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Inside

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Cost of Ownership for c-Si Front & Back-Side Metallization Processes

With this edition of Applied Cost Modeling, we are publishing the second installment in a series on the application of cost of ownership (COO) and overall equipment efficiency (OEE) to crystal silicon-based (c-Si) photovoltaic (PV) metallization.

Case Study

This case study will look at the COO of front and back-side metallization using the DEK Solar PV3000 as an example. We will look at the base costs and then contrast them to a single head system as well as perform sensitivity analyses to find those areas for future cost improvements.

COO Review[3]

A more detailed discussion of COO can be found in the first paper in this series in the 6th edition of Photovoltaics International[4]. To review, the basic COO algorithm is described by:

First published in Photovoltaics International, 8th edition.

[Continued on page 3]

Editorial Board

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Calendar of Events

January 2013

13-16 Industry Strategy Symposium (ISS)
Ritz-Carlton
Half Moon Bay, CA

February 2013

5-7 PV America East
Pennsylvania Convention Center
Philadelphia, PA

12-14 Spanish Conference on Electron Devices
Palacio de Congresos, Universidad de Valladolid
Valladolid, Spain

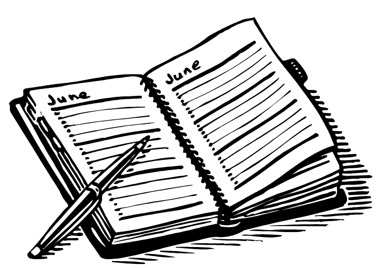
24-26 Industry Strategy Symposium (ISS) Europe
Regina Palace Hotel
Stresa, Italy

March 2013

10-12 PV Fab Managers Forum
Leonardo Royal Hotel
Berlin, Germany

April 2013

1-4 North America Standards Meetings
SEMI Headquarters
San Jose, CA



$$C_U = \frac{C_F + C_V + C_Y}{L \times TPT \times Y_C \times U}$$

Where:

C_U	=	Cost per good unit (wafer, cell, module, etc.)
C_F	=	Fixed cost
C_V	=	Variable cost
C_Y	=	Cost due to yield loss
L	=	Process life
TPT	=	Throughput
Y_C	=	Composite yield
U	=	Utilization

<u>OEE Review[5]</u>

One of the most popular productivity metrics is OEE. It is based on reliability (MTBF), maintainability (MTTR), throughput, utilization, and yield. All these factors are grouped into the following four sub-metrics of OEE.

1. Availability (joint measure of reliability and maintainability)
2. Operational efficiency
3. Throughput rate efficiency
4. Yield/quality rate

As we see above, it requires many parameters to calculate OEE. If the accuracy requirement is not a critical factor, use the following formula to calculate an approximate OEE value:

OEE = Number of Good Units Output in a Specified Period of Time / (Theoretical Throughput Rate x Time Period)

<u>Relationship Between Metrics</u>

There are many equipment performance metrics at different levels. They may appear disjointed; however, that is not true. They all fit nicely into a hierarchal tree.

Figure 4 depicts the hierarchy tree of the equipment performance metrics. As shown in the figure, when a time dimension is added to quality and safety, it becomes reliability. Reliability and maintainability jointly make up availability. When production speed efficiency and production defect rate are combined with availability, it becomes productivity (OEE). Acquisition and operational costs make up Life Cycle Cost (LCC). When scrap, waste, consumables, tax, and insurance cost are added to LCC and the total is normalized by the production volume, it becomes COO.

<u>COO Inputs</u>

The following are the results of the COO analysis run on the PV3000 metallization line. Table 1 highlights the major input parameters.

Parameter	**PV3000**
Throughput	3,000 wafers/hour
Wafer Size	156 mm
Wafer Cost	$3
Mean Time Between Failure (MTBF)	>2,000 hours
Mean Time to Repair (MTTR)	<2 hours
Equipment Cost	$2,300,000
Equipment Yield	99.7%
Utilities	$41,470/year/system
Consumables	$8,713,308/year/system
Maintenance	Owner provided

Table 1: Major COO Inputs

In addition to the Table 1 parameters, where required, the author used example values from SEMI E35[3] for administrative rates and overhead. These values where provided by SEMI North American members and may not be applicable to other geographic regions.

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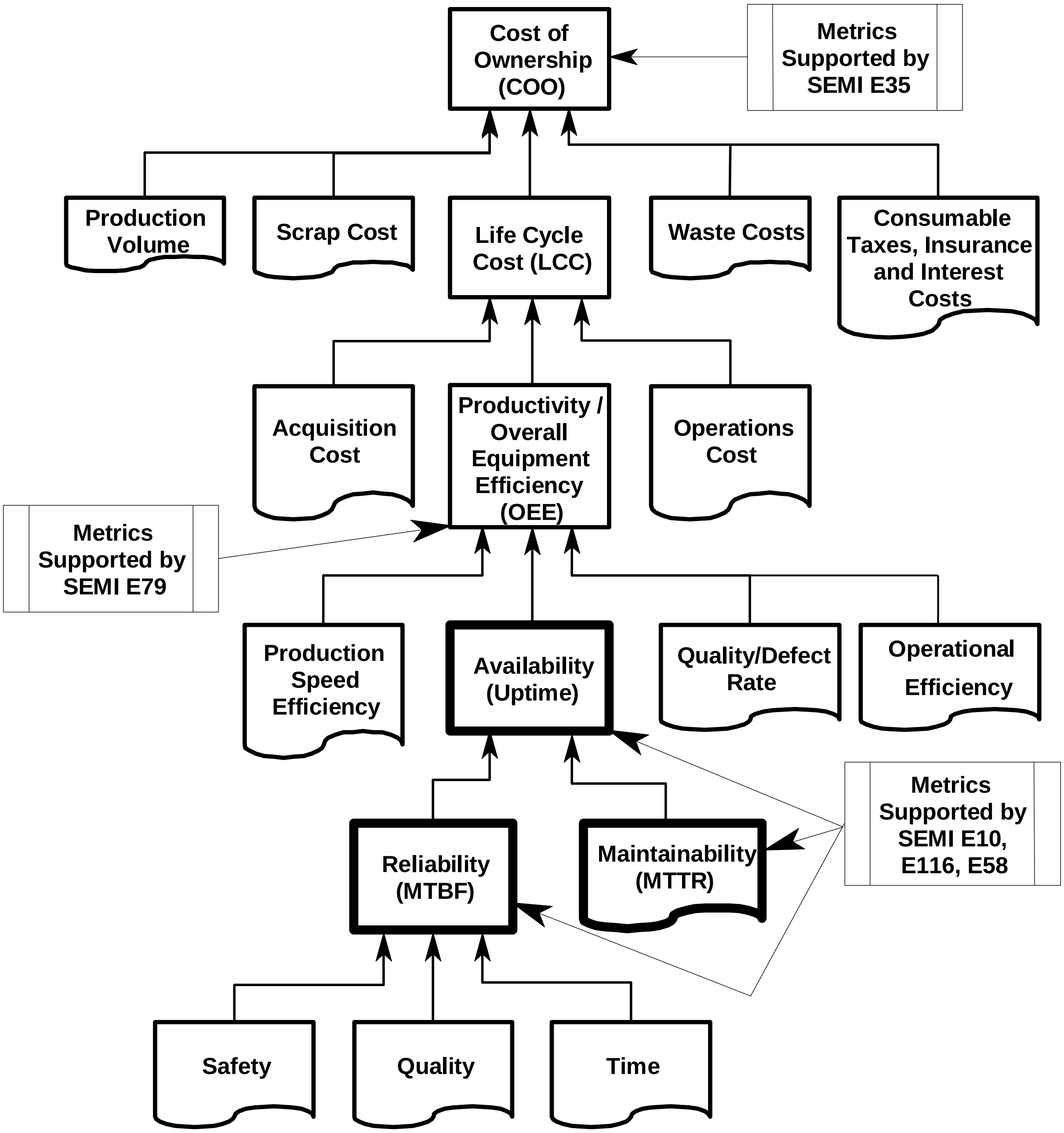

Figure 4: Hierarchy of Equipment Performance Metric[6]

However, it is the author's experience that these example values do not impact the COO results on a relative basis.

Cost Drivers

Examination of the detailed TWO COOL®[7] COO model in Table 2 highlights the main cost and productivity factors. Recurring costs are approximately 30x initial capital costs over the life of the process, which are driven primarily the cost of aluminum paste used for back-side metallization.

Cost Per System	2,300,000	Dollars
Number Of Systems Required	1	Systems
Total Depreciable Costs	2,355,000	Dollars
Equipment Utilization Capability	97.52	Percent
Production Utilization Capability	97.52	Percent
Composite Yield	99.70	Percent
Good Wafer Equivalents Out Per Week	490,009.49	G.W.E.'s
Good Wafer Equivalent Cost		
With Scrap	0.44480	Dollars
Without Scrap	0.43578	Dollars
Average Monthly Cost		
With Scrap	947,079	Dollars
Without Scrap	927,858	Dollars
Process Scrap Allocation		
Equipment Yield	100.00	Percent
Defect Limited Yield	0.00	Percent
Parametric Limited Yield	0.00	Percent
Equipment Costs (Over Life of Equipment)	2,541,145	Dollars
Per Good Wafer Equivalent	0.00995	Dollars
Per Good cm2 Out	0.00005	Dollars
Recurring Costs (Over Life of Equipment)	111,108,291	Dollars
Per Good Wafer Equivalent	0.43486	Dollars
Per Good cm2 Out	0.00228	Dollars
Total Costs (Over Life of Equipment)	113,649,436	Dollars
Per Good Wafer Equivalent (Cost Of Ownership)	**0.44480**	**Dollars**
Per Good cm2 Out	0.00233	Dollars
Per Productive Minute	22.17	Dollars

Table 2: COO Results

Next we will look more closely at the top cost drivers and opportunities for improvement.

Table 3 takes a closer look at the cost breakdown according to the 13 categories specified in SEMI E35. The top Pareto costs are Materials/Consumables, which includes utilities, supplies, consumables, and waste disposal; Labor; Depreciation, which is impacted by equipment costs, throughput rate, and utilization; Scrap; and Maintenance, including repair parts and technician labor.

The top 3 cost drivers account for 97% of the total COO. For this reason, we will focus our attention on those areas as we examine the cost sensitivities to input parameters that drive Material/Consumable costs, Labor, and Depreciation.

Cost Driver Sensitivities

The first factors to be examined are supplies and consumables. Table 4 below shows the annual costs per system by supply item.

One of the issues in defining a sensitivity analysis for some of the above items is their interrelationship with other factors. Changing the price/quality of the screens could impact throughput, paste consumption, or yield; paste consumption changes could impact throughput and the conversion efficiency of the device. Since silver paste is an industry concern, we will examine what cost benefits could be achieved by

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Cost Drivers per Good Wafer Equivalent		
Material/Consumables	0.41138	Dollars
Labor	0.01254	Dollars
Depreciation	0.00922	Dollars
Scrap	0.00903	Dollars
Maintenance	0.00133	Dollars
Floor Space Costs	0.00070	Dollars
Support Personnel	0.00057	Dollars
Training	0.00001	Dollars
System Qualification Costs	0.00001	Dollars
ESH Preparation and Permits	0.00000	Dollars
Moves And Rearrangements	0.00000	Dollars
Other Materials	0.00000	Dollars
Other Support Services	0.00000	Dollars

Table 3: Pareto of Cost Drivers

Supply/Consumable	Annual Cost per System
Electricity	$28,470
Exhaust	$13,000
Screens	$768,821
Aluminum Paste	$4,356,654
Silver Paste	$3,587,833

Table 4: Annual Supply/Consumable Costs

reducing the consumption or cost per kilogram.

As can be seen from figure 5, the usage of silver paste has a significant impact on the total COO. A 50% reduction in usage provides approximately a 20% reduction in the total COO for the process. While it may not be possible to achieve this level of reduction and maintain the cell efficiency, it certainly shows a significant opportunity for continued research in conducting materials.

Likewise, the price of silver paste has a similar impact on the total COO (figure 6). A 50% reduction in price provides an approximate 20% reduction in the total COO for the process. As might be expected, much of the cost of silver paste is driven by the cost of the metal. This can be seen by the relatively pricing for both aluminum ($85/kg) and silver ($700/kg) pastes; with more of the cost of the aluminum paste being driven by the cost of the included polymers. Given the annual costs for both pastes, it would be well worth the effort to examine alternatives.

The industry is looking at transparent and semitransparent conductor materials such as Indium Tin Oxide (ITO) as a replacement for silver. While working to achieve lower shadowing on the front-side to improve cell performance will help drive down the cost/watt, it appears that finding a replacement or reduced usage or price for aluminum would perhaps provide an equal cost/watt improvement.

The next factor to be examined is labor content, which represents 3% of the total cost of these integrated process steps. Labor is defined as direct operator labor and the model is based on one operator overseeing one machine. Since these are highly automated machines with sufficient throughput to support a 30 MW line, it is not likely that the factory would be significantly larger in order to allow for further amortization of labor content. However, figure 7 does examine COO sensitivity to labor content should such opportunities present themselves.

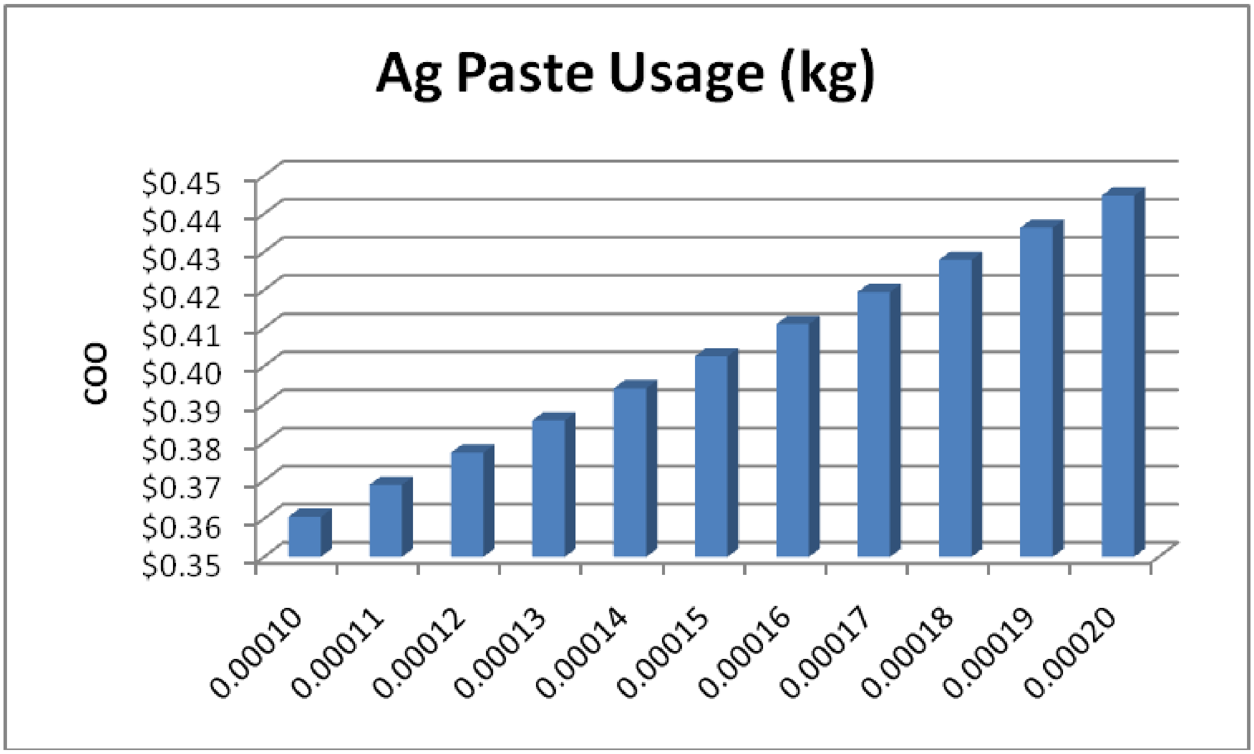

Figure 5: Sensitivity Analysis Silver Paste Quantity vs. COO

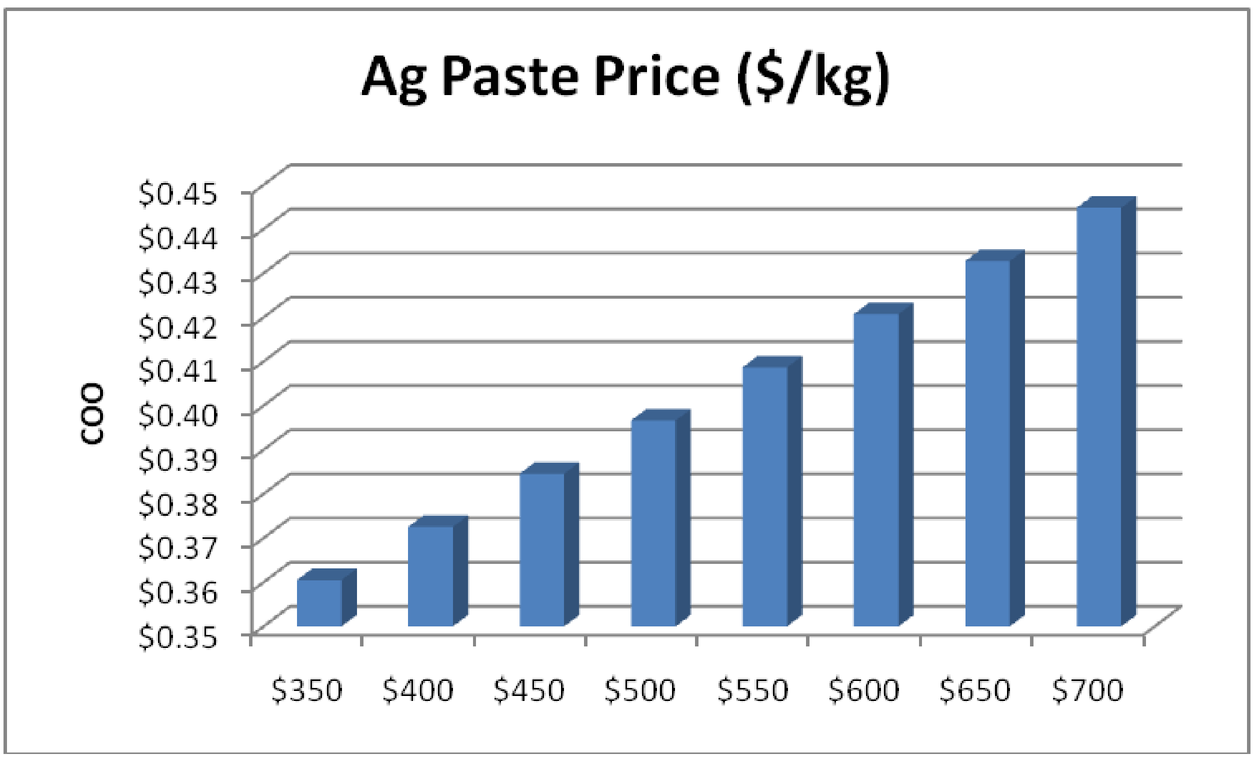

Figure 6: Sensitivity Analysis Silver Paste Price vs. COO

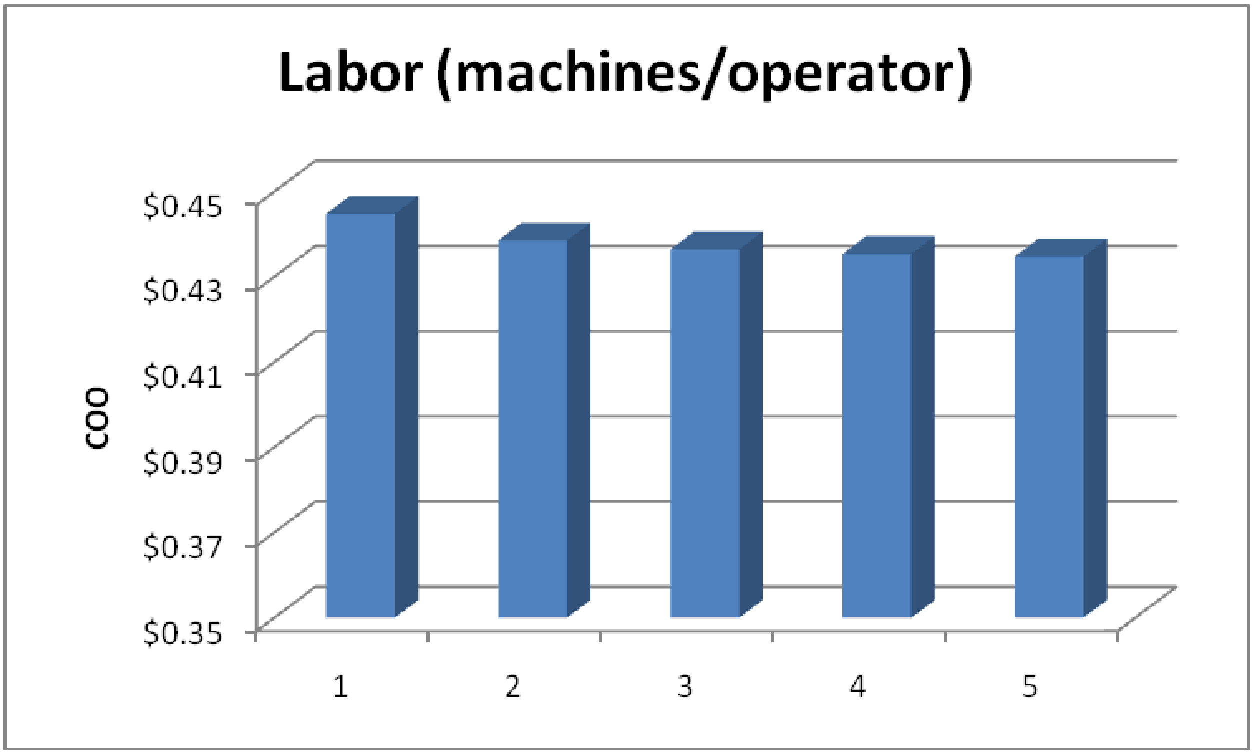

Figure 7: Sensitivity Analysis of Labor vs. COO

Lastly, we look at the factors impacting depreciation; purchase price and throughput. (see figures 8 and 9).

Purchase price has a modest impact on COO in high throughput equipment, especially those with higher variable costs. The cost impact in this case is approximately $0.0047 (1%) per $1,200,000 (~50%) change in purchase price. This indicates that even if the purchase price was zero, the impact on COO would only be approximately 2%.

However, as can be seen in figure 9, improvements in throughput can have a significant impact on COO depending on where on the curve the equipment is operating. In this case, the printing line is operating at an average throughput of 3,000 wafers per hour (wph) and a 200 wph near the average only impacts COO by 0.4%.

Another question that arises from the previous discussion is whether the assumption that a 3 print head system is, in fact, a lower cost alternative to the traditional single print head systems. For this analysis, we modified the model from a throughput of 3,000 wph to 1,200 wph and from a capital cost of $2.3M to $1.2M. It should be noted that the design throughput of the PV3000 is 3,600 wph, but we used a conservative value of 3,000. We did not make the same assumption for the single print head system, so the actual costs for that system may be higher. We also assumed that the consumables per wafer were the same since the end product should have the same specifications.

Even with the below, we found that the COO value for the single head system was $0.47 per good wafer compared to the $0.44 of the PV3000. Therefore, it is our estimation that the multiple head system has approximately a 7% cost advantage over traditional systems.

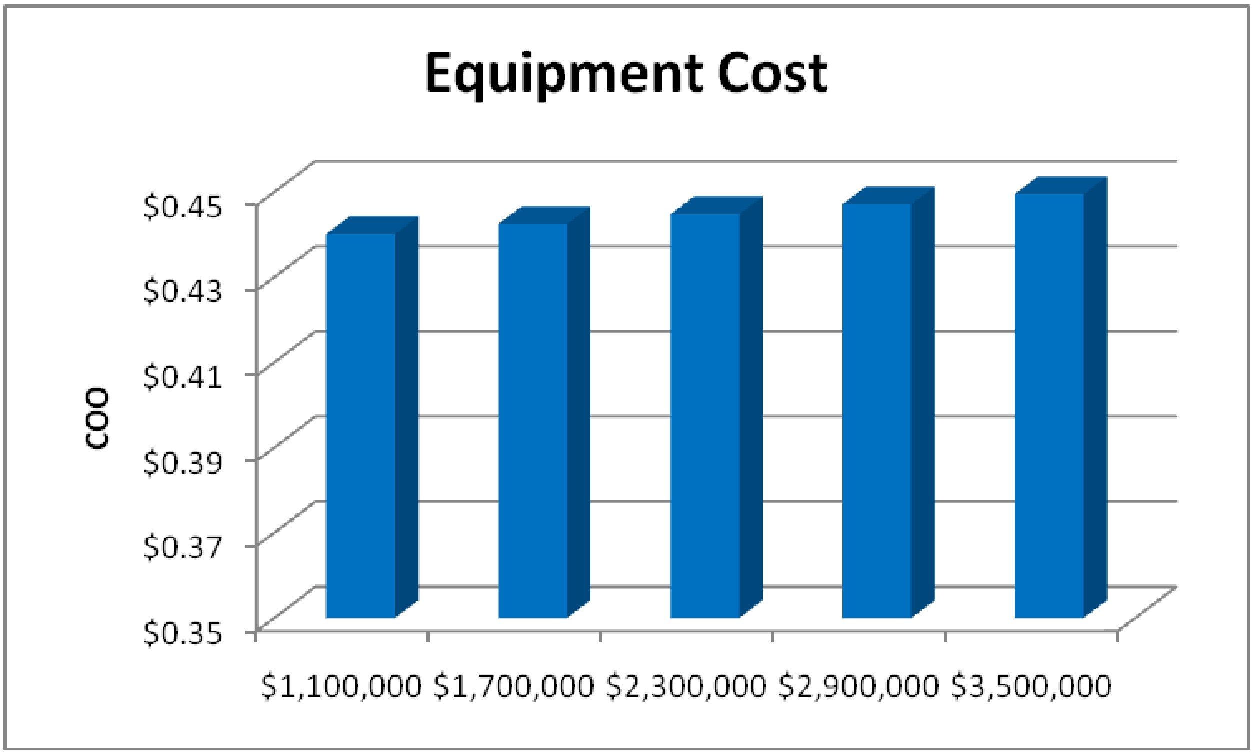

Figure 8: Sensitivity Analysis of Purchase Price vs. COO

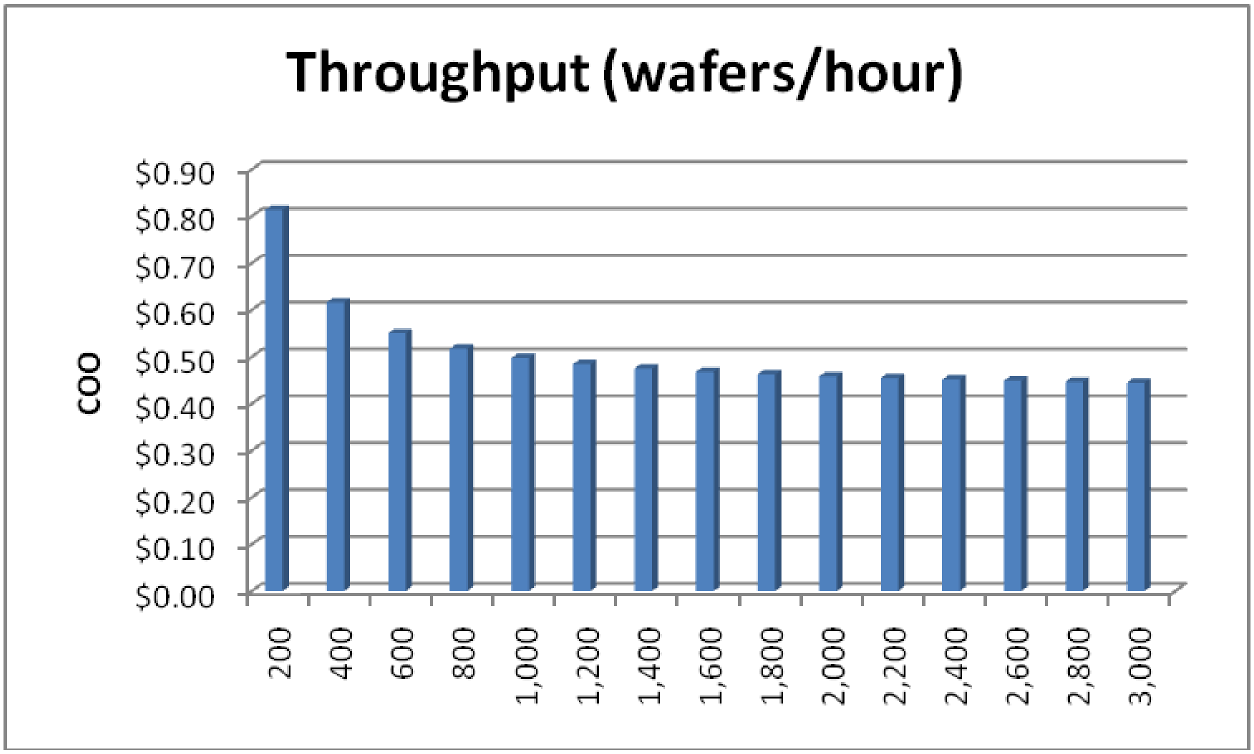

Figure 9: Sensitivity Analysis of Throughput vs. COO

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Overall Equipment Efficiency	**81.02**	**Percent**
Availability Efficiency	**97.52**	**Percent**
Engineering Usage	0.00	Hours/Week
Standby	0.00	Hours/Week
Hours Available/System (Productive Time)	163.83	Hours/Week
Down Time	4.17	Hours/Week
Scheduled Maintenance	4.00	Hours/Week
Unscheduled Maintenance	0.17	Hours/Week
Test	0.00	Hours/Week
Assist	0.00	Hours/Week
Non-Scheduled Time	0.00	Hours/Week
Equipment Uptime	163.83	Hours/Week
Total Time	168.00	Hours/Week
Performance Efficiency	**83.33**	**Percent**
Throughput At Capacity/System	3000.00	Layers/Hour
Theoretical Throughput	3600.00	Layers/Hour
Operational Efficiency	100.00	Percent
Rate Efficiency	83.33	Percent
Quality Efficiency	**99.70**	**Percent**
Equipment Yield	99.70	Percent
Redo Rate	0.00	Percent

Table 5: OEE Results

Overall Equipment Efficiency

Table 5 shows the OEE of the PV3000. As you can see, the OEE is in excess of 81% based on a maximum throughput rate of 3,600 wph. If that factor is eliminated, the OEE is over 97%, leaving little room for improvement.

Conclusions

The photovoltaics industry has gone through some immense changes over the past few years, yet it is still developing rapidly in many ways. This means that while this paper can offer a snapshot of the metallization process and its costs today, these will very likely look quite different even a year from now. The upstream processes in solar cell manufacturing have gone through a practical revolution in the past few years and this, combined with the pressures inherent within the metallization process itself, are now driving huge transformations within this part of the solar cell production cycle.

As the industry moves forward, it will continue to focus on faster throughputs, better yields, higher accuracies, and higher aspect ratios. There will also be higher levels of automation, right through to the end of the line. The ultimate goal is to have a hands-off, lights-out operation where the materials are automatically fed into a line which monitors and runs itself. The surface mount technology (SMT) industry is almost there, so there is every possibility that the solar industry will achieve the same.

Each improvement in the process has its development costs and while, in many cases, COO will be reduced as a result of their adoption, it may, in other cases actually increase. While this may at first seem counterproductive in a world of lean manufacture and cost pressures, it should also be remembered that COO should be measured against changes in cell efficiency. For the solar industry, the combination of these factors gives the most crucial metric of cost per watt and there is no doubt that the many developments mentioned here have brought or will bring significant improvements to the cost per watt of solar power and will continue to make solar energy a cheaper proposition for the future.

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3. E35, Guide to Calculate Cost of Ownership (COO) Metrics for Semiconductor Manufacturing Equipment, www.semi.org.
4. D. Jimenez, "Cost of Ownership and Overall Equipment Efficiency: A Photovoltaics Perspective," Photovoltaics International, Ed. 6.
5. E79, Standard for Definition and Measurement of Equipment Productivity, www.semi.org.
6. Dr. Vallabh Dhudshia, "Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers," iUniverse, 2008.
7. TWO COOL® is a commercial software package from Wright Williams & Kelly, Inc.

Authors

Mr. Darren Brown is the Global Business Manager of DEK's Alternative Energy Group, responsible for maintaining the company focus on PV Solar and Hydrogen Fuel Cells and developing processes and equipment for these new and emerging technologies. In recent years the group has paid particular attention to developing the PV1200 Metallization Line and the next generation PV3000. Since joining DEK in 1995, Darren has held positions as a Support Engineer, Global Applied Process Engineer, and UK Sales Manager before heading up the Alternative Energy Business Unit. Darren has contributed articles and conference presentations on both Fuel Cells and Solar throughout Europe, USA and Asia. Daren can be reached at +44 (0)1305 208435 or dwbrown@dek.com.

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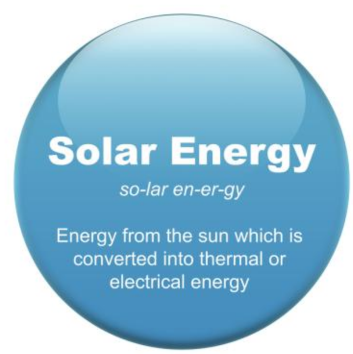

The Affordable Care Act and the Patient Experience

Mark Allen Stinson, WWK Healthcare

RE-ENGINEERING HOW HEALTH CARE PROVIDERS APPROACH FACILITY DESIGN, TECHNOLOGY IMPLEMENTATION AND MANAGEMENT

The importance of meeting patient expectations and measuring their experience with health care institutions and providers is now of paramount importance. Now there is a way for companies and their employees to track that information.

The Center for Medicare and Medicaid Services has developed a Patient Experience Rating Profile on every hospital participating as a provider receiving reimbursement from the Medicare program. The profiles are compiled from input received from actual Medicare patients who receive services from a hospital. The benefit to employers? Employees and general public will now have the ability to compare one hospital's HCAPHS (Hospital Consumer Assessment of Health Care Providers) scores against another's. If history is any indication, soon the program will be expanded to include all Medicare providers (hospitals, clinics, surgery centers, etc.). And, most certainly, the entire health care insurance industry will soon follow suit.

Ten questions are asked of Medicare patients by the CMS task forces following discharge from their respective hospital(s). They are:

- How often did nurses communicate well with patients?
- How often did doctors communicate well with patients?
- How often did patients receive help quickly from hospital staff?
- How often was patients' pain well controlled?
- How often did staff explain about medicines before giving them to patients?
- How often were the patients' rooms and bathrooms kept clean?
- How often was the area around patients' rooms kept quiet at night?
- Were patients given information about what to do during their recovery at home?
- How do patients rate the hospital overall?
- Would you recommend the hospital to your friends and family?

In order to view the online results of hospitals, the HR department and individual employees can:

1. Type http://hospitalcompare.hhs.gov/ into the web browser.
2. Once the welcome page opens type in the zip code and press "Enter".
3. Choose those hospitals for comparison by checking the boxes to the left of the hospitals' names – up to a maximum of three (3) per query.
4. To see how one hospital compares to the others in this sampling, simply click on the report tab.

Why is this information important to employees under the age of 65? In addition to the Medicare/Medicaid populations, this website will prove to be an invaluable tool for employees of any age as they wade through the murky waters of choosing a hospital and/or health system in this time of uncertainty and increasing danger. Finally, there is transparency in reporting quality and outcomes from the actual end user, the patient.

Today, hospitals and health care providers feel their major competition is other providers. In reality, the major source of competition to the health care industry is other service industries and the retail sectors of the economy. We are a consumer driven society and other industries must provide their consumers with prompt, courteous and efficient service in order to remain competitive. Why, then, should we allow for a different expectation from our patients?

The importance of meeting patient expectations and measuring their experience with our health care institutions and providers is now of paramount importance. Patient outcome data and facility rankings have been virtually hidden from the general public. This has been addressed with the HCAPHS system. The impact of the ACA will be profound on many levels and will require a complete reengineering of how health care providers approach facility design, technology implementation and management.

As technology has rendered immediacy to every aspect of our lives, why should our country's citizenry remain satisfied with the archaic pre-admission processes that plague every patient and/or family member entering each portal of the health care system? As the retail industry has perfected ready access points for their customers, why should anyone tolerate the deplorable lack of signage and endless maze of corridors at our hospitals? And, if focus groups are used by every major industry to design products, develop branding strategies and determine price points, what possesses the health care industry to design their buildings, determine service lines and charging structures without input from their patients and end users?

The patient experience begins, not upon arrival to the multi-level parking structure, but in their homes, in their doctor's offices and in their general lack of understanding of how the United States health care system works. It continues throughout the inpatient confinement or outpatient episode. And, it does not end upon discharge or completion of a serial treatment. The patient experience actually concludes upon their return, if possible, to activities of normal daily living. The degree to which the health care provider or institutions assist in the transition from each milestone of the total patient care continuum is the real means by which their patients will measure their experience.

As with any change, and many will be required of the health care industry, great care needs to be given in the development of metrics to measure the impact of each change. A transition strategy should be developed for each of the optimized processes along with a concise implementation timetable that allows for the appropriate sequencing of the proposed changes. In the budgeting of such an undertaking, serious consideration should be given to the development of a "real-time" patient experience measurement program. This is not one of the standard health care industry patient satisfaction instruments, but a specific software and hardware platform designed to measure the actual experience of the patient and/or family at the time they are receiving services.

A recent planning exercise on patient expectations yielded these patient suggestions for health system stakeholders:

1. Allow us to register from home.
2. Allow us to schedule our appointments/tests/procedures from home.
3. Don't make us repeat the same information over and over again.
4. Don't make us walk the entire hospital to obtain services. If an exam uses equipment that is portable, bring the equipment to us.
5. Give us access to clinical information that was obtained as a result of our treatment/test/procedure immediately so the entire health care team can benefit from the information.

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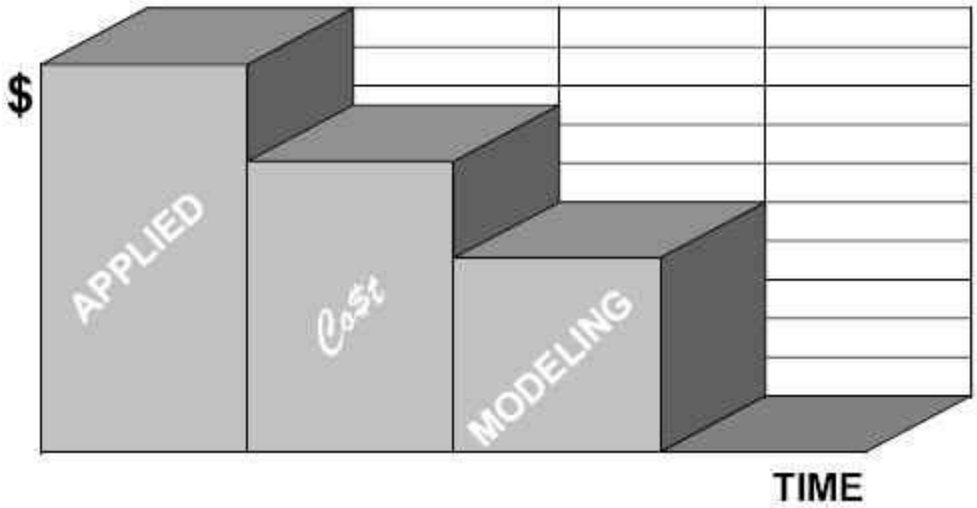

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