PVGroup
an Initiative of SEMI

FEBRUARY 2009

Global Photovoltaic Standards Roadmap Guidance Document

SEMI® International Standards

EXECUTIVE SUMMARY

At the first SEMI PV Group Photovoltaic Committee meeting in early September 2006, executives from the Photovoltaic (PV) industry gathered to discuss where SEMI could contribute most to the growth of the PV industry. One of the major elements mentioned was the need for industry standards at the manufacturing equipment and materials level. Dr. Heinz Ossenbrink, Unit Head Renewable Energies of the European Commission Joint Research Center, stated the need for standards in PV as "Standards in photovoltaic are essential for the industry in order to lower trade barriers and to reduce the cost of ownership for cell and module manufacturers of their production facilities. Both elements are key to reach competitiveness of the photovoltaic industry in a global energy market."

In response to this industry need, SEMI PV Group Standards activities have gained strong momentum over the past two years with Standards Committees, Working Groups, Sub-Working Groups, and Task Forces established in Europe, North America and Asia. In consultation with those Committees, and under the oversight of PV Group Regional Advisory Committees, the determination was made that a forward-looking, anticipative look at technology advancements, research and development efforts and government policies was needed to guide global standards efforts in an efficient and expeditious manner. This document on Phase 1—*Global Photovoltaic Standards Roadmap Guidance Document*—is the outcome of that realization.

SEMI PV GROUP ESTABLISHES CORE TEAM

In May 2008, SEMI PV Group established a Core Team of volunteer experts representing equipment and materials manufacturers, cell makers, third parties and other special interests. The Core Team agreed to support the development of a global Standards Roadmap for photovoltaic (PV) manufacturing processes, from feedstock materials to finished cells and modules with the goal to present a comprehensive draft Roadmap by July 2009. This Guidance Document summarizes the activities and findings of Phase 1 of this effort, including the assessment of 80 categories of SEMI Standards developed for the semiconductor and flat panel display industry—with respect to their applicability and usefulness for PV manufacturing. This exercise will provide immediate benefits to the entire PV manufacturing value chain by identifying already available, proven specifications, test methods and safety guidelines that are providing current value to other industries. While more in-depth reviews of individual standards need to occur, the Core Team feels that by identifying "Applicable" and "Possibly Applicable" SEMI Standards for the PV industry, a solid first step in the right direction has been taken.

The primary objective of this Guidance Document is to communicate to the large and diverse PV manufacturing community an approach to accelerate technology development and sustainable growth in the industry as well as share information about existing solutions that can immediately be applied to the photovoltaic manufacturing process. In particular, this document aims at providing initial sug-

gestions of Standards development and deployment in order to:

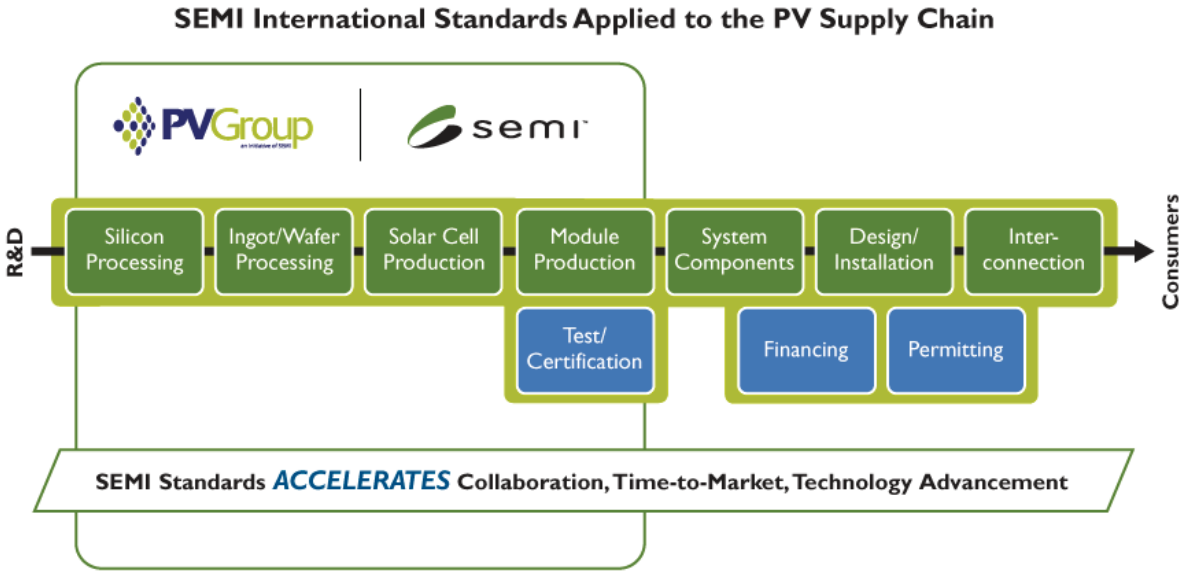
- Reduce manufacturing cost
- Streamline and improve the various elements of the manufacturing process
- Mitigate risks for operating personnel, facilities and the environment
- Create a forward-looking approach to addressing technology advancements, taking into account R&D efforts, government policies and other factors
- Collectively develop global, consensus-driven solutions positively influenced by industry stakeholders

The Guidance Document identifies 80 categories of SEMI Standards that were reviewed for their applicability to the PV manufacturing industry. A total of 64 SEMI Standards topics were judged "Applicable" to the PV industry, among which 31 were rated as "Top Priority" for their potential to deliver immediate cost benefits to the industry with limited revision. Applicable standards areas cover every segment of the PV manufacturing supply chain, including silicon production, wafering, cell manufacturing, and module manufacturing in both front-end and back-end processes. A more detailed review of the nearly 800 individual SEMI Standards and Safety Guidelines is considered a short-term priority.

The Guidance Document further describes planned collaborative initiatives involving other Standards Developing Organizations (SDOs) such as ASTM International, IEEE and others, as well as the increasing participation of research laboratories like the United States National Renewable Energy Laboratory (NREL). and the value of their contributions. It is important to note that the review and assessment of SEMI Standards presents an opportunity to leverage existing and proven solutions to address PV manufacturing challenges. The Core Team does not intend to develop new standards exclusively through the SEMI International Standards Program. Rather, the intended approach is to maximize expertise and volunteer resources where they are currently organized and leverage other SDOs' historic focus areas to collectively and globally pursue the development of new PV standards with a sense of urgency.

THE NEED FOR A GLOBAL PV STANDARDS ROADMAP

Many new and emerging technologies—automotive, semiconductors, flat panel displays, microelectromechanical systems (MEMS)—have developed and prospered, to a great extent because of a shared understanding among their supply chains that reducing the cost of making devices, improving efficiencies along processes and manufacturing steps, and mitigating risks for operators, machinery and the environment are at the core of sustainable growth, globalization and widespread adoption of technology. Industry standards activities are desperately needed in the PV industry to reduce cost and accelerate investment in innovation. Although some standards are



applicable, the PV industry has either been dominated by de-facto standards from dominant players, or has had no standards at all.

SEMI Standards are in a unique position to accelerate appropriate standards activities for the PV industry. First, many semiconductor standards are immediately applicable to the PV industry. Materials and equipment suppliers who serve the display, semiconductor and PV industries do not want to support a new set of communication protocols, labeling requirements, testing metrics, physical interfaces and other features where they add no value to the customer. Second, the SEMI International Standards Program has a proven standards development process with a thirty-five year history, developing nearly 800 Standards and Safety Guidelines, many directly applicable to PV. Third, PV Group Regional Advisory Committees in Europe, North America and Asia, comprised of stakeholders from all segments of the industry, including cell and module makers, have demanded effective standards.

THE BENEFITS OF STANDARDS

Suppliers:

- Reduce product development cost and cycle time
- Avoid unnecessary product variants, allowing for economies of scale
- Increase reliability
- Allow focus on unique value-added features
- Remain at the forefront of technological advancements
- Smooth technology migration

Customers:

- Reduce factory integration costs and production ramp time
- Lower manufacturing and maintenance costs
- Clarify expectations for suppliers
- Enable incremental change at proportional cost

Industry:

- Reduce/eliminate duplication of efforts
- Provide level of commonality
- Promote competition by lowering barriers to entry
- Provide "anonymous" interaction

In order to become a cost-effective energy source, PV needs to lower its costs per energy unit to the same level as current energy sources: i.e., in the range of U.S. $0.25 (20 Euro-cents) per kWh peak in grid-connected systems (price point depends on local conditions and energy price evolution). With cell manufacturing representing approximately 40% of the total system cost, any manufacturing inefficiency in areas such as buffer stock, change of carrier, machine-to-machine communication and process observables for advanced process control needs to be eliminated. It is critical that consensus-based, global Standards are developed and implemented to accelerate the path to grid parity, leading to greater adoption of solar energy and providing the foundation for reducing our dependency on traditional, non-renewable energy sources.

Many semiconductor equipment manufacturers that have diversified into PV are using some existing SEMI Standards, but the PV industry has specialized, unique needs, and a different set of stakeholders. In addition, many customers are increasingly developing custom requirements to support legacy systems that increase costs without delivering manufacturing yield or efficiency. To meet grid parity targets, the PV equipment industry has to intensify their standardization efforts in order to reduce costs and develop an efficient, global supply chain whose R&D investments are focused on innovation. Rather that crudely or informally using semiconductor and other existing industry standards, PV standards must be for, and by, the PV industry. They need to be managed by independent committees comprised of PV industry representatives whose interest lies with the solar power industry.

In response to this need for industry standards, an intensive effort to organize industry stakeholders has been underway since 2006. PV Standards Committees have been formed in Europe, Asia, and North American with numerous task forces and working groups also established. Early on in this effort, it became apparent that a global assessment of existing standards that may be applicable to the PV industry was necessary. It was also determined that the task of prioritizing and coordinating industry standards activities was essential to speed critical initiatives, eliminate redundant activities, provide communications, and provide global guidance.

In response to this need, PV Group established a Core Team of volunteer experts representing equipment and materials manufacturers, cell makers, third parties, standards specialists, and other industry stakeholders. The Core Team agreed to support the development of a Global Standards Roadmap for PV manufacturing processes, from feedstock materials to finished cells and modules with the goal to identify

3-5 PV-focused priority areas where currently no standards exist and present a summary of related development work in progress by July 2009.

ROADMAP CORE TEAM HISTORY

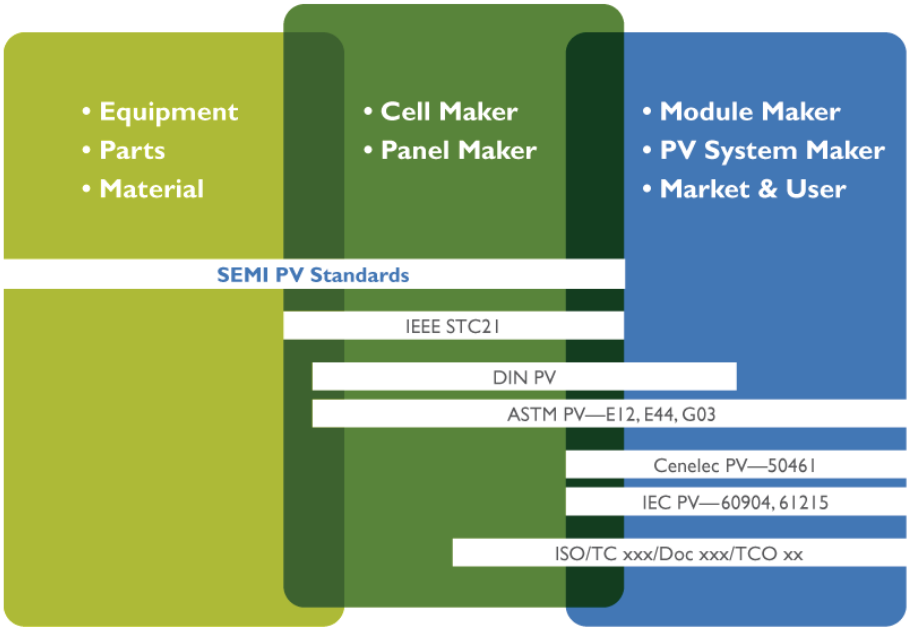
The Core Team was assembled in May 2008 based on inputs from PV Standards Committees, SEMI Standards staff engineers, and regional PV Group Advisory Committees. Selection of the Core Team members was based on the need to have all industry segments participating, standards engineering expertise, familiarity with existing standards applicable to the PV industry, geographic region and the desire to contribute. The following companies are currently represented on the Core Team and are participating in the Standards Roadmap, including the authoring of this Phase 1 Guidance Document:

- Abbie Gregg Inc.
- Applied Materials
- Advanced Energy Inc.
- BayTech-Resor
- Brooks Automation
- Caerus Systems
- Cook Engineering
- Corning
- Dow Corning
- Dupont
- Fraunhofer IPA
- Linde Grop
- Matheson-TriGas
- Oerlikon
- Q-Cells
- SolarWorld USA
- Ulvac
- Underwriters Laboratories
- Additional industry stakeholders who wish to join the effort are most welcome!

In Phase 1 of the Roadmap project, the Core Team determined that a logical first step towards the successful development of a Standards Roadmap was to review what is currently available. The team started by reviewing the existing portfolio of nearly 800 SEMI Standards documents and provide a high-level assessment as to their applicability to PV manufacturing. The following Assessment of SEMI Standards provides for a detailed summary of the findings. Core Team members and SEMI staff have since then reached out to other SDOs, such as ASTM International and IEEE as well as prominent research institutions such as NREL in an attempt to be as comprehensive in approach and implementation as possible.

To assure balanced industry, technology and regional representation, the Core Team believes that additional members and more widespread participation are needed. The Core Team primarily consists of representatives from Europe and North America. In order to deliver on Phase 2—the identification of

Application of International Standards in the Photovoltaic Industry



several high-priority areas specific to PV manufacturing that will benefit from a standardized approach—the Core Team will need to hear from other sources to make sure they identify the "right" issues, and set priorities and timelines in agreement with overall PV industry development needs. Through representative and active stakeholder contributions, more efficient and effective standards development can proceed. Companies and individuals are encouraged to join the standards development work (Committees, Task Forces, Working Groups and Core Team) in their areas of interest. All will benefit from the positive influence of quality industry standards, by developing expertise on subject areas and standards implementation, and through intelligence gained by industry networking.

ASSESSMENT OF SEMI STANDARDS

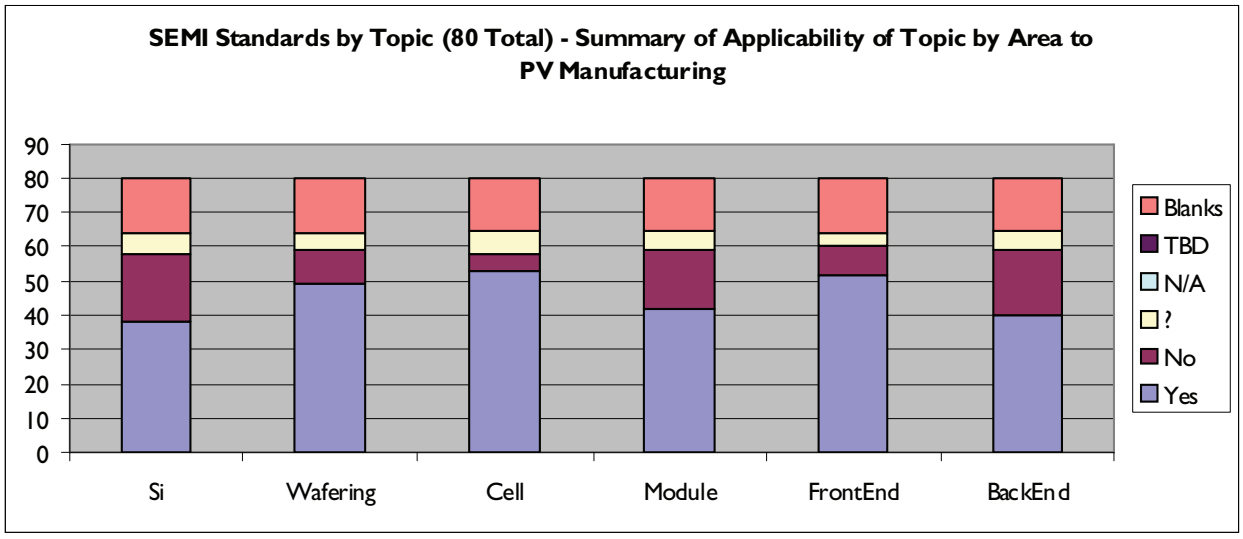
The first task of the Core Team was to determine what existing SEMI Standards were a) immediately applicable to PV, b) applicable with modifications, and c) not applicable. A review 80 topical areas were reviewed and assessed, and produced the following initial findings.

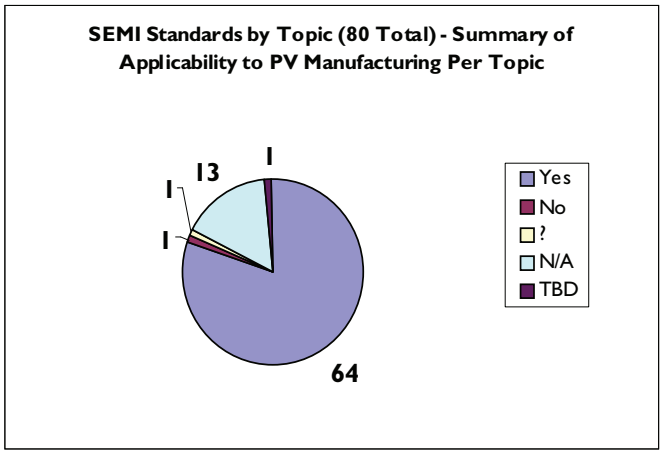
Preliminary Quantifiable Results

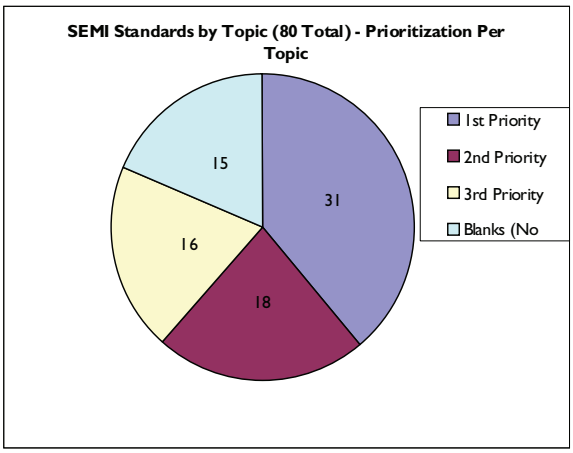
The following graphs and charts are provided for consideration and further discussion:

Figure 1: Summary of Applicability of Topic by Area
Figure 2: Applicability of Standard to PV
Figure 3: Initial Priority of Standard

The graphs illustrate that 80% of existing SEMI Standard topics reviewed (64 of 80) are applicable to PV. (See Attachment 1 for detailed topic information.)







KEY FINDINGS FROM THE PHASE I REVIEW AND ASSESSMENT

300 mm Carriers and Physical Interfaces

This topic includes specifications for wafer carriers, tool load ports for receiving the carriers, and equipment interfaces (hardware and interlock) to facilitate automated loading of the tool load ports. It is believed the PV industry could benefit from establishing a standard carrier that multiple suppliers could produce and all equipment could interface with.

Two questions should be considered prior to PV standards development:

1. Will PV wafer transport be fully automated between process steps?
2. Do the contamination control requirements of PV require a closed (pod) or open (cassette) type approach?

Based on answers to these questions, the appropriate 300 mm wafers standards could be adapted to PV manufacturing. Changes required: size of carrier, thinner wafers, and square orientation. The newly established PV Carrier Task Force (North America) will address these issues in the coming months and coordinate activities with cell manufacturers and suppliers.

Chemical and Gases Purity Topics

In coordination with the Facilities-Related topics, there are 13 (about 16%) that are being focused on by the PV Chemical and Gas Purity Task Force. The goal is to determine cost-savings opportunities as well as standardization of these materials by assessing: 1) manufacturing requirements, 2) process flows, and 3) purity content. A survey will be sent to key manufacturers, and results will be reported in Phase 2. These chemical and gas purity topics include: Chemical and Gas General Specifications; Chemicals and Gas Testing; Chemical Hazards; Gas Particle Specifications; Gas Source Equipment; Gases – Atmospheric; Gases – Noble; Gases – Process; Gases – Specialty; Process Chemicals – Acids; Process Chemicals – Bases; Process Chemicals – Miscellaneous; and Process Chemicals – Solvent.

Device Tracking

Current SEMI Standards cover ID marking symbologies, mark characterization, IDs on wafers, carriers, devices and fixtures. Device tracking is included in Traceability Committee and I&C Committee documents. Much of this appears useful for PV applications. Additional PV-centric wafer, cell and module manufacturing standards are needed. We will use process flows developed for Item 114 to capture and identify the PV operations that can utilize current specifications and those that need new standards.

Equipment Metrics

This section includes guides and specifications for tool load port, tool / automation interfaces, automation contamination control, tool performance (uptime, downtime, through-put, etc.), cost of ownership, OEE, mass flow controllers, etc. Additional PV-centric wafer, cell and module manufacturing standards are needed. We will use process flows developed for Item 114 below to capture, and identify appropriate PV metrics (e.g., yield, etc.), and determine which of the current specifications can be directly applied.

Facilities

Ten of the Facilities related topics are directly applicable to PV (13% of the total). As part of their current activities, the PV Facilities Task Force has determined that there are approximately 130 Standards that can be utilized for PV manufacturing. Many of these documents are guides and test methods, and should be easily converted to PV applications.

Some installation and system-specific guidelines will need to be modified based on:

1. PV chemistries and production materials,
2. PV facilities layouts,
3. PV tool and equipment types, and
4. Work completed by other groups (e.g., gas & chemical systems, safety).

A list of utilities used by PV will be developed and referenced when drafting specifications. Work will continue through 2009 (Phase 2) on assessing these standards. These facilities-related topics include: Chemical and Gas Distribution Systems; Equipment – Facilities Interface; Facilities – Electrical; Fire Safety; Fluorocarbon Components; High Purity Piping Systems; Stainless Steel Components; Surface Mount Gas Distribution Systems; Tubing, Fittings, and Valve; and Ultrapure Water.

Flat Panel Display

Although FPD Color Filters are not applicable, FPD Mask, FPD Polarizing Films, and FPD Substrates topics do apply to PV. Thin film PV fabrication generally uses laser scribing rather than photolithography for patterning. This does not directly apply to PV since polarizing films are typically polymer sheet rather than deposited films. However, optical test method standards may be adaptable to PV. The FPD Substrate topic covers specifications for the size, thickness, flatness, edge condition and chemical

durability of glass substrates; specifications of cassettes and shipping case for horizontal transport and storage of substrates; and specifications of single substrate transfer by AMHS to/from production tools (reference position and orientation, handshaking method). Changes required include much thicker substrate for PV (3-5 mm), and substrate with precoated TCO films. Specifications are needed for PV flat glass and covered glass.

Safety Guidelines

All Safety Guidelines have been deemed applicable to the PV manufacturing process, either partially or in their entirety. Document titles as well as "Purpose" and "Scope" sections will have to be modified to specifically include PV (the current focus of Safety Guidelines is on semiconductor manufacturing). Revisions to these documents or the creation of new Safety Guidelines focused on PV may have to occur in the future.

Silicon

Specifications in this topic include Standards for monocrystalline Silicon (mono-Si), compounds, and other wafer materials, as well as nomenclature for defect inspection and defect identification; specifications for geometric and electrical properties of wafers and films; wafer shippers; lists of applicable SEMI, ASTM, JIS and DIN test methods; extensive terminology; wafer ordering information; and defect limits. Many of these issues are applicable to PV wafers, for which current specifications will need improvement and modification as cell technologies advance.

Missing

1. Si feedstock (as defined by the manufacturing process) specifications and test methods
2. Wafer characteristics from selected production methods
3. PV-centric terms/definitions (e.g. efficiency, lifetime, etc.)
4. Test wafers
5. PV-centric test methods

The Core Team recommends the development of process flows for wafer manufacturing, as well as cell and module manufacturing, to identify critical areas where Standards will benefit users. Note: This recommendation is equally applicable to the thin film process.

Silicon Materials & Process Control (Test Methods)

This topic includes methods for determining electrical, geometrical, contamination and compositional characteristics of silicon wafers and deposited films. Several documents in this category of Standards are applicable to PV wafer manufacturing, however, additional PV-centric wafer, cell and module manufacturing Standards are needed. The Core Team will use the above process flows to capture, identify and specify appropriate test and characterization needs, e.g. carrier lifetime of silicon brick, IR imaging, roughness/subsurface damage, cell conductor grid geometry, TCO film haze, etc.

PHASE 2 OF GLOBAL PV STANDARDS ROADMAP

Phase 2 will begin in January of 2009. The Core Team will focus on:

1. Completing Standards assessment on a more detailed level, also taking into account relevant standards from other SDOs
2. Identifying and prioritizing several areas specific to PV manufacturing where currently no Standards exist but which, based on industry consensus, will benefit from a standardized approach.

The objective of Phase 2 is to develop a comprehensive description of documents applicable to PV (by document) and to get significant Standards development underway with tangible results to be presented in the first Roadmap draft in July 2009. This report (the first draft edition of the Global PV Standards Roadmap) will be released at the Intersolar North America/SEMICON West 2009 exposition and conference in San Francisco.

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CALL FOR ACTION

It is critical that other organizations, research institutions and industry stakeholders join the Core Team—or form their own group in liaison with PV Group—to support, harmonize and drive the efforts going forward. Input and contributions are urgently needed to achieve the Core Team objective and help develop specifications, test methods, safety guidelines and other documentation required to accelerate the growth of the PV industry. The following listing is a "wish list" from the Core Team, listing organizations, research institutes and industry entities that are urged to participate. This list is by no means exhaustive or complete. Anyone with a stake in the PV field is welcome to join the team.

Organizations

- EPIA (EU)*
- VDMA (EU)
- KPRA (Korea)
- SNEIA (China)
- ITRI (Taiwan)
- JPEA (Japan)**

*EPIA is already actively supporting the European PV Standards Committee in SEMI
**JPEA is partnering with SEMI PV Group for the PVJapan expositions

Applied Research

- Forschungszentrum Juelich (EU)
- Fraunhofer IPA
- NIST (NA)
- Sandia National Labs (NA)

Other Regional Institutes From

- Japan
- Korea
- Taiwan (ITRI)
- China

Equipment Suppliers

- Entegris
- Others

Materials Suppliers

- Linde
- Wacker
- MEMC
- Others

Cell/Module Manufacturers

- Deutsche Solar
- Deutsche Cell
- Trina Solar
- First Solar
- SunPower

Other cell/module manufacturers from other regions

- China
- Taiwan
- Korea
- Japan
- Others

PV STANDARDS ACTIVITIES

(as part of the SEMI International Standards Program (Europe, N. America, Taiwan)

To provide additional context for the work of the Core Team, this section gives a brief overview of the PV standardization activities in the SEMI International Standards Program. Standards Committees in the SEMI International Standards Program are global by nature, with regional "chapters" to accommodate time zones and more localized efforts. All voting members of a global committee are required to cast their vote on all draft documents ("ballots") issued by that committee, regardless of the region in which it originated. The global Photovoltaics Standards Committee is actively developing standards in Europe, North America and Taiwan. Hopefully, other regions such as China and Japan will join these initiatives shortly.

Standards development has been on the forefront of major technology development as well as the expansion into related new fields. While SEMI Standards were initially developed primarily for the semiconductor manufacturing process, the SEMI International Standards Program, in its 35-year history, has expanded to accompany and support industry stakeholders in entering related fields such as FPD, MEMS and now PV.

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CONCLUSION

The assessment of published Standards with respect to their applicability and usefulness to PV was a critical first exercise that is still in progress. The Core Team will remain focused on the objectives set out in this document.

This Guidance Document does not aim to be complete or thoroughly comprehensive at this stage. Much more analysis, discussion and industry engagement is needed. But it is a critical first step in a rational, open, and global process for manufacturing cost reduction and standards-driven technology development for the industry. The purpose of this document is to make the global PV industry community aware of currently available Standards that can and should be adopted from other related manufacturing technologies. The Core Team feels that time is of the essence to stabilize and sustain the current growth in the PV industry worldwide and standards development and adoption is key to this outcome. Development and adoption of global standards must be a high priority in order to ensure that industry resources are focused on manufacturing challenges that generate unnecessary cost, on the development of common measurement and testing parameters for novel materials, on the integration of systems, subsystems and processes, and on other issues that hinder the continued growth and worldwide adoption of PV technology.

The PV Standards Roadmap Core Team enthusiastically welcomes and encourages additional stakeholders—from industry, academia and other SDOs—to participate in the process. To learn more about the Core Team and how to join, please contact Bettina Weiss, Sr. Director, Photovoltaic Segment at SEMI PV Group at bweiss@semi.org.

Visit us at www.pvgroup.org to learn more about PV Group.

THE GLOBAL PV STANDARDS COMMITTEE CHARTER

Explore, evaluate, discuss, and create consensus-based standard measurement methods, specifications, guidelines, and practices that, through voluntary compliance, will promote mutual understanding and improved communication between users and suppliers of photovoltaic manufacturing equipment, materials and services to enhance the manufacturing efficiency and capability in order to reduce manufacturing cost in the photovoltaic (PV) industry.

There are active PV Standards Committees and Task Forces in Europe and North America, and a growing Working Group with subgroups in Taiwan. Taiwan is expected to petition for full committee status to the International Standards Committee (ISC) by July 2009.

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ATTACHMENT 1—REVIEW OF 80 TOPICAL AREAS

Standards Topics—APPLICABLE to PV

300 mm carriers and physical interfaces	Automated Material Handling Systems	Ball Grid Arrays	Chemical and Gas Distribution Systems
Chemical and Gas General Specs	Chemicals and Gas Testing	Chemical Hazards	Chip Carriers
CIM Framework	Cluster Tools	Device Tracking	Documentation/Training
Electromagnetic Compatibility	Electronic Data Interchange	Equipment Communications:	Equipment Metrics:
Equipment Models:	Equipment Process Control	Equipment – Facilities Interface	Facilities – Electrical
Fire Safety	Fluorocarbon Component	FPD Polarizing Films	FPD Substrates
Gallium Arsenide	Gas Particle Specifications	Gas Source Equipment	Gases – Atmospheric
Gases – Noble	Gases – Process	Gases – Specialty	High Purity Piping Systems:
Human-Machine Interfaces	Indium Phosphide Wafers	Jig ID	Leadframes
Mass Flow Controllers	Minienvironments	Photolithography	Metrology
Photoresist	Physical Interfaces	Process Chemicals – Acids	Process Chemicals – Bases
Process Chemicals – Miscellaneous	Process Chemicals – Solvent	Radio Frequency Identification (RFID	Reticle Data Management
Safety Guidelines	Scanning Surface Inspection Systems	SiC	Silicon
Silicon Materials & Process Control (Test Methods)	Stainless Steel Components	Statistical Control	Surface Mount Gas Distribution Systems
Terminology	Tubing, Fittings, and Valve	Ultrapure Water	Wafer Edge Profile
Wafer Marking:	Wafer Probers	Wafer Shipping System	XML (eXtensible Markup Language)
Unclassified			

Standards Topics—POSSIBLY Applicable to PV

300 mm Packaging	FPD Color Filters	LCD Backlight Unit	Mask and Mask Equipment
MEMS	MEMS Micro Fluidic	Molding Compounds	Package and Chip Carrier Tooling
Package Specifications	Sensor Actuator Network	Silicon on Insulator	Substrate Carriers and Pods

Standards Topics—NOT Applicable to PV

Automated Test Equipment	FPD Masks	Lead Finishes	Package Test Methods