

A large, glowing green light bulb is the central focus of the cover. A monarch butterfly with black and orange wings is perched on the top rim of the bulb. The background is dark, making the glowing bulb and the butterfly stand out. The overall theme is innovation and technology.

# INTERNATIONAL STANDARDIZATION AS A STRATEGIC TOOL

**Benefits of standardization  
in the microelectronics industries and  
their implications on nanotechnology  
and other innovative industries**

**By Werner Bergholz, lead author;  
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Werner Bergholz graduated in Physics from Göttingen University, Germany, in 1975. After 10 years of research in semiconductor and material physics in Göttingen, Aarhus, Denmark and Oxford, United Kingdom, he joined the Siemens semiconductor division in 1985. Following various positions in research, procurement and production (since 1999 in Infineon Technologies), Werner accepted a Professorship of Electrical Engineering at the International University, Bremen in 2002. His research topics include defects in semiconductors, failure mechanisms in integrated circuits, quality and productivity engineering and the development of industry standards. He is also active as a consultant in these areas.

Werner's participation in the SEMI (Semiconductor Equipment and Materials Institute) standards programme dates to 1996. He is Co-chairman of the Silicon Wafer Technical Committee and Co-chairman of the European Regional Standards Committee; he is also active in the area of nanotechnology standardization with DIN (Deutsches Institut für Normung) and DKE (Deutsche Kommission für Elektrotechnik Elektronik Informationstechnik).



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Bettina has been working in the semiconductor industry for more than 15 years. She joined the SEMI organization in January 1996 in the SEMI Europe office in Brussels, Belgium as Standards Coordinator. In spring 1997, she transferred to SEMI Global Headquarters in San Jose, California as Standards Development Specialist and, in 2000, became Manager, Program Development where she was responsible for the expansion of the SEMI International Standards Program into new technologies and new regions. In November 2003, she accepted the position of Director, International Standards as chief staff of the SEMI International Standards Program. In this capacity, she has been responsible for strategic planning, execution of SEMI Board of Director directives, policy and advocacy issues for Standards, regional support of implementation and activity growth and other areas.

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## **International University Bremen, Germany**

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# Benefits of standardization in the microelectronics industries and their implications on nanotechnology and other innovative industries

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## Summary

*Standards development in the microelectronics industry has started in the 1970s and has been one of the key enablers for the industry to move from lab to fab. This paper analyzes the experience from building up a portfolio of over 740 industry standards within the Semiconductor Equipment and Materials International (SEMI) International Standards Program and develops a quality management-based (QM) model for standardization development based on ISO 9001:2000 QM standard principles and the EFQM model of Business Excellence. The key feature of this model is that standards development must mirror the way production processes are developed and improved, since it can be viewed as an industry-wide sharing of best practice approaches for part of the value-adding chain in that industry, to the benefit of all stakeholders including end users. As an example, the process must start with a quality function deployment (QFD)–like process to identify the optimum concept for the users of the prospective standard. One unexpected result of a user survey was that SEMI standards are not only used for procurement and production purposes but that knowledge management applications (training, technical documentation, etc.) are deemed even more important. This model is applied to the emerging nanotechnology industry. In addition to terminology, material characterization and environment, health and safety standards, product performance standards are urgently needed, in particular for electronic products. Due to the commonality between microelectronics and nanotechnology, a “reuse” of SEMI standards technical content and experience can significantly accelerate the development of such standards. This paper proposes the launch of a global initiative to create a suite of anticipatory standards, similar to the recent I300I initiative which supported the transition from a 200 mm to a 300 mm wafer diameter in the microelectronics industry.*

## 1 Introduction

Since the early 1970s, the microelectronics industry has grown from little more than a US\$ 1 billion in laboratory-style manufacturing for high-end military and space applications to an industry now approaching the US\$ 300 billion mark, with an average compound annual growth rate of 14%. There is general consensus that there are primary driving forces responsible for this success. Some compare it to the impact of steam power invented by James Watt or to electricity generation and distribution by Werner von Siemens and Thomas Alva Edison. These forces include

- dramatic increases in productivity due to continuous reduction of design rules (Moore’s Law, Figure 1) [2]<sup>1</sup> and the increase in wafer size;
- improvements in circuit performance.

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<sup>1</sup> Figures in square brackets refer to the Bibliography.

These dramatic improvements in productivity and quality of integrated circuits have not only led to a complete new range of electronic products of consumer and industrial applications. In the digital (r)evolution age, they have also changed the way manufacturing and logistics are organized, and our overall approach to doing business [2, 3]; there is no end in sight of this extraordinary market growth

Another important contributor, which has had a “turbo charge effect” to drive microelectronics up the industrial learning curve, is less visible: Standardization. It started in the early 1970s and has since then moved into all relevant areas of the microelectronics supply chain.

It is the purpose of this paper to analyze standardization activities in microelectronics, mainly based on the SEMI standards portfolio, with the following aspects and objectives in mind.

- Standardization is closely related to quality management (QM). This will become evident as we take a closer look at the standards development process.
- Success factors and lessons learned.
- Application to the emerging nanotechnologies.

## **2 Review of SEMI Standards Activities**

### **2.1 The first “island” solution**

In the 1950s and 1960s, several scattered efforts undertaken by Institute of Electrical and Electronics Engineers (IEEE), the Japan Electronics Industry Development Association (JEIDA), now JEITA and the American Society for Testing and Materials (ASTM) to develop standards around material characterization and clean room conditions marked the very beginnings of standardization in the semiconductor industry.

In May 1973, Semiconductor Equipment and Materials International (SEMI), which had been founded three years prior as an industry association of semiconductor equipment and materials suppliers took the initiative to create standards for two- and three-inch wafers – primarily as an emergency measure: At that point in time the industry had to cope with over 2,000 user-specific wafer specifications, with extremely undesirable consequences from an economic, productivity and quality standpoint. Due to the rapid expansion of the industry in the early 1970s, there was a silicon shortage. The problems and the waste did not end there. Due to the different wafer geometries, equipment manufacturers had to supply individual and tailored solutions for almost every customer.

In retrospect, it is therefore not surprising that by 1974, the first draft standards for two- and three-inch silicon wafers had a very high acceptance rate: 80% to 85% of all silicon wafers used in this young industry complied with the SEMI standard.

### **2.2 Internationalization and the “Tower of Babel”**

By the early 1980s, standards had been developed for equipment, chemicals, and other materials. It has been estimated that, through standardization of chemical specifications, the cost for analytics was reduced by 60%, and productivity gains improved the availability of chemicals significantly.

Until 1980, the SEMI Standards Program was primarily a US-based organization. The VLSI initiative in Japan and the expanding microelectronics industry in Europe triggered parallel standardization activities of JEIDA and the Deutsches Institut für Normung (DIN), leading to regular liaison activities among SEMI, JEIDA, ASTM and DIN. Of similar impact as the first silicon standards were the SECS-I (SEMI Equipment Communications Standard) and SECS-II standards for factory communication, a collaborative effort by SEMI and JEIDA. SECS-I and SECS-II standardized the communication between the equipment computers and the computers of the factory shop floor Manufacturing Execution System (MES), introducing a common software language among the components and making tool/host interactions easier and more efficient. The “Tower of Babel” in semiconductor factories became a thing of the past. Later, the GEM (Generic Equipment Model)-SECS standards further improved communication between

equipments of different suppliers and the MES system, and it is estimated that the cost for host site software was reduced by 80% compared to pre-GEM-SECS times.

### 2.3 Environment, Health and Safety

From today's perspective, it is surprising that safety standards for equipment were not among the first to be developed. The creation of the SEMI S2 Safety Guideline (Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment) in the early 1990s was another milestone for the industry in terms of utilizing the potential savings by standardization and, in this case, increasing operator and equipment safety to a standard industry level and beyond.

As an example, in 1993 Intel used the SEMI S2 standard for the first time for their selection of tools for 200 mm Fab 10 in Ireland. It is estimated that on average start-up time for the tools was reduced by two weeks, resulting in an overall saving of US\$ 6 million for that fab, which was of the order of 1% of the total cost.

Nowadays, any equipment manufacturer will have a hard time to sell equipment not compliant to SEMI S2, so these savings continue to bear fruit for any new fab.

### 2.4 200 mm and 300 mm wafers transitions

The transition from 150 mm to 200 mm wafers to increase productivity and yield occurred in the early 1990s, an opportunity for standardization the industry unfortunately missed.

Initially, two different thicknesses (725  $\mu\text{m}$  and 737  $\mu\text{m}$ ) had been introduced, and the number of edge profile specifications exceeded 200, with no apparent technical advantage. More expensive silicon and shortages were not the only problems caused by the lack of standardization. Robotics for equipments had to be very complex to accommodate different wafer thicknesses. They also had to accommodate different tool heights and footprints. Such circumstances made the dream of an automated fab impossible.

Learning from the missed opportunity, at the beginning of the transition from 200 mm to 300 mm, there was industry consensus that this time standards for 300 mm wafers, equipment, wafer carriers, handling equipment etc. were to be developed before the cutting of any metal for equipment of pilot production of silicon wafers. In other words, the objective was to develop anticipative standards to facilitate the transition to the next generation wafer size.

The International 300 mm Initiative (I300I) under the umbrella of SEMI and Sematech (1995-2001), led to the development of a comprehensive suite of 300mm standards, including new hardware and software standards to improve factory automation and integration. By and large, the goals of developing consensus-based, global standards which represented best practice both in terms of technology and cost reduction at the time were achieved.

In retrospect, the development of the 300 mm standards portfolio was the best overall concept for production selected from a large number of potential realizations in terms of cost, process stability and robustness, serviceability and other important factors. In other words, a form of generic production process had been designed by the consortia, which was a kind of best practice at the time. The analogy to the QM tool "Quality Function Deployment (QFD)" is obvious. [4]

Not surprisingly, a survey among wafer fabs showed that the use of SEMI standards had increased with the transition to 300 mm, and only 4% reported a decrease (Figure 2a). A survey conducted in 2004 showed that only 7% of all microelectronics companies do not use SEMI standards in their business transactions with suppliers.

An estimate of the total cost savings is difficult to obtain since such data is company confidential. It is clear, however, that many millions of US\$ per fab were saved – the ultimate contribution to competitiveness and quality for the benefit of the device manufacturers and all supply chain participants, including society at large.

### **3 A model for the development and application of standards, based on experience with SEMI standards in the microelectronics industry**

In a competitive and global economy, the various parts of the manufacturing food chain need to be continuously improved. In fact, continuous improvement is one of the pivotal points of the ISO 9001 Quality Management standard.

Developing a standard or suite of standards (as in I300I) and integrating them into a production process is a way to optimize the value-adding chain on an industry-wide scale rather than a company-wide scale. The development of standards for the microelectronics industry since the 1970s has been a joint effort of industry stakeholders to improve the manufacturing process and reduce cost.

More to the point, standards development entails the selection of segments of the value chain which, through standardization, are optimized, resulting in better, faster and more cost-effective manufacturing.

From this analogy, it can be deduced that QM tools used to improve manufacturing processes must mirror the standards development process, since both are essentially part of the production process development. The two most popular QM tools used in industry are the ISO 9001:2000 standard and Total Quality Management (TQM). For TQM, there are mainly three different models used worldwide: The Deming Prize in Japan, the Malcolm Baldrige Award in the US and the EFQM Model (European Foundation for Quality Management) in Europe. We chose to apply the EFQM model (which is the most recent of the three) to model the standards development process at SEMI (a worldwide standardization of the TQM models has started).

#### **3.1 Systematic evaluation of the standards development process**

As in most standards development organizations, the standards development process consists of the following steps.

1. Decide on a standards project.
2. Work in a task force until consensus has been reached.
3. Approve the document according to a defined voting procedure.
4. Audit the process through an independent committee.
5. Publish the final document.

A literature search reveals that almost all standards-developing organisations encounter certain challenges in their development process, such as the amount of time required for the development of the standard, the lack of volunteers and support by their companies, or standards not meeting the original intent or satisfying the original need [6].

To identify improvement potentials, the Quality Function Deployment tool was applied in a simplified form.

##### **3.1.1 QFD [4] and the “Voice of the customer”:**

A comprehensive approach to speed up standards development and to improve its technical quality can be derived from the QM tool “Quality Function Deployment”. At the core of QFD is a systematic, matrix-based technique which translates customer and user requirements into technical concepts. The important step before starting the actual development process is to assess a number of different concepts to implement the customer requirements in terms of difficulty of development, usability in production and services, and, in addition, robustness. This way, it is ensured that a technical committee does not lose too much time by pursuing an inappropriate project. QFD is the direct path towards the optimum concept. This technique has been pioneered in the Japanese car industry in the 1970s and 1980s and recently helped to cut down the development time of the Toyota Prius hybrid car to 13 months only [5].

One of the most important changes in the revision to ISO 9001 in 2000 was therefore to strengthen the role and the voice of the customer. It is in this spirit that the SEMI standards development process is being redesigned.

In the past, SEMI standards work was not always focused on the users of standards, and the decision on what kind of standard to develop was sometimes left to well-meaning volunteers, who nevertheless often had too technical a view and did not see the “big picture”. To address these shortcomings, two improvements are in the implementation phase within the SEMI International Standards Program:

- Since 2004, every project is ranked according to urgency of need, effect on the industry, and estimated technical difficulty. On the basis of these parameters, it is decided whether to proceed further with the proposed activity or not.
- SEMI established the Manufacturing Technology Forum (MTF), a pre-standards forum to discuss needs and economic benefits before user requirements are issued, in order to develop a mutual understanding of how technology challenges are interpreted and resolved jointly.
- QFD principles are used to identify and select the best technical concepts

### **3.1.2 Managing the business process of standards development for continuous improvement of efficiency and effectiveness**

A key performance indicator for the efficiency of standards development is development time. Development times between five and seven years are not uncommon for the development of international standards. By comparison, development times for SEMI’s international standards (Figure 3) are relatively short, with an average of two years and possible in as little as nine months. All the same, in view of how fast the industry moves, it is still too long.

To this end, SEMI is addressing the main bottlenecks of standards development. The frequency at which face-to-face meetings were held used to be an important element, but the allocation of time and travelling cost required to attend had a negative impact on the level of participation. Nowadays, the possibilities of IT technologies for virtual meetings are being integrated into the process in order to expedite the development of the standard, while at the same time maintaining a minimum of face-to-face meeting to ensure traditional human interaction and group dynamics. Trade shows and other international events organized by SEMI provide a convenient opportunity for such working sessions, since many volunteers have to travel to these events anyway. It is realistic to expect that, by the full use of IT technology, the development time for standards can still be reduced by up to 50%.

The effectiveness of standards is best measured by the degree of industry acceptance and usage of the standards. The results of a recent SEMI survey were, by and large, positive, but also revealed some weak areas with a lot of potential for improvement. These results will be addressed in detail in 3.2.

### **3.1.3 Quality check and traceability**

In the development of a standard, great care has to be taken that the consensus and voting procedures laid down in the rules are strictly adhered to and documented. This audit process is taken care of in the SEMI standards program by a global Audit and Review Subcommittee via an e-mail and on-line voting procedure. Experience has shown that, in addition to the quality check there is another advantage in using this process: the review, which takes place seven times a year, allows for e-mail discussion for a period of two weeks, where members of the global Audit and Review Subcommittee identify issues and address them in a team effort together with the responsible chairpersons. In 70% of all cases, such issues can be resolved during this two-week period, avoiding costly delays in publication and deployment time. In addition, there is a continuous improvement of the procedures to make the process more fail-safe.

Traceability is a key QM requirement of ISO 9001. For standards development and historic data tracking and maintenance, the following mechanism has been implemented: all committee

documentation is in a repository. Whenever a standard is revised, the changes are summarized in a revision history table which is part of the standard. It contains the information about the relevant task force, technical committee and voting documents, should it be necessary to trace the evolution of the standard in detail.

Since a standard is an integral part of the value chain in the production process, it was deemed critical to have full traceability in case of any technical or legal issue in connection with a particular product. This is particularly important as microelectronic products are used extensively in the automotive, airline and medical industries.

### 3.1.4 TQM originated improvements

With the European Regional Standards Committee (ERSC) at SEMI, the EFQM model has been used for the last five years, resulting in a number of improvements, the most important ones of which are as follows:

- Development of a mission, vision and value statements
- Annual management self-assessment
- Recognition and appreciation to the volunteers through the establishment of a European annual awards program and appreciation expressed to the management of the standards leadership
- Team-building events
- Planning sufficient time for networking and informal exchange of opinions and technical trends during the standards meetings
- Increasing training of the volunteers in the standards procedures in order to improve the efficiency of standards work.
- Increased engagement of the device manufacturing community by developing relevant technical conferences on standards-related technology or industry issues, and holding the event close to their facilities

As a result of these actions, participation in standards development work has increased significantly.

### 3.2 Perceived benefits of microelectronics standards – do they fulfil user expectations?

As ISO 9001 prescribes, it has to be determined that a particular product or service is what the customers really need. To that end, SEMI developed a questionnaire that was distributed to all SEMI member companies to survey the perceived benefit of SEMI standards to the industry. One of the key results was that 98% of all companies use SEMI standards in some form (not necessarily for procurement), 77% use them frequently or extensively (Figure 4). The large majority of companies stated that they had experienced a significant reduction in cycle times through the use of standards (Figure 5).

In a study by DIN [7] more tangible results were reported. The Volkswagen Motor Company could save between 20 and 60% in manufacturing cost if they were using standard rather than custom-built parts for their Golf models. Airbus industries reported savings up to a factor of 15 by switching from custom to standard parts. An excellent description of the impact standards have had on the industrialized world and their all-encompassing nature can be found in a paper by Reuter and Muller-Esner [8]

One surprising result from the SEMI survey was that the use of standards for procurement purposes was significant; however, the use of standards for training, technical documentation and knowledge management was even more frequently mentioned. This has been highlighted in an “Iceberg Model” (Figure 6) for the benefits and utilization of standards, i.e. the larger part of the benefit and utilization of SEMI standards was invisible before the survey was conducted.

### 3.3 Standard and innovation: Incompatible?

It could be argued that a highly innovative industry should not be forced into the constraints of standards, since the optimum technical solutions may only evolve if there is enough freedom to try out different concepts and solutions in practice. There is also a concern of the possible sharing of intellectual property information (a critical asset for companies in the high-tech industry) in the development of an industry standard.

This paper argues to the contrary. If the development of a standard is properly managed at the early stages of technological development, the industrial learning curve progress accelerates, benefiting all parties involved, in particular the end users. At the same time, there is ample room for competition in terms of product design, intelligent and robust processes, defect reduction strategies, etc.

1. The development of standards prior to any production or large-scale development work can be viewed as pre-competitive best practice sharing among industry participants based on existing technologies.
2. The joint anticipatory development of a suite of relevant standards for production on 300mm wafers was effectively a joint Quality Function Deployment operation (as mentioned before). As a result, the production process was significantly improved compared to the 200mm technology transition right from the beginning. One example is that through the rigorous adherence to the concept of a defined quality area within the 294mm circle on a 300mm wafer, the yields on 300mm wafers were dramatically more homogenous over the wafer than in all previous wafer generations.
3. Through early standardization, the development task for equipment and materials manufacturers was well-defined and not hindered by a multitude of different requirements from different customers. Development was faster and the availability of sufficient wafers and equipment was never significantly disturbed. Although figures about cost/prices are not available, there is anecdotal evidence that the original ambitious target for cost digression curves was in effect overtaken by reality.
4. Progressing through the industrial learning curve is easier if there are large numbers of the same type of wafers or equipment. If there is a defined base level for performance enabled by standardization, the fine-tuning of the process is facilitated since there is no large variability of the manufacturing processes through frequent set-up changes.
5. The networking aspect and the availability of a neutral forum to express new ideas and discuss technology trends does support innovation. This has also been found in the DIN study [7].

In some cases, the standards turned out not to be the optimum solution, or new technical insights were gained that impacted the original draft. This is acceptable if the standards are updated in a timely manner and through a well organized change management process (another standard QM tool).

The concern regarding IP has been addressed within the framework of the SEMI standards program by an IP check and by disclosing potential IP issues early and publicly in the development process with the goal to avoid IP in a standard wherever possible. If this is prevented by technical reasons, a waiver is sought from the owner of the IP.

## 4 Application of the QM-based model for standards development to nanotechnologies

Standards development work in emerging fields such as nanotechnologies could have an even higher growth potential than in the microelectronics industry. Standards are recently being developed and initially focus on the following three aspects:

- a) Terminology;
- b) Environmental, Health and Safety (EHS) issues;
- c) Analysis and characterization techniques.

By applying the standards development model developed in 3 to nanotechnology, the following conclusions can be drawn:

The initial steps taken by national and international standard development organizations are the right ones.

- EHS must have high priority to address public concerns and ensure safe technologies.
- Terminology and analysis and characterization techniques are necessary pre-requisites for any procurement specification for nano materials and also deserve a high degree of attention.

In addition, the following further recommendations can be derived.

- Microelectronics is now approaching design rules of 45 nm which, by definition, is part of nanotechnology. Many of the SEMI EHS and other characterization standards can therefore be considered nanotechnology standards. When new nanotechnology standard activities are proposed by standards development organizations, existing SEMI standards should first be reviewed to identify those that could possibly be adapted, modified or even used in their original form. This may be particularly relevant for the characterization of small particles, structures, thin layers and structural defects.
- While there are nanotechnology products already on the market (paints, stain-resistant garments, etc.), there are no standards for the characterization of the actual product performance; neither is there any substantial work on the relation between product performance and key control characteristics of nano materials. The work on such standards is urgent since quality managed production, a pre-requisite for many industries, would be difficult, if not impossible, if these types of standards did not exist.
- Nanotechnology standards are urgently needed - yet the development time can be anticipated to be of the order of five years. This appears far too long for this highly innovative field. Therefore, it is proposed to create a fast track for standards development, by benchmarking the standards development processes of selected standard development organizations. Development times of less than two years are possible. Moreover, applying QFD principles should be applied for efficiently selecting the best concept. Last but not least, team-building and other aspects of group dynamics should be included, using well-proven TQM principles. These techniques will also facilitate the consensus process.
- Creation of a worldwide consortium similar to I3001 to produce a suite of standards similar to I3001.

Microelectronics has shown that late standards, or none at all, are costly for everybody, and early, anticipative standardization is a win-win situation. There is an urgent need for action to enhance and expedite nanotechnology standards development now.

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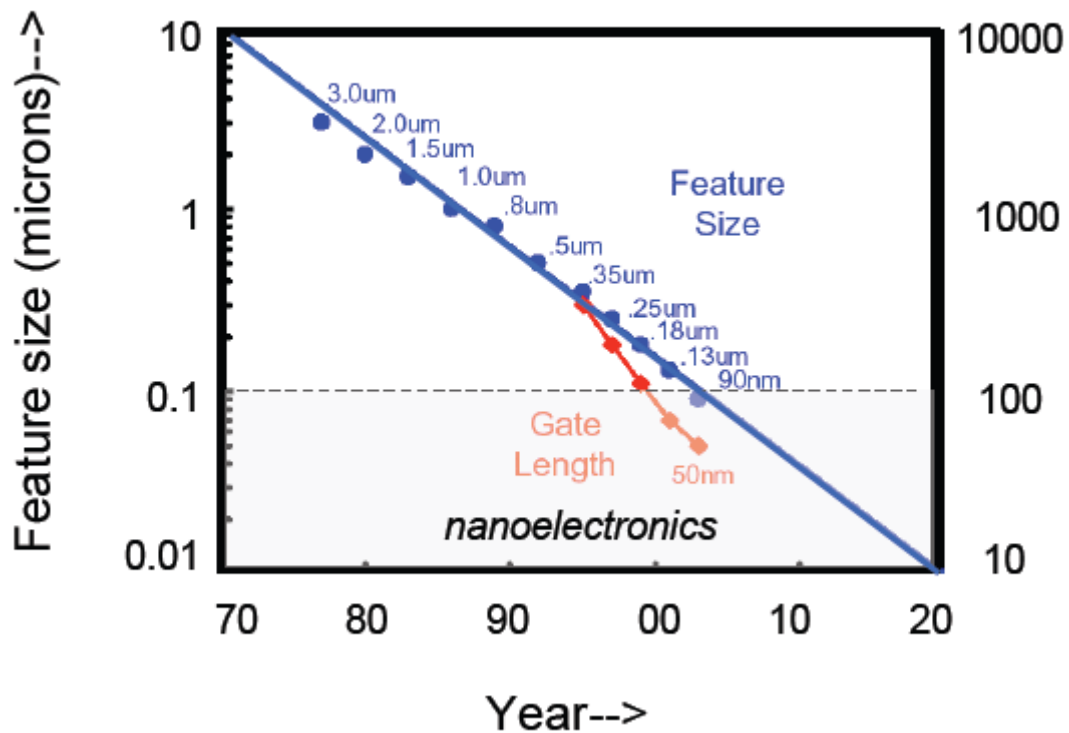
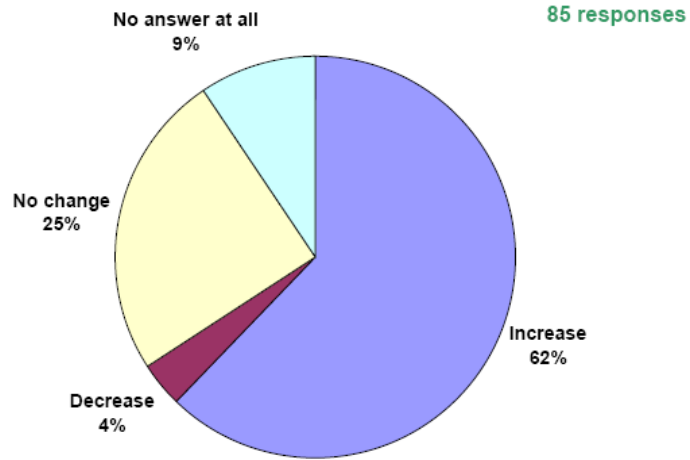


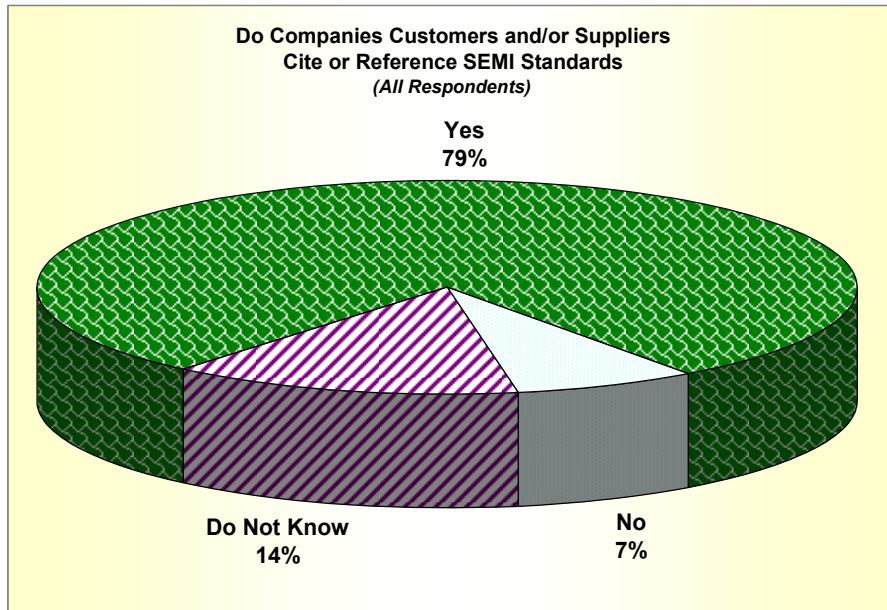
Figure 1 – Illustration of Moore's law:

By shrinking the minimum feature size over the last 3 decades, the number of transistors (functions) per chip doubled every 18-24 months. Since the cost for processing the chips is, at a first approximation, independent of the feature size, the gains in productivity are a major cost reduction tool. (In addition, productivity gains/cost reductions have been achieved by an increase in the wafer diameter.)

Has the Availability of 300 mm Standards Increased or Decreased Your Use of SEMI Standards Over the Last Four Years?



**Figure 2a – Increase in use of standards (300 mm standards have significantly increased the use of standards in the semiconductor industry)**



**Figure 2b – Use of SEMI standards in business documentation with suppliers (79% of all responding companies use SEMI standards, 7% do not.)**

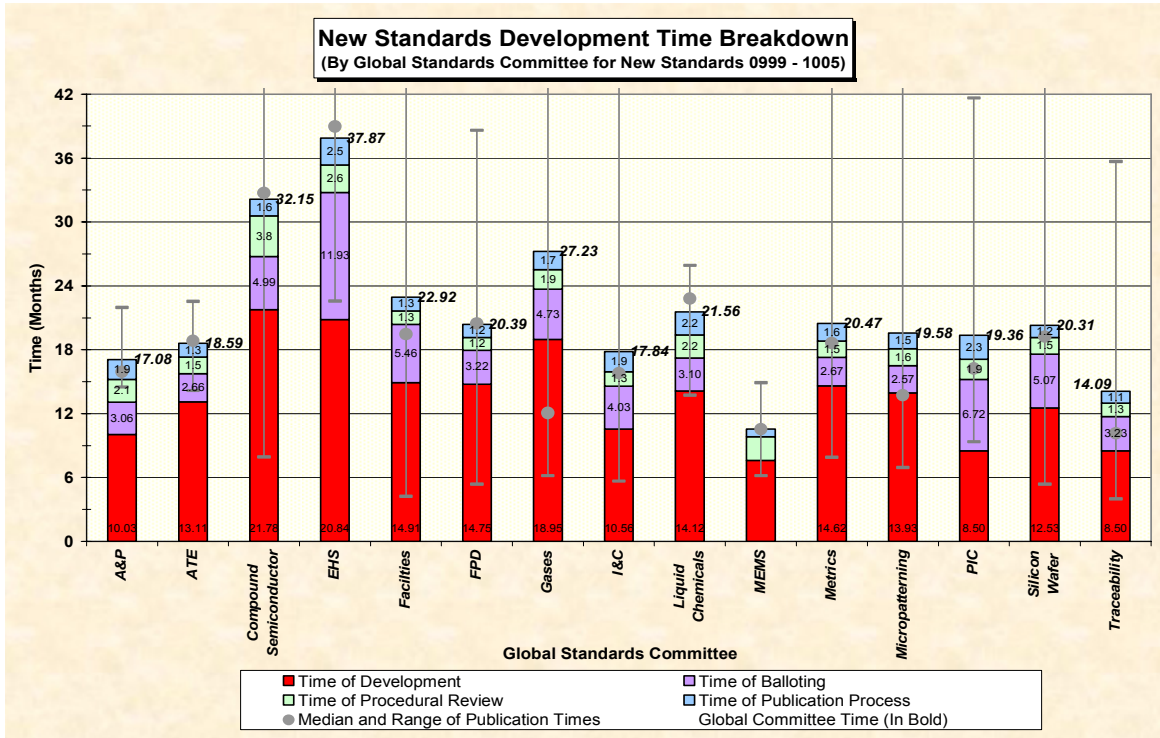


Figure 3 – Development times for SEMI standards, broken down according to the development steps. It shows that the total development time for new standards is about 2 years, with EHS being the longest (for good reasons)

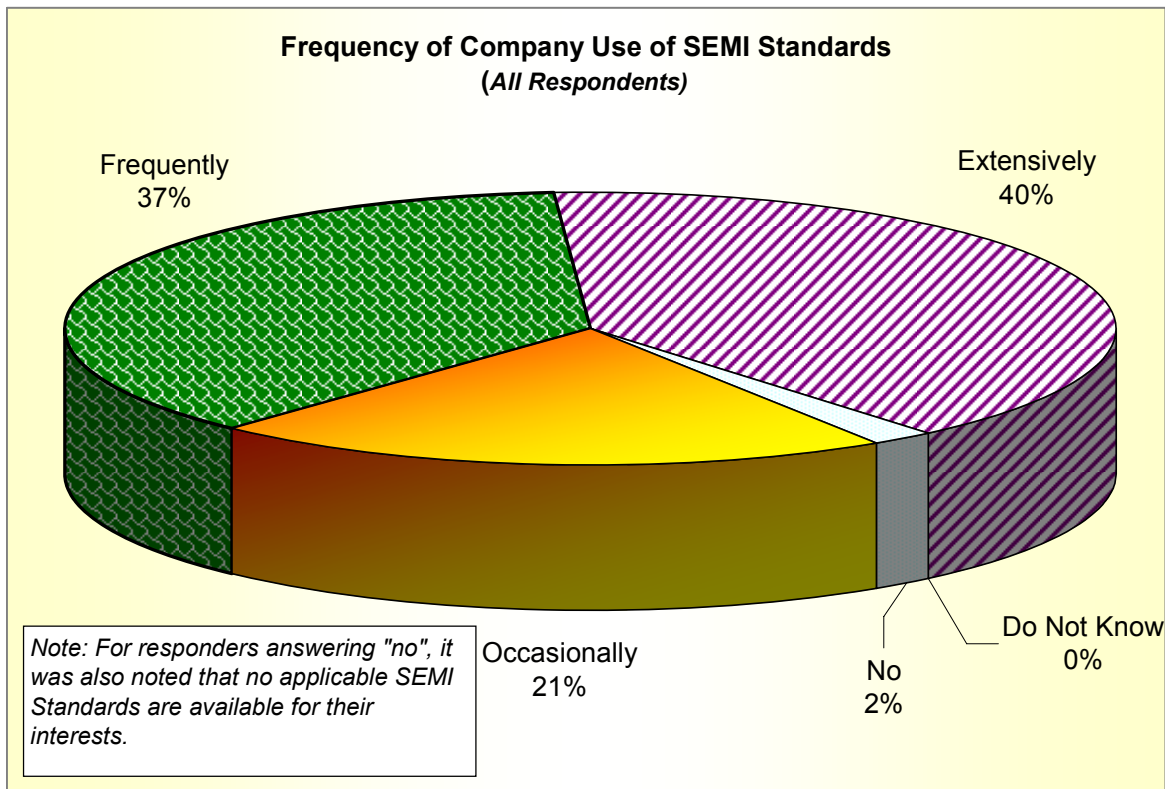
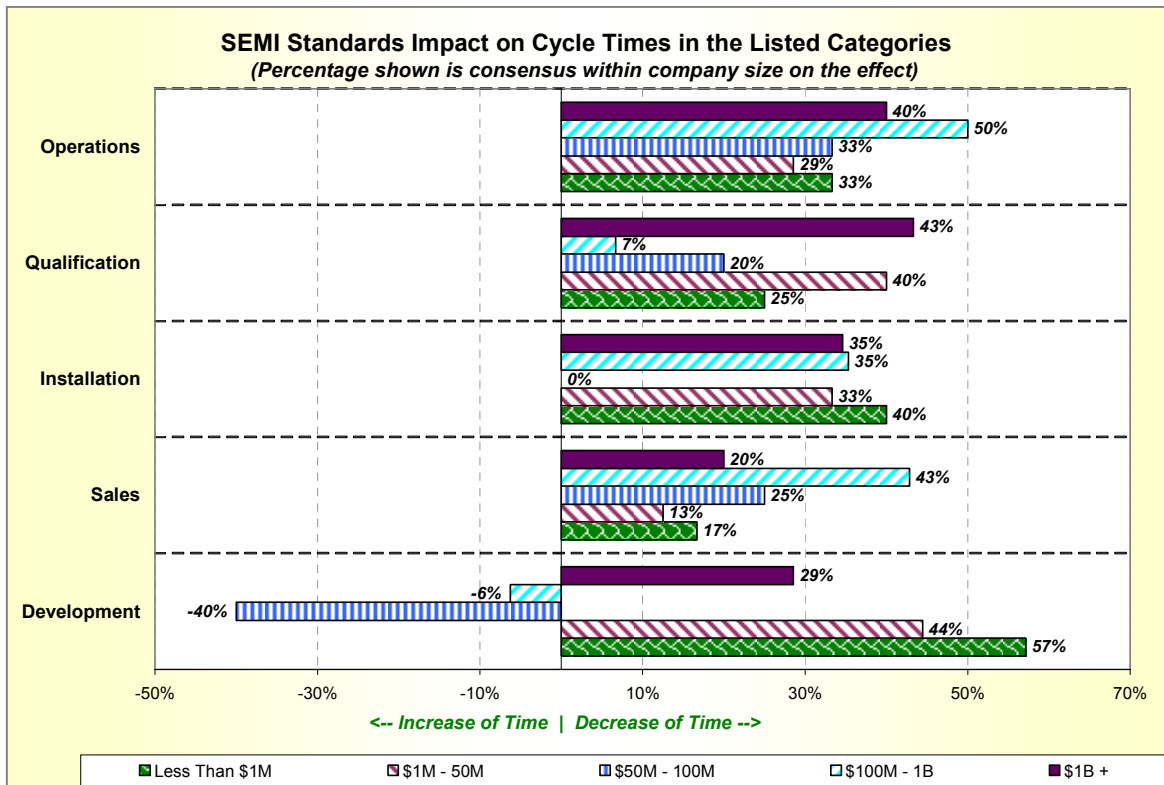
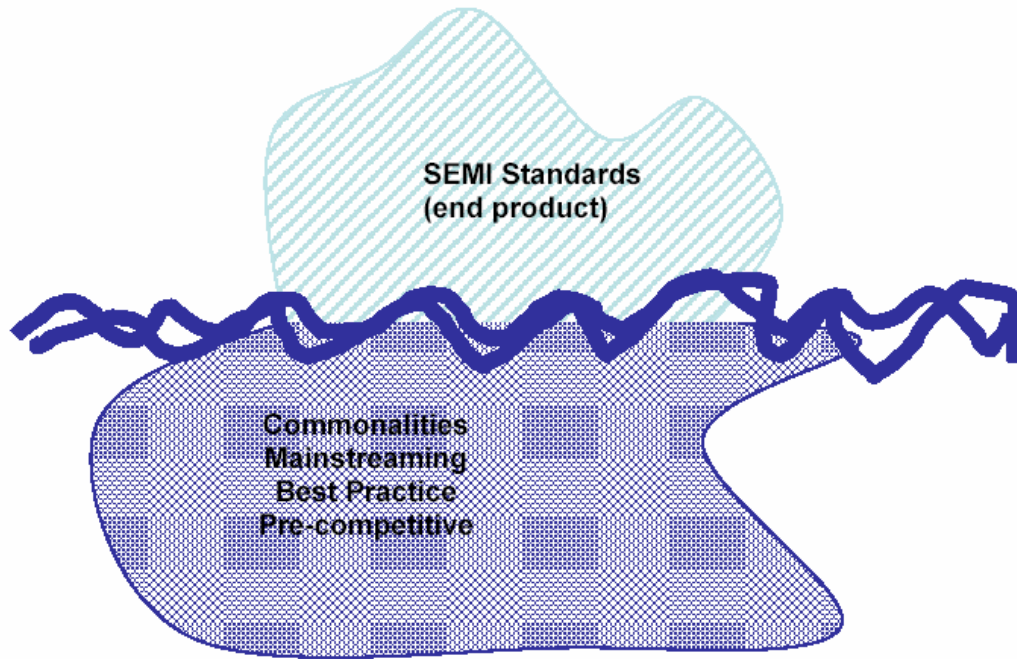


Figure 4 – Result of a recent SEMI survey among its member companies (98% of all companies use standards, almost 77% frequently or extensively.)



NOTE For operations, qualification, installation and sales, the cycle times have been considerably reduced by standardization, there is only an improvement for very small and large companies, for medium-sized companies there is an increase. The reasons for this are not entirely clear and are being analyzed. It is hypothesized that this is due to recent issues encountered with the development of software standards for equipment control.

**Figure 5 – Effect of standards usage on cycle times for different operations.**



NOTE The "visible" benefit for procurement purposes is smaller than the hidden benefits through applications of standards in the area of knowledge management.

**Figure 6 – Iceberg model of the perceived benefits of standards.**

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