
</tr>
<tr>
<td>POTTANT</td>
<td>- PRIMARY CELL PROTECTION</td>
</tr>
<tr>
<td>POROUS SPACER</td>
<td>- OPTICAL COUPLING</td>
</tr>
<tr>
<td>SUBSTRATE</td>
<td>- AIR RELEASE&lt;br&gt;- MECHANICAL SEPARATION&lt;br&gt;- STRUCTURAL&lt;br&gt;- MECHANICAL PROTECTION&lt;br&gt;- WEATHER BARRIER&lt;br&gt;- HEAT EMITTER&lt;br&gt;- EDGE SEALING</td>
</tr>
<tr>
<td>BACK COVER</td>
<td></td>
</tr>
<tr>
<td>GASKET &amp; SEAL</td>
<td></td>
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</tbody>
</table>

- ADHESIVES AND PRIMERS WHERE REQUIRED

- NOTE: TWO DESIGNS - SUBSTRATE OR SUPERSTRATE<br>ONLY ONE STRUCTURAL COMPONENT

**MODULE FABRICATION TECHNIQUES**

1. SHEET LAMINATION METHOD
2. LIQUID CASTING METHOD

- GOAL: IDENTIFY COST-EFFECTIVE MATERIALS AND PROCESSES
PLenary Sessions

Pottant Development

- POTTANT IS THE HEART OF THE ENCAPSULATION PACKAGE - RECEIVED GREATEST EMPHASIS

- REQUIREMENTS:
  - OPTICAL TRANSPARENCY
  - LOW MELTING POINT
  - ELECTRICAL INSULATION
  - RUBBERY (LOW MODULUS)
  - NO CELL BREAKAGE!
  - RESISTANT TO FLOW IN SERVICE
  - SUITABLE FOR AUTOMATED PRODUCTION (HIGH VOLUME)
  - COST EFFECTIVE

- THESE PROPERTIES FOUND IN TRANSPARENT "ELASTOMERS"

- PROBLEM - LOW COST POLYMERS MAY HAVE DEFICIENCIES:
  - HEAT (OXIDATION) SENSITIVITY
  - LIGHT (ULTRAVIOLET) SENSITIVITY
  - WATER (HYDROLYSIS) SENSITIVITY

- ALL TRANSPARENT "ELASTOMERS" SURVEYED TO SELECT COMPOUND WITH DESIRED PROPERTIES AND ABILITY TO BE STABILIZED WITH ADDITIVES - IMPART ENVIRONMENTAL STABILITY

Current Candidates

A. LAMINATION FILMS:               COST
  ETHYLENE VINYL ACETATE (EVA)   $ 0.55/ LB
  ETHYLENE METHYL ACRYLATE (EMA) $ 0.95/ LB

B. CASING LIQUIDS:
  POLY N-BUTYL ACRYLATE (BA)     $ 1.09/ LB
  ALIPHATIC POLYURETHANE (PU)    $ 3.60/ LB
Development of EVA Pottant

EVA BEST OVERALL CHOICE:
ETHYLENE VINYL ACETATE POLYMERS (EVA)

ADVANTAGES

- MANY GRADES AVAILABLE
- OXIDATION (HEAT) STABLE
- HYDROLYSIS (WATER) STABLE
- WIDE RANGE OF VISCOSITY
- EASY TO PROCESS
- LOW COST
- GOOD ADHESIVE PROPERTIES

DEFICIENCIES

- THERMOPLASTIC (NO CREEP RESISTANCE)
- ULTRAVIOLET SENSITIVE

MCQUELE FABRICATION GRADE DEVELOPED DESIGNATION: EVA A9918

- CONTAINS CURING AGENTS AND STABILIZERS
- DEFICIENCIES SUCCESSFULLY CORRECTED

Properties/Benefits EVA A-9918

- NO COLD STORAGE REQUIRED
- HIGH TRANSPARENCY
- DIMENSIONAL STABILITY
- GOOD FLOW AND VOLUMETRIC FILL
- FAST CURE (40,10 /FT^2 IN VOLUME)
- EASY LAMINATION (MODULE PROCESSING)
- EXCELLENT ENVIRONMENTAL STABILITY
- LOW COST
- PRODUCED AS ROLLS OF FILM
PLENARY SESSIONS

Other Candidate Encapsulation Materials

STRUCTURAL COMPONENTS:

SUPERSTRATE: LOAD-BEARING TOP SURFACE
- TEMPERED LOW-IRON FLOAT GLASS 1/8" THICK $0.75/FT²

SUBSTRATES: LOAD-BEARING UNDER SURFACE
- COLD ROLLED MILD STEEL, 28 GA. $0.26/FT²
- WOOD HARDBOARDS, 1/8" THICK $0.14/FT²

(NOTE: THESE MATERIALS REQUIRE ADDITIONAL TREATMENT FOR ENVIRONMENTAL STABILITY)

POROUS SPACER: VACUUM EVACUATION, MECHANICAL SPACING AND ELECTRICAL ISOLATION
- CRANEGLAS 230 NON-WOVEN GLASS MAT $0.02/FT²

OUTER COVERS: MECHANICAL PROTECTION, SOIL RESISTANT, UV SCREENING
- ACRYLAR X-22417 (3M CORP.) $0.07/FT²
- TEDLAR 100BG3OUT (DU PONT) $0.10/FT²
- TEDLAR 400BG620SE (DU PONT) $0.30/FT²
- FEP FILM, 2 MIL THICK $0.20/FT²

(NON-SCREENING, OUTSTANDING WEATHERABILITY HIGH TRANSPARENCY, OPTICAL COUPLING)

* ALL PRICES ARE FOR VOLUME PRODUCTION
Other Candidate Encapsulation Materials (Cont'd)

BACK COVER FILMS:  MECHANICAL PROTECTION, ELECTRICAL ISOLATION, AND HEAT REFLECTION

- TEDLAR 150BS30 WH (DU PONT) $0.13 /ft²
- TEDLAR 200DL20 WH (DU PONT) $0.16 /ft²
- SCOTCHPAR 20CP WHITE (3M) $0.12 /ft²
- KORAD 63000 WHITE (XCEL CORP) $0.09 /ft²

GASKETS & SEALANTS:  EDGE PROTECTION

- EPDM GASKET (E-633, PAWLING RUBBER CO ) *
- BUTYL TAPE (5354, 3M CORP) *

* VARIIES WITH PERIMETER

ADHESIVES / PRIMERS:

- PRIMERS IDENTIFIED FOR ALMOST ALL INTERFACES
- HIGH DURABILITY AND LOW COST (~ $0.02 /ft²)
- SELF-PRIMING GRADE OF EVA DEVELOPED

EVA Bond Strengths, Pound/Inch of Width

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>CONTROL 2</th>
<th>2 WK IMMERSION</th>
<th>2 HR BOILING WATER</th>
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</thead>
<tbody>
<tr>
<td>SUNADEX GLASS</td>
<td>34.8</td>
<td>30.0</td>
<td>32.3</td>
</tr>
<tr>
<td>WINDOW GLASS</td>
<td>39.6</td>
<td>37.9</td>
<td>27.1</td>
</tr>
<tr>
<td>WINDOW GLASS</td>
<td>35.4</td>
<td>41.9</td>
<td>COHESIVE</td>
</tr>
</tbody>
</table>

(SELF-PRIMING EVA)
Anti-Soiling Treatments

SURFACE: ACRYLAR  IMPROVEMENT 3.9%

SURFACE: TEDLAR  IMPROVEMENT 3.8%

SURFACE: GLASS  IMPROVEMENT 1.5%
Aging and Lifetime Predictions

- How long will modules last?
- New accelerated aging technique developed: outdoor photothermal reactor (OPTAR)
- Combines natural light and heat

Severity Index

**TIME TO DEGRADATION - EVA 9918**

- OPTAR 105°
- OPTAR 90°
- OPTAR 70°
- RS/4 85°
- RS/4 50°
- RS/4 HET

**LOG TIME (HOURS)**

- OPTARs most efficient aging technique
- Modules have very high endurance
  - No effect: 20,000 hrs - 70°C / sunlight
  - Little effect: 20,000 hrs - 90°C / sunlight
  - Strong effect: 20,000 hrs - 105°C / sunlight
- Degraded modules show no power loss
- Encapsulation system works well
- Life prognosis: GOOD
Module Fabrication

- VACUUM LAMINATION - METHOD OF CHOICE

- RELATIVELY SIMPLE EQUIPMENT
- DRY FILMS - NO LIQUIDS
- ALL COMPONENTS ASSEMBLED IN ONE STEP
- FAST CYCLE TIMES
- AUTOMATION / HIGH VOLUME POSSIBLE
- COST EFFECTIVE

- LAMINATORS COMMERCIALY AVAILABLE
  (SPIRE CORPORATION)
PLENARY SESSIONS

Current Status

HOW CLOSE DID WE COME?

<table>
<thead>
<tr>
<th>&quot;TYPICAL&quot; MODULE</th>
<th>VOLUME COST, $/FT²</th>
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<tbody>
<tr>
<td>LOW IRON GLASS</td>
<td>0.75</td>
</tr>
<tr>
<td>EVA (TWO LAYERS)</td>
<td>0.20</td>
</tr>
<tr>
<td>POROUS SPACER</td>
<td>0.02</td>
</tr>
<tr>
<td>PRIMERS / ADHESIVES</td>
<td>0.02</td>
</tr>
<tr>
<td>BACK COVER (TEDLAR)</td>
<td>0.16</td>
</tr>
<tr>
<td>GASKET / SEAL (EST.)</td>
<td>0.15</td>
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$1.30 / FT²

- MAJOR ENCAPSULATION COMPONENTS DEVELOPED/IDENTIFIED AND COMMERCIALLY AVAILABLE
- EVA POTTANT FILM - WIDE INDUSTRIAL ACCEPTANCE
- Viable manufacturing process identified
- FIELD PERFORMANCE - VERY PROMISING

Remaining Efforts

- LIFETIME ANALYSIS: DEVELOP AND VERIFY PREDICTIVE AGING METHODS

Summary

FSA PROGRAM HAS RESULTED IN HIGH PERFORMANCE COST-EFFECTIVE ENCAPSULATION SYSTEMS FOR PHOTOVOLTAIC MODULES