Solar & Beyond: Making the Case for Aluminum Extrusions

December 8, 2011
AEC Webinar

Presenters:
Craig Werner
Tony Mascarin
Webinar Overview

• Introductions
  – Craig Werner (WES LLC)
  – Tony Mascarin (IBIS)

• Studies:
  – Goals of the studies
  – Why AEC chose IBIS
  – CSP (complete): approach, analysis and results
  – PV (in process): approach, analysis and results thru Nov.2011

• Q&A
Introductions and Background

• **Tony Mascarin**
  - Industrial Engineering and Management of Technology - Vanderbilt University
    Management Studies - Leeds University
  - Has worked extensively in advanced materials analysis and alternative energy and automotive technologies
  - Experience includes several manufacturing engineering positions at automotive and aerospace component suppliers

• **IBIS Associates, Project Manager & Managing Partner**
  - During 20 year tenure at IBIS, Tony has worked on hundreds of advanced materials and manufacturing projects, focused on the analysis of innovative polymer, polymer composite, lightweight metals and advanced coatings projects, including applying these analyses to focus new technology development and to target markets for new business ventures
  - Managed Vehicle Manufacturing Costing, System Downsizing, and MPG improvement studies for Aluminum Association Transportation Group
Introductions and Background

• Craig Werner
  – BS Industrial Engineering Penn State
  – MBA/Operations Management Carnegie Mellon

• 25 years in Manufacturing at Werner Co.
  – World’s leading ladder company / family business 1922-1997
  – aluminum extrusions, fiberglass pultrusions and ladders

• Left Werner Co. and founded WES LLC in 2007
  – Using technical and modeling expertise, we help aluminum extruders optimize their operations
  – Using extrusion and structural engineering expertise, developed proprietary structural solutions for parabolic CSP solar frames for the solar market and provide structural engineering and design for clients (full time MS Structural Engineer)

• Craig has chaired and volunteers extensively for the AEC
Goals of the studies

• In early 2011, as part of AEC’s strategic plan initiative ("Indispensable"), additional focus was placed on the market development/industry promotion

• Teams were set up to focus on three initial market areas, based on existing or potential market opportunities:
  – Building and Construction
  – Transportation
  – Solar

• Craig Werner accepted the position chairing the Solar team

• Solar Team Objective
  – To obtain a professional, 3rd party assessment of the “value proposition” of using aluminum extrusions -vs- steel for solar structures
Why an independent, 3rd party assessment?

• During attendance at various solar shows, meeting with key extrusion suppliers and customers, Craig Werner heard various forms of the same comment from the large customers:

  • “Aluminum costs 3 times what steel costs. I see no compelling reason to consider aluminum extrusions -vs- less expensive steel parts in our structures”

  • Taken naively, this is true, BUT substituting aluminum extrusions for steel is NOT simply a direct substitution, but requires redesign to take proper advantage of the many advantages that extrusions offer!
Goals of the studies

- IBIS and the AEC Solar Team decided to conduct two separate studies:
  - **Phase I**: (complete)
The CSP / Parabolic Trough study allowed an extremely detailed, thorough view of the limited numbers of designs available
    - *This study was conducted and the final results are summarized in today’s webinar*
  - **Phase II**: (in process)
A PV structures analysis is in process, evaluating the use of aluminum extrusions for various systems (panel framing, panel mounting and racking systems)
    - *Status of the study through November 2011 will be summarized in today’s webinar*
Goals of the studies

- The AEC solar team evaluated potential 3rd party experts and selected IBIS Associates, Inc.
- IBIS are a team of experts specializing in Technology Strategy and Business Development Consulting
- IBIS focuses on competitive position assessments of traditional and advanced materials and manufacturing technologies
- The automotive industry relies heavily on key research summarized by IBIS on the total effect of light-weighting vehicle components; the IBIS study is widely recognized and cited
Manufacturing Cost Analysis
AEC Solar Outreach: CSP Frame Structures

Tony Mascarin & Ted Hannibal
Final Results - August 2011

IBIS Associates, Inc.
Waltham, Massachusetts
Scope

Independent analysis of manufacturing and installation costs of Aluminum and Steel CSP structures

• Using information available in the public domain, IBIS determined what it costs to fabricate, assemble, ship and install parabolic trough collectors for two separate material systems: aluminum extrusions versus galvanized steel

• Manufacturing costs are estimated on a “greenfield” wherein all of the costs and respective investments are considered to reside within each manufacturing scenario.
Scope

Independent analysis of manufacturing and installation costs of Aluminum and Steel CSP structures

• IBIS’ approach was to create parts and material processing models for the aluminum extruded and galvanized steel frame designs, detailing components/materials/processes and modeling the costs associated with these elements.

• The results are a strategic COST analysis (not a final “PRICE” analysis, as it does not include SG&A costs nor profit.)
Workplan

1.) Establish baseline designs for comparison
   • 1a.) Eurotrough, Skal-ET 150 & HelioTrough as steel baselines
   • 1b.) “Generized” Aluminum based on public data of Acciona/FPL designs

2.) Collect component, material, process

3.) Build component list and process flow diagrams

4.) Construct cost models for component production and assembly

5.) Use cost model to establish cost comparisons and sensitivity analyses

6.) Validate results via external expert reviewers
Steel Baseline - Eurotrough

Consortium composed of industry partners and supported by European commission

- Collector Length: 12 meters
- Aperture Width: 5.7 meters

Skal ET is a scaled up design of the Eurotrough by Flagsol which replaced square tube sections with angles

- The solar collector assembly in this design is 150m long vs. the 100m Eurotrough
Eurotrough & Skal ET Subassemblies

- Collector Length: 12 meters
- Aperture Width: 5.77 meters
- Total Aperture Area = 69.2 m²
HelioTrough Collector Design

- Torque tube design
- Center of gravity below mirror surface (Counter weights)
- Gapless SCA (no mirror gap across the pylons)
- Hydraulic drive
- Aperture width: 6.77 m (+20%)
- HCE: 89.9 mm diameter (+27%)
- 4.7 m length per HCE (+18%)
- Length of one SCE: 19.1 m (+60%)
- 10 SCEs per collector (Total length: 191 m)
- Aperture area: 1293 m² gross / 1263 m² net
HelioTrough

- Collector Length: 19.1 meters
- Aperture Width: 6.77 meters
- Total Aperture Area = 129.3 m²
SenerTrough

- Torque tube design
- Stamped cantilever arms made from electrogalvanized sheet
  - Reduced galvanizing cost
  - Unprotected edge not necessarily a problem
- Bolted connections
  - May be problematic over time

<table>
<thead>
<tr>
<th>Subassembly</th>
<th>Number of Pieces</th>
<th>Mass (kg)</th>
<th>Mass (lbs)</th>
<th>SAREA (sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque Tube</td>
<td>59</td>
<td>1234.7</td>
<td>2722.6</td>
<td>551.6</td>
</tr>
<tr>
<td>Cantilevers</td>
<td>28</td>
<td>399.7</td>
<td>881.4</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>87</strong></td>
<td><strong>1634.5</strong></td>
<td><strong>3604.0</strong></td>
<td><strong>551.6</strong></td>
</tr>
</tbody>
</table>

~ 22kg/m² of aperture

- Collector Length: 12 meters
- Aperture Width: 5.77 meters
- Total Aperture Area = 69.2 m²
## Summary of Steel Designs

<table>
<thead>
<tr>
<th>Subassembly</th>
<th>Original Eurotrough Design</th>
<th>Revised Skal-ET Design</th>
<th>HelioTrough</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Pieces</td>
<td>Mass (kg)</td>
<td>Mass (lbs)</td>
</tr>
<tr>
<td>Torque Box</td>
<td>138</td>
<td>777.1</td>
<td>1713.5</td>
</tr>
<tr>
<td>Cantilevers</td>
<td>252</td>
<td>432.7</td>
<td>954.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>390</strong></td>
<td><strong>1209.8</strong></td>
<td><strong>2667.5</strong></td>
</tr>
</tbody>
</table>

*Used to determine galvanizing costs

~ 18kg/m² of aperture

~ 18kg/m² of aperture

~ 21kg/m² of aperture
Generic Aluminum Frame 12m Baseline

- Based on Acciona – Nevada Solar One experience
- Also installed by Florida Power & Light, but heavy duty, hurricane strength version
- Baseline distilled from patent data and known component sizes, estimated for 8m and 12m frames
  - 8m scaled-up to 12m length and wider 5.77m aperture area
Generic Aluminum 12m Frame Summary

- Collector Length: 12 meters
- Aperture Width: 5.77 meters
- Total Aperture Area = 69.2 m²

### Generic Aluminum 12m

<table>
<thead>
<tr>
<th>Subassembly</th>
<th>Number of Pieces</th>
<th>Mass (kg)</th>
<th>Mass (lbs)</th>
<th>Structure Surface Area* (sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Extrusions</td>
<td>173</td>
<td>604.0</td>
<td>1332.0</td>
<td></td>
</tr>
<tr>
<td>Al Plate &amp; Brackets</td>
<td>4</td>
<td>7.6</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>Torque Plate (steel)</td>
<td>2</td>
<td>127.0</td>
<td>280.0</td>
<td>24.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>24.6</td>
</tr>
</tbody>
</table>

*Used to determine galvanizing costs

~ 10.7 kg/m² of aperture
SkyFuel Analysis

Lightweight Aluminum Space Frame

SkyFuel’s Aluminum collector design serves as additional proof that Aluminum solutions can indeed be an effective alternative to the current steel collector designs.

Source: SkyFuel Presentation at CSP Summit 2011

- 40% Fewer Parts
- 30% Less Material
- 2x Assembly Speed

Module Weight, kg/m²

LS-2 | LS-3 | EuroTrough | NY Solar One | SkyTrough™

29 | 33 | 29 | 24 | 16

Source: SkyFuel Presentation at CSP Summit 2011
Aluminum Price 2001-2011

- LME price from approx $1250-3200/tonne
  - $0.57-$1.45/lb, currently $1.17/lb
  - *Cost analysis uses $0.90/lb, (i.e., long term avg. price)*
- Surcharge for Midwest extrusion billet
  - + $0.20/lb
Assembly Data

Aluminum exp with Lauren Engineering

- Florida
  - average 20-21 man hours per frame (total construction, not just structure)
  - Installation crews of 6 - 8
    > 1-2 men on crane
    > 3-4 men on mirror
    > 2-3 men HCE Tube

Other datapoints for Al (from team-members)

- 8 man-hours assembly at Nevada (8m frame)
  - 4 hrs under ideal conditions
- 13 man-hours at FPL (12m frame)
Comparative Mfg & Assembly Process Flows

Fabrication
- Extrusion (Chords, Struts, Angles, Nodes)
- Cut & Machine
- Kit & Package

Transportation
- Shipping (Truck)

Assembly
- On-site Assembly
  - Additional Components
    - Torque Plates
    - Mirrors
    - Receivers
    - Motors
    - Hydraulics

Steel
- Torque Box (Eurotrough, Skal-ET)
  - Cut Tubes
  - Weld Box Sides
  - Zn Galv.
  - Kit & Package

- Cut Tubes
  - Weld Arms
  - Zn Galv.

- Torque Tube (Heliotrough)
  - Pipe Mill
  - Hammer-forged & weld mounts
  - Zn Galv.

Aluminum
- Cut & Machine
- Kit & Package

- Shipping (Truck)

- Mech Ass'y Box
- Mech Ass'y Arms
- Transport Flatbed
- On-site Assembly
  - Additional Components
    - Torque Plates
    - Mirrors
    - Receivers
    - Motors
    - Hydraulics
Cost Modeling Methodology

• The following cost estimates are built from the bottom up, and consider all variable and fixed elements of each of the operations required to fabricate, assemble and install Solar Thermal Parabolic Collectors.

• These are the direct manufacturing costs that would be incurred by a company that is completely integrated from raw material acquisition through to final field installation.

• There are no SG&A costs nor profit added to these estimates.
## Cost Model Results – Generic Aluminum 12m

<table>
<thead>
<tr>
<th>COST SUMMARY BY ELEMENT</th>
<th>Generic Aluminum 12m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/frame</td>
</tr>
<tr>
<td>Material Cost</td>
<td>$1,828.44</td>
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<tr>
<td>Direct Labor Cost</td>
<td>$313.04</td>
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<tr>
<td>Utility Cost</td>
<td>$9.57</td>
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<tr>
<td><strong>FIXED COST ELEMENTS</strong></td>
<td></td>
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<tr>
<td>Equipment Cost</td>
<td>$257.27</td>
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<tr>
<td>Tooling Cost</td>
<td>$2.88</td>
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<tr>
<td>Building Cost</td>
<td>$8.02</td>
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<td>Maintenance Cost</td>
<td>$111.65</td>
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<td>Overhead Labor Cost</td>
<td>$73.52</td>
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<tr>
<td>Cost of Capital</td>
<td>$123.97</td>
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<tr>
<td><strong>TOTAL OPERATION COST</strong></td>
<td><strong>$2,728.36</strong></td>
</tr>
<tr>
<td>Cost per Unit Area (m^2)</td>
<td>$39.40</td>
</tr>
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</table>
## Cost Model Results – Eurotrough 12m

<table>
<thead>
<tr>
<th>COST SUMMARY BY ELEMENT</th>
<th>Eurotrough 12m</th>
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<tbody>
<tr>
<td></td>
<td>$/frame</td>
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<tr>
<td>Material Cost</td>
<td>$2,870.39</td>
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<tr>
<td>Direct Labor Cost</td>
<td>$649.42</td>
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<td>Utility Cost</td>
<td>$8.82</td>
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### FIXED COST ELEMENTS

<table>
<thead>
<tr>
<th></th>
<th>$/frame</th>
<th>percent</th>
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<tbody>
<tr>
<td>Equipment Cost</td>
<td>$124.70</td>
<td>3%</td>
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<tr>
<td>Tooling Cost</td>
<td>$0.48</td>
<td>0%</td>
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<td>Building Cost</td>
<td>$6.48</td>
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<tr>
<td>Maintenance Cost</td>
<td>$55.19</td>
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<td>Overhead Labor Cost</td>
<td>$210.22</td>
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<td>Cost of Capital</td>
<td>$86.56</td>
<td>2%</td>
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</table>

**TOTAL OPERATION COST**

$4,012.26

**Cost per Unit Area (m^2)**

$57.95
## Cost Model Results – Skal ET

<table>
<thead>
<tr>
<th>COST SUMMARY BY ELEMENT</th>
<th>Skal ET 12m</th>
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<tbody>
<tr>
<td><strong>$/frame</strong></td>
<td><strong>percent</strong></td>
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<tr>
<td>Material Cost</td>
<td>$2,575.51</td>
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<tr>
<td>Direct Labor Cost</td>
<td>$735.77</td>
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<td>Utility Cost</td>
<td>$10.58</td>
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**FIXED COST ELEMENTS**

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<tr>
<th></th>
<th>$/frame</th>
<th>percent</th>
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<tbody>
<tr>
<td>Equipment Cost</td>
<td>$133.99</td>
<td>3%</td>
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<tr>
<td>Tooling Cost</td>
<td>$0.48</td>
<td>0%</td>
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<tr>
<td>Building Cost</td>
<td>$6.73</td>
<td>0%</td>
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<td>Maintenance Cost</td>
<td>$59.48</td>
<td>2%</td>
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<td>Overhead Labor Cost</td>
<td>$238.17</td>
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<tr>
<td>Cost of Capital</td>
<td>$89.02</td>
<td>2%</td>
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</table>

**TOTAL OPERATION COST**

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>$3,849.74</td>
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Cost per Unit Area (m²)

<p>| |</p>
<table>
<thead>
<tr>
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<tr>
<td>$55.60</td>
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## Cost Model Results – Steel HelioTrough

<table>
<thead>
<tr>
<th>COST SUMMARY BY ELEMENT</th>
<th>HelioTrough 19m</th>
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<tr>
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<td>Material Cost</td>
<td>$5,714.78</td>
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<tr>
<td>Direct Labor Cost</td>
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<td>Utility Cost</td>
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</table>

<table>
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<th>FIXED COST ELEMENTS</th>
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<tr>
<td>Equipment Cost</td>
<td>$299.41</td>
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<td>Tooling Cost</td>
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<td>Building Cost</td>
<td>$3.31</td>
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<td>Maintenance Cost</td>
<td>$125.13</td>
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<td>Overhead Labor Cost</td>
<td>$141.09</td>
<td>2%</td>
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<tr>
<td>Cost of Capital</td>
<td>$176.94</td>
<td>3%</td>
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</table>

**TOTAL OPERATION COST**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$6,907.44</td>
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</tbody>
</table>

Cost per Unit Area (m^2) $53.42
## Cost Model Results – Steel SenerTrough

### COST SUMMARY BY ELEMENT

<table>
<thead>
<tr>
<th>Element</th>
<th>Cost</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Cost</td>
<td>$2,792.86</td>
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<tr>
<td>Direct Labor Cost</td>
<td>$197.48</td>
<td>6%</td>
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<td>Utility Cost</td>
<td>$2.14</td>
<td>0%</td>
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<tr>
<td><strong>FIXED COST ELEMENTS</strong></td>
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<td></td>
</tr>
<tr>
<td>Equipment Cost</td>
<td>$130.35</td>
<td>4%</td>
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<tr>
<td>Tooling Cost</td>
<td>$94.57</td>
<td>3%</td>
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<tr>
<td>Building Cost</td>
<td>$1.97</td>
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<tr>
<td>Maintenance Cost</td>
<td>$77.81</td>
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<tr>
<td>Overhead Labor Cost</td>
<td>$63.92</td>
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<tr>
<td>Cost of Capital</td>
<td>$100.50</td>
<td>3%</td>
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<tr>
<td><strong>TOTAL OPERATION COST</strong></td>
<td><strong>$3,461.60</strong></td>
<td></td>
</tr>
<tr>
<td>Cost per Unit Area (m²)</td>
<td><strong>$49.99</strong></td>
<td></td>
</tr>
</tbody>
</table>

The cost per unit area is calculated as the total operation cost divided by the unit area.
## Scenario Comparison

- **Collector Cost Comparison in $/frame**

<table>
<thead>
<tr>
<th>Collector Length</th>
<th>Generic Aluminum</th>
<th>Eurotrough</th>
<th>Skal ET</th>
<th>Sener Trough</th>
<th>Heliotrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>$1,727</td>
<td>$1,430</td>
<td>$1,439</td>
<td>$1,842</td>
<td>$1,446</td>
</tr>
<tr>
<td>Fabrication</td>
<td>$654</td>
<td>$258</td>
<td>$289</td>
<td>$410</td>
<td>$2,225</td>
</tr>
<tr>
<td>Assembly</td>
<td>--</td>
<td>$517</td>
<td>$622</td>
<td>$122</td>
<td>$324</td>
</tr>
<tr>
<td>Galvanizing</td>
<td>$54</td>
<td>$1,390</td>
<td>$1,082</td>
<td>$806</td>
<td>$2,394</td>
</tr>
<tr>
<td>Shipping</td>
<td>$47</td>
<td>$94</td>
<td>$95</td>
<td>$127</td>
<td>$281</td>
</tr>
<tr>
<td>Field Assembly</td>
<td>$246</td>
<td>$323</td>
<td>$323</td>
<td>$154</td>
<td>$237</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,728</strong></td>
<td><strong>$4,012</strong></td>
<td><strong>$3,850</strong></td>
<td><strong>$3,462</strong></td>
<td><strong>$6,907</strong></td>
</tr>
</tbody>
</table>
Collector Cost Summary (per collector)

Scenario Comparison - Breakdown by category

Direct Mfg Cost ($/part)

- Aluminum Collector Baseline
- Steel Eurotrough
- Steel Skal ET
- Steel HelioTrough
- Steel SenerTrough

Categories:
- assembly
- shipping
- galvanizing
- torque plate
- subassembly & components
- secondary forming
- extrusion
- primary raw material cost
Collector Cost Summary (per sq meter)

Scenario Comparison - Breakdown by category - cost per unit area

Direct Mfg Cost ($/sq meter aperture area)

- Aluminum Collector Baseline
- Steel Eurotrough
- Steel Skal ET
- Steel HelioTrough
- Steel SenerTrough

- assembly
- shipping
- galvanizing
- torque plate
- subassembly & components
- secondary forming
- extrusion
- primary raw material cost
Steel costs less than aluminum on a $/lb basis, but aluminum is approximately 1/3 the weight of steel. Using aluminum extrusions for the frame structure provides costs and performance benefits which far outstrip the pure material cost differences.
Material Market Price History

At no time from 1991 through 2011 would the comparative prices of steel, zinc and aluminum extrusions have resulted in a case where the cost of the modeled extruded aluminum frame would have been greater than the galvanized steel frames.
Expert Review Results

- Analysis results reviewed with technology developers, materials suppliers, facility owners, & construction engineers

- Based on published operating results at Nevada Solar One (NSO), which utilizes aluminum frames, the optical efficiency and energy performance of aluminum frames is equal to or better than tested steel designs.

  “The National Renewable Energy Laboratory recommends a combined “slope error” (mirror error plus frame-alignment error of ~3.0 milliradians or less for solar trough arrays. NSO operates with a combined slope error near 2.0 milliradians. This translates to a focus improvement of 34 to 38% over NREL recommendations.”

  MACHINE Design.com May 7, 2009
Expert Review Results

- System designs, fabrication costs, secondary operation direct costs all confirmed to with known costs to component suppliers and manufacturers

- Manufacturing economics for steel confirmed with NREL experts and NREL internal cost studies of solar field development costs
  - The IBIS study was considered more detailed and rigorous in terms of structure design and materials comparisons, but consistent with quote based results from their WorleyParsons report.
AEC IS Indispensable to our members...

• Individual companies would have found doing this difficult:
  – $ for study
    > Likely difficult for all but the largest companies
• Ability to have a broad perspective from multiple extruders
  – Likely impossible without AEC and cooperation among extruders

The total quarterly installed capacity can be attributed to three concentrating photovoltaic (CPV) projects, 2 megawatts in Arizona, 1 megawatt in CA, and 1 megawatt in New Mexico.

It marks the largest quarter for CPV installations in U.S. history. However, this record is likely to be broken soon: the Cogentrix 30-megawatt Alamosa Solar CPV installation in Colorado closed a $90.6 million loan guarantee from the Department of Energy in September and is expected online by the end of the year.

- 500 MW installed US
- 3.5 GW in permits approved in public lands by Fed
Phase 2 – PV (Photovoltaics) Currently in progress

- PV represents an equally large market
  - More PV installed, but less in utility power plants
- Aluminum already dominant in modules & pitched roof installations
- Competing with Galvanized Steel, SS, Composites in commercial & utility systems
PV Project Workplan

• Define target installation, along with production scenario, performance parameters, and lifecycle usage description (functionally equivalent steel and aluminum concepts)
• Identify the assemblies and components to be addressed, for both material systems
• Outline design and installation differences for each system
• Develop manufacturing-installation cost model for target components
• Establish and link usage lifecycle cost framework
• Conduct analyses and sensitivities to key variables
• Report findings
5 Target Scenarios Evaluated

- 5 kW Residential Pitched Roof
- 80 kW Commercial Flat Roof
- 1 MW Small Utility Ground Mount
- 5 MW Medium Utility Ground Mount
- 50 MW Large Utility Ground Mount
### Component Build-Up and Costing

<table>
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<tr>
<th>Cost Calculations</th>
<th>Pitched Residential Roof Top</th>
<th>Commercial Flat Roof Top</th>
<th>Small Ground Mount Utility</th>
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Example Results (WIP)

- Component pricing (above)
- Forthcoming results will also include
  - Labor, Maintenance, Transportation
  - Sensitivities to key variables and location
Questions?
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