Whatever, Whenever, Wherever: How Globalization Impacts Service Delivery
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A Letter from Charlie Pappis

GOING LOCAL IN A GLOBAL ECONOMY

If you work in the microelectronics industry, you probably have a lot of frequent flyer miles and can name your favorite restaurant in each of at least a half dozen countries. “Think Global, Act Local” is nothing new, but the phrase has more resonance than ever before as our customers become more global, expanding manufacturing beyond traditional regional markets to countries throughout Asia, India, Eastern Europe and even setting up new factories in the United States. And, each factory has to realize cost and cycle time benefits of local parts repair, refurbishment, cleaning and sourcing. Both of these trends stress the importance of cooperation globally and locally. Innovation and entrepreneurs come from all directions. Manufacturers and suppliers on opposite sides of the world are compelled to collaborate more effectively to serve the needs of global customers and ensure compliance with complex international regulation.

These are some of the challenges we tackle in this issue of Nanochip Fab Solutions. You will find out why everything old is new again in an article that looks at the market drivers behind the strong surge in demand for refurbished 200mm equipment and how Applied Materials is ready for it. In a new section called “A Customer Story,” veteran journalist Dave Lammers interviews Texas Instruments, explaining why and how the company is leveraging a unique mix of new and used 300mm and 200mm equipment to support its fast-growing analog and power management IC businesses.

This issue of Nanochip also considers the many challenges of managing a global supply chain, including best practices to ensure availability of critical parts when the chain is disrupted. You’ll read about innovative parts localization programs from Applied Materials that offer customers multiple options to leverage local resources and reduce their cost of ownership—without compromising performance, reliability or service level. And, as solar energy approaches grid parity, you will learn why strong partnering and collaboration can enable cell manufacturers to maximize output and tightly control cell efficiency distribution.

Finally, we also tackle one of the biggest challenges confronting all global nanotechnology manufacturers: increasingly stringent government environmental regulations—and compliance with localized requirements.

Think global, act local: four simple words that really challenge suppliers in our industries. At Applied Materials, we take the challenge seriously—and are firmly committed to doing both for our customers.
n today’s global economy, the relationship between manufacturers and suppliers is more critical and more complex than ever before. Despite the best laid plans, disruptions to global supply chains do occur, whether from natural disasters, socio-political events, or economic downturns and upturns. To successfully build and manage global supply chains, equipment providers cannot simply hope for the best—they must establish strong relationships with suppliers, build-in redundancy, and plan for business continuity so they can keep customers supplied when disaster strikes.

**BEST PRACTICES MITIGATE RISK**

According to Barry Murash, vice president of Service Product Operations at Applied, there are four best practices providers should bear in mind as they build their global supply chains. The first and most important of these is sourcing excellence.

“A supply chain depends on the strength of its suppliers,” said Murash. “Providers must invest time in establishing strong supplier relationships. This means collaborating with them on multiple fronts, including performance, quality and supplier health. A financially weak supplier can put the supply chain at risk just as easily as an earthquake or a volcano can.”

Second, establishing process-based methods for working with suppliers is very important. “Successful supply chain interactions rely on existence of solid business practices and discipline around established routines,” explained Murash. “During a natural disaster, these routines get interrupted. The challenge is to quickly enact

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temporary routines that are robust enough to enable the business process to work in spite of the disruption.”

A third best practice is to simplify the parts portfolio. “When companies use common parts across their designs, it reduces the number of critical parts that must be supplied when disruptions occur,” said Murash. Although portfolio simplification requires focused, intensive management of the global supply chain, it results in a stronger supply base and increased responsiveness to customers.

Fourth, it is essential to cultivate alternative sources and not stockpile parts in one geographic region. This approach is not only more economical for customers, it helps ensure business continuity as well. Murash and his team became keenly aware of the value of this best practice in the wake of the triple catastrophe that struck Japan earlier this year.

“Sometimes it’s tempting to consolidate suppliers in one geography because of the cost savings,” said Murash. “But doing so makes your supply chain vulnerable. During the earthquake, tsunami and nuclear meltdown that devastated Japan this spring, we were able to get parts to customers because Applied has alternative supply streams in Korea and Taiwan. Without that built-in redundancy, it would have taken us months to find other qualified sources.”

DIVERSE, GLOBAL FOOTPRINT HELPS NAVIGATE DISRUPTION

“When serving a global customer base, providers need to leverage the breadth of their own global resources,” observed Murash. “Keeping the supply chain diverse enables providers to adapt and react quickly when the chain is disrupted. The goal is to provide quality, value and delivery for the customer no matter what the circumstances.”

Fortunately, Applied Materials’ scale and global footprint help in providing a proactive approach to managing disruptions. Applied has 8 manufacturing centers, a network of over 1,000 suppliers and 51 logistics centers and worldwide transportation capabilities. Applied Service Product Operations is supported by 2,900 employees in Worldwide Operations, driving functional excellence in Sourcing, Logistics and Manufacturing, located across 19 countries. Applied Global Services has over 400 supply chain professionals dedicated to supporting the services business for all the segments Applied Materials serves.

Murash added that the rapidly changing and increasingly complex marketplace is putting more pressure on supply chains. With the growth in mobility devices such as smart phones and tablets, Applied has seen a resurgence of demand for services to support older generation technologies such as 200mm and below platforms and Gen 5 display tools. “This is where Applied’s global reach and extensive engineering and supply management capabilities come into play,” said Murash, “Through established processes and experienced people we are able to maintain a supplier network of parts to keep the tools producing at full capacity.” Applied currently services 105 platforms and has greater than 22,000 tools in its installed base that include technologies that were first brought to market as long ago as 20 years.

PUTTING CUSTOMERS FIRST WHEN DISRUPTIONS HAPPEN

At a recent analyst meeting, Joseph Flanagan, senior vice president of Worldwide Operations at Applied, announced that he is focused on making operations a competitive advantage for the company by putting the customer first and building a robust framework for continuous improvement around the world.

Murash and his team faced the challenges of executing this strategy while assisting stricken customers in Japan. Roads were closed, critical parts were in short supply, and power was out in some parts of the country. In such an extreme situation, how do providers do right by customers but still keep their own businesses running? Where is the middle ground?

For Barry Murash, there was no middle ground initially. “Customer and employee safety was our top priority. Nothing superseded that.”

As for the costs involved in keeping customers supplied during a disaster, Murash acknowledged the financial dilemmas equipment providers face. Who pays the freight charges for expedited parts? Who covers support costs outside the customer’s normal service level agreement? But ultimately he summed up his service philosophy this way: “Always act with urgency to support customers. You can figure out the costs later.”

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If you are a global semiconductor manufacturer, you know that management of equipment spare parts procurement and repair is a critical business strategy. Although you have a choice of suppliers and are focused on reducing costs, you don’t want to risk compromising performance, reliability or service level. There’s no single, easy solution. Parts can be purchased from multiple sources: large and small, experienced and less experienced. OEM is not always the cheapest. So what is the best strategy? Recognizing the importance of cost, cycle time and proximity to customers for rapid turnaround, quick continuous improvement and custom parts development, Applied has adopted a “go local” strategy so that customers have a choice of buying local in their region where it makes sense.

Applied Materials is integrating a dynamic, flexible and quality-conscious local supply chain into their existing worldwide infrastructure, resulting in several new spare parts programs being offered to serve global customers more effectively. Whether your etch process has been qualified using a silicon ring with optimized specifications or your CVD application requires a high performance faceplate, customers can now source parts like these from vendors in Asia through Applied Materials.

Adapting Strategy to Ensure Spare Parts Quality at Lower Cost
Feedback from customers in Korea, Taiwan and China indicated a pressing need for spare part cost reductions, faster delivery and custom solutions without compromising part quality. Customers also expressed a desire to work with suppliers on local terms (language, time zone, etc.). At the same time, some governments had begun providing incentives to companies who purchase parts and services from local vendors in an effort to stimulate local economies—a move that helped provide further cost savings to manufacturers in these countries.

In 2010, Applied responded by adding localized parts sourcing and repair to its supply chain strategy. In the first year of implementation, the company’s Applied Global Services (AGS) business completed a fast-track process to approve and certify 31 new suppliers in these key Asian markets to support buy-local initiatives while paving the way for broader access to lower cost parts for North American and European customers. This process included rigorous First Article Inspection (FAI) to ensure conformance to specifications by each local supplier. In the first year of the program, these new local sources reduced supplier-added cycle time by up to 4x while significantly expanding AGS’s local engineering service capability.

This model drives sustainable and scalable cost reduction throughout the replacement part and repair supply chain. In fact, the AGS spare parts program has been so successful that Applied is using the same methodology to implement a “go local” spare parts program in other regional markets and for its display and solar businesses.

Taking Local Benefits Global
Although Applied’s localization program is currently based in Asia, the benefits are global. Global manufacturers want to maintain process uniformity from tool to tool and fab to fab from one country to the next. This drive for consistency requires global availability and support of locally qualified spare parts. These customers leverage AGS’s operational infrastructure to procure parts, sourced from local vendors in Asia for fab operations in North America and Europe. And if an issue arises, Applied manages corrective actions to help ensure it won’t happen again. Additionally, fabs operating exclusively in North America or Europe can also benefit from this localization.
program. AGS can act as a manufacturer’s low-cost region program manager, supplying qualified, low-cost region parts fully supported by Applied Materials.

**FIVE CATEGORIES OF PARTS REDUCE COSTS AND CoO**

Applied’s localization program adds to its existing portfolio of parts programs. The new program helps semiconductor manufacturers achieve their cost reduction and quality goals with five categories of parts (see Table 1).

- **Standard parts** that ship as default part on new tools. These parts meet stringent specifications to achieve process results in a wide range of applications.

- **High-performance parts** improve chamber performance, reducing CoO by 50%. For example, high-performance silicon impregnated silicon carbide (SiSiC) rings and XRZ o-rings on the Applied Producer® etch platform have lasted 50% longer than standard parts.

- **ValueSource parts** are manufactured to Applied’s standard, exacting specifications, but in a lower cost region, resulting in a cost reduction of up to 20%. ValueSource parts are typically available for existing released equipment/processes.

- **ValueSpec parts** feature relaxed tolerances, and are often sourced from low-cost regions, reducing costs by 30%.

- **Customer-Directed parts** enable customers to simplify their supply chain logistics and consolidate operations by folding independent, local, qualified suppliers into an Applied-managed Applied Performance Service agreement.

Applied’s spare parts programs supply consumable, non-consumable parts and repair services. Consumables include an array of parts including faceplates, o-rings, ceramics, CMP membranes and pads and machined metal parts. Non-consumables include generators, robots, injector valves, plasma sources, electrostatic chucks and mass flow controllers, among others.

At the heart of the Applied parts program is the corrective maintenance support provided by thousands of field service organization (FSO) employees managing service contracts in every region of the world.

**LOCAL STRATEGY IS A WIN FOR EVERYONE**

Applied has received positive customer feedback regarding the effectiveness of the parts localization program. One customer, who has been working with local suppliers for a long time, said that “Applied Materials is the only OEM vendor that can provide such complete solutions that benefit our localization objectives.”

AGS is experiencing a steady increase in ValueSpec and ValueSource parts ordering in Korea, Taiwan and China, and expects to expand the program to Japan in the near term. The success also shows in the qualification of 31 new, local suppliers with many others in the pipeline, and the addition of more than 1,000 part numbers. By incorporating local suppliers into the Applied global supply chain, the AGS parts localization program really is a win for everyone involved: customers receive lower cost, higher quality spare parts and service, local suppliers and economies generate increased revenues, and Applied Materials stays close to the customer, increasing overall satisfaction and repeat business.

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Eleven years ago, when Texas Instruments Inc. (TI) began engaging with foundries for its digital CMOS production, few could have predicted the major changes the Dallas-based company would make to its manufacturing strategy. Far from going fab-lite, TI instead has created a unique mix of new and used equipment to support its fast-growing analog and power management IC businesses.

**ADVANCED CMOS TO FOUNDRIES**

As CMOS technology moved from 130 to 90 to 65 nanometers, TI executives became “more comfortable with what the foundries had,” said Kevin Ritchie, TI’s senior vice president of technology and manufacturing. Digital CMOS, he recalled in an interview last month at TI’s Dallas headquarters, “was driving an incredible amount of capex spending, and technology was churning very fast.” Meanwhile, the cyclical cell phone industry made TI’s management concerned about “leaving a lot of stranded capacity behind” if the company spent heavily on internal digital IC capacity.

In the first half of 2006, TI debated about doing the front end of the line in house and farming out the more generic metallization steps. In January 2007, TI’s management made a major decision to focus internal digital CMOS resources on designing for low power and performance, putting CMOS manufacturing largely in the hands of TI’s foundry partners.

“We came to realize that we weren’t going to get ahead in design rules, or our ability to pattern, or get the tools ahead of anyone else. And it took a lot of dollars to change to the next-generation technology,” Ritchie said.

Today foundries account for 25% of TI’s digital CMOS production. Of that, about 60% is “advanced” digital CMOS wafers, a percentage that TI expects to increase over time. For analog, 90–95% is built internally, a ratio expected to remain steady. Foundries will continue to supplement TI’s internal analog capacity, and provide specialized, low-volume production.
During the same 2006–2008 time period, TI’s management watched as analog revenues, including power management devices for mobile systems, began to grow steadily. Though half of TI’s current revenues still come from digital CMOS, including wireless system-on-chips (SoCs), the company now emphasizes its strategic directions toward analog and embedded processing.

**RFAB EVOLUTION**

The move to advanced CMOS foundry production left the question of what to do with RFAB, which is located in the Dallas suburb of Richardson. The building was finished in May 2006, garnering several awards for its environmentally friendly design. Speculation arose that the RFAB shell would be sold. (continued)

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**Applied Materials Receives TI Supplier Excellence Award**

In April 2011, Applied Materials, Inc. received the prestigious 2010 Supplier Excellence Award from Texas Instruments (TI) for the outstanding contributions of Applied’s service group. Applied was selected as one of the 16 recipients of the award from TI’s worldwide supplier base of more than 12,000 companies for its continued commitment in helping TI meet its goals to grow its business.

As TI opened the world’s first 300mm analog fab, set up its first facility in China, and added a new fab in Japan, Applied Materials expanded its role as a supplier to TI to support this significant expansion ramp. Applied’s role included help to execute the largest and most comprehensive relocation project in the industry. Applied also provided enhanced service, equipment and automation capabilities to TI in the past year.

Commenting in a recent press release, Rob Simpson, vice president of Worldwide Procurement and Logistics at TI, said, “This award is our highest level of supplier recognition, presented only to those that have significantly set themselves apart through their achievements. Applied has played a key role in supporting the growth of our business and we appreciate its commitment and dedication to our success.”

“We are proud to play a part in TI’s growth, and have worked hard, using our extensive global support resources and capabilities, to help TI meet its objectives,” said Charlie Pappis, group vice president and general manager of Applied Global Services. “We are especially honored to have our long and productive relationship with TI recognized by this sixth award—the second time in three years—for our service solutions. We will continue to strive to meet TI’s high standards and support them in their efforts to drive business success.”

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**From Left to Right: Dan Boyle, Applied Global Services (AGS) North America Sales Manager; Werner Finsterbusch, VP AGS Sales; Jesse Morris, TI Account Manager; Charlie Pappis, VP and General Manager, AGS; Rob Simpson, VP, WWW Procurement & Logistics, TI; Bob Nees, Director, WWW Procurement & Logistics, TI; Mary Kay Vaughan, Sr. Manager, WWW Procurement & Logistics, TI, and Paul Coniglio, AGS Eastern North America Sales Manager**
Instead, TI managers began discussing how to use RFAB for analog production. “In the logic space where we were playing, we knew that we had little ability to differentiate. But in analog, the processes create differentiation,” Ritchie said. (Editor’s Note: Other logic manufacturers may not agree about lack of differentiation.) As the debate ensued, some proposed filling RFAB with 300mm equipment, but initially management was split 75–25% towards the 200mm wafer size. Going to 300mm for analog “was more out of the box” than the decision to outsource a quarter of digital CMOS development to foundries, Ritchie said.

Analog processes at 300mm pose several challenges: Analog devices often require a 20-micron thick epitaxial (epi) silicon layer, which the wafer manufacturers were not supplying at the 300mm diameter. And there were worries about 300mm wafers warping because of the high temperatures (in the range of 1200°C) involved in anneal, implant and other analog processing steps.

When German DRAM maker Qimonda announced a major restructuring in late 2008, including the sale of 300mm manufacturing lines, Ritchie said TI swung in favor of manufacturing analog devices on a 300mm toolset. “The Qimonda 300mm toolset became available, and for pennies on the dollar,” he said. The deal was closed in October 2009.

MOVING AND PREPARING QIMONDA EQUIPMENT FOR ANALOG PROCESSES
The Qimonda tools had been used for 65nm DRAM manufacturing, while TI’s mainstream analog process, called Linear BiCMOS (LBC7) is at 250nm design rules. Ritchie said tool suppliers were readily able to disassemble, move, and reassemble the tools without problems. Qimonda didn’t have epi tools, so those were purchased new, as were some furnaces.

“We could use all of the Qimonda 248nm and i-line lithography tools, and all the plasma tools. All told, we averaged about 15 to 17 cents on the dollar,” Ritchie said, meaning that the company paid roughly $150,000 for tools that would have cost millions if purchased new. TI calculates a 30–40% productivity gain from the shift to 300mm wafers from the 200mm diameter, he said.

TI also upgraded its Freising, Germany and Miho, Japan fabs to 200mm processing, in part by moving equipment from the closed K-fab in Dallas that at one time had been the company’s digital CMOS development center. Some of the 200mm tools acquired from Qimonda also went to Freising and Miho.

To prepare RFAB for production, TI began working with its wafer suppliers to develop the 20-micron thick layer of first epi with the right oxygen content and defect levels. Since then, TI has purchased epi tools and grows the first epi layer in house.

It took roughly six months to develop the 300mm epi wafer supply with TI’s three silicon suppliers. “All of this 300mm epi equipment is available and capable of putting down a thicker film. But it hadn’t been done for that wafer size.” CMOS, non-analog “needs 1–3 microns of epi, and the wafer suppliers hadn’t gone above that,” he said.

The challenges were largely in process integration, including adapting tools to the double-charge implants, higher processing temperatures, and other unique steps in analog IC production.
Tom Weichel, RFAB manager, said equipping a new fab with used 300mm equipment is “very unique, perhaps an industry first.” The move involved about 1,000 items, weighing about 15 million pounds. About 230 tools are on the RFAB floor now, with about 75 more currently being installed.

Weichel said that most of the tools acquired from Qimonda were first purchased by that company in 2004, aimed at 70nm DRAM production. “We had to adapt it to an analog flow, but most of the equipment was in good shape,” he said.

As TI was equipping the building and adding the gas and chemical delivery systems, it also was building the human resources needed to operate the facility. Weichel said the company relied on a mix of new hires and experienced personnel to bring the RFAB facility on line successfully.

“We still have the flexibility to grow this facility as necessary,” Weichel said, noting that TI’s policy is to “provide capacity ahead of demand.” Those supply assurances are important to TI customers large and small.

ADDITIONAL ACQUISITIONS TO EXPAND ANALOG MANUFACTURING
With the initial RFAB line in production, TI made two other major acquisitions in 2010 to broaden its analog manufacturing base. In August, when flash memory manufacturer Spansion Japan began financial restructuring, TI purchased the Spansion Aizu site in northeastern Japan. The 200mm Aizu fab is operated by TI today, but some equipment from the non-operating 300mm Aizu fab was moved to RFAB to expand the number of wafer starts in Richardson. Other 300mm tools from Aizu were sold at the time of closing to Taiwan-based foundry UMC.

In the fourth quarter of 2010, TI acquired a 200mm fab in Chengdu, China from foundry SMIC and the Chinese government. There is a second shell at the Chengdu site that could be equipped either as a 200mm or 300mm factory.

Slightly more than 90% of the tools at RFAB are refurbished tools. Even the Muratec AMHS system is refurbished, with the track and stockers taken down from the Qimonda Virginia fab, modified to a different ceiling height, and reinstalled in Texas.

“Moving the tools was the easiest part; most of the work was in process integration,” said Ritchie. “We found that some tools were too good for what we needed—the etchers were too vertical, for example. And every process had to be reintegrated to 300mm. The challenge was to tune processes to get them to match the older 200mm equipment, to get the same parametric performance.”

To get 300mm to make sense economically for analog production, “we have to buy used tools. If we have to buy new tools, the math doesn’t work. To pull the trigger on Aizu or Chengdu (at 300mm) we have to be able to buy used tools,” Ritchie said.

“You hear about the big tool purchases in deals like the ones with Qimonda or Spansion, but we are out there every day, buying one here, one there,” said Ritchie.

RFAB is now processing 350 wafers per day. According to Ritchie, TI is only 10 tools short of the 400 it needs to ramp to 935 wafers per day, which would represent $2 billion in annual revenue. Fully loaded, RFAB is capable of $5 billion in production. Together, the new analog production sites at RFAB, Aizu and Chengdu give TI the potential to add $10 billion in revenue.


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At the beginning of 2010, John Cummings, senior director, marketing Applied Global Services Equipment Product Group, said few customers thought they would be adding 200mm capacity. But as last year progressed, demand became so strong that major customers were ordering dozens of tools at a time. Sales of refurbished equipment went from a few tools per quarter at the bottom of the 2009 downturn to nearly triple-digit unit sales in the current upturn.

The industry expects 200mm production to remain a key workhorse of the industry for the foreseeable future. According to Cummings, about half the semiconductor industry’s capacity—approximately 180 fabs—run 200mm wafers now. Add in 6-inch wafers, and the total more than doubles\(^1\). Dan Tracy, senior director, Industry Research & Statistics, SEMI said his organization clearly sees growing activity in 200mm wafer production. “Coming out of the 2009 downturn, 200mm wafer shipments grew by 40% in 2010. Overall 200mm fab capacity increased 2.5% globally last year, and we estimate another 3.5% to 4.0% growth in installed 200mm fab capacity for 2011.”

**200mm Growth Driven by Analog, DiscreteS and Sensors**

Driven by power ICs, MEMS, analog, discrete, and other fast-growing product categories, refurbished 150mm and 200mm equipment is in such strong demand that customers are finding it difficult to acquire used platforms and chambers, especially for epitaxial deposition.

“Almost any new consumer product has MEMS sensors and power management chips. All of this gadgetry drives demand for 200mm equipment,” said Durga Chaturvedula, Applied’s director of product management for 200mm emerging markets. While smart phones have several leading-edge ICs, they are surrounded by many other devices—power chips, discrete sensors, gyroscopes, and others—made on 200mm equipment. “Three-fourths of the chips in a smartphone are on 200mm and below. Some chips need cutting-edge technology, of course, but pretty much everything else is done on 200mm or smaller wafers,” he said. Cummings added that power management ICs, which include products such as voltage regulators, power transistors, and rectifiers, help in the

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\(^1\) Source: iSuppli

**FIGURE 1**

In 2010, more wafers were produced on 200mm equipment than 300mm equipment and trend is expected to continue in 2011. Wafers produced on 150mm and 200mm equipment equals twice as much as 300mm. Source: iSuppli
efficient distribution of electricity. These chips are being driven by rapid adoption of portable devices like smart phones and tablets, where extending battery life is critical, as well as the market growth of alternative, energy efficient systems.

EPI FOR HIGH-VOLTAGE ICs
The smart grid and a shift to hybrid and electric vehicles are just two of the drivers for high-voltage applications. Silicon logic requires thin layers of epi—up to 5 microns—while applications such as insulated gate bipolar transistors (IGBT) and power modules need thick layers of epi, greater than 100 microns thick. “Epi is becoming one of the key steps driving additional demand for 200mm equipment—not just for emerging technologies but for traditional power devices as well,” said Chaturvedula.

However, finding used 200mm epi platforms and chambers has become difficult. Now, with epi systems selling in greater numbers than when the products were new, Cummings said, “there are no cores left. So we have had to rebuild the entire supply chain for new builds.”

MANUFACTURING IS BACK IN US
When demand came back up, Jack Blaha, managing director of AGS Equipment Product Group Operations, said the company restarted 200mm manufacturing at Applied’s Austin, Texas campus and worked to revive its supply chain. “We have successfully ramped our Austin operation and are now building 200mm tools with both refurbished and ‘98% new’ content,” Blaha said. “Overall, customers still want refurbished systems because of the lower costs, but certain applications are in short supply and we are moving to more new content.”

REFURBISHED CORES WITH NEW CHAMBERS AND ENHANCEMENTS
Applied is busy refurbishing used platforms, adding new chambers and enhancements, particularly for epitaxial deposition. Some of these chambers have productivity enhancements drawn from technology developed for Applied’s 300mm tools. Last year Applied unveiled a portfolio of upgrades, the PLUS line of 200mm tools, that draws on the “latest and greatest from our 300mm equipment,” Chaturvedula said.

“Our 200mm PLUS products for CMP have quite a few new features, and lower cost of ownership. For example, customers have seen nearly a 4% increase in uptime with our new Upper Pneumatics Assembly. A new PM reduction kit reduces cleaning time by 50% and minimizes excursions. We have Producer PLUS, Endura PLUS, and so on, using technologies developed originally for our 300mm tools,” he said. As a result, tools originally targeted at 130nm linewidths are being refurbished and upgraded for 90-, 65-, and in some case sub-65nm design rules.

Brand-new technologies are also being deployed on 200mm platforms. “With exploding demand for sensors, gyroscopes, and other MEMS devices, Applied’s goal is to be the most-effective MEMS equipment solution provider,” Chaturvedula said. “We are building our portfolio of products to add process steps specific to MEMS.” He said that Applied developed a new chamber for deep trench etch, a key step in the MEMS space where most of the production is on 150mm and 200mm wafers. “The company has an active engineering program to develop further enhancements to this chamber,” he said. “Additionally, we acquired important release etch capability from Semitool, which involves etching the buried oxide layer to release the mechanical structure on the chip.”

NEW OPPORTUNITIES FOR 200mm
The future of the 200mm equipment business offers both technical challenges and business opportunities. Driven by consumer and energy applications, the next generation of emerging devices based on MEMS, through-silicon vias (TSVs), photonics and wafer level packaging technologies, will depend on lower costs and rapid return on investment. Power devices in consumer electronics are expected to rise in demand, driven by their low-cost, compact size and power management. Global energy concerns are pushing more products to use less energy placing greater emphasis on power management ICs. Innovative engineering across a number of toolsets leads to greater process flexibility and accommodates a broader range of emerging device requirements. For example, CMOS image sensors were the first volume adopters of TSVs made on 200mm wafers, and Applied Global Services has a nearly complete toolset for key TSV steps.

“Applied is continuing its investment in R&D for 200mm technologies because we believe that new, exciting applications for 200mm wafers and equipment are still evolving and will continue to deliver new opportunity for a number of years.” Cummings concluded, “Leading edge does not necessarily mean marching down the scaling path on the largest wafers.”

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(1) SEMI’s world fab watch database.

Author: David Lammers and Nanochip Staff. For additional information, please contact John_Cummings@amat.com.
The semiconductor industry is paying more attention to energy and resource consumption. There are two main drivers for this awareness: one, rising energy prices are increasing cost per wafer and two, energy and resource consumption and its environmental impact measured by the carbon footprint of final products draws a lot of interest from the public, customers and regulatory authorities. This article explains where and how fabs consume power and identifies opportunities to reduce overall power and resource consumption.

Figure 1 shows power consumption distribution by facility systems in a 300mm fab. Data was taken from multiple sources (2), (3), (4), (5) and integrated into a tool-based equivalent energy consumption model. This diagram reveals a large amount of power is consumed by equipment, but approximately 55% is consumed by facility systems. This consumption is mainly driven by process requirements, e.g. exhaust, cooling, nitrogen, compressed air and ultrapure water (UPW) consumption. The energy needed for facility systems varies among fabs—between 35% and 65% of total power consumption. This variation depends on climatic and operational conditions:

- Need for cooling, including raw water temperature cooling or heat recovery
- Use of natural gas for boiler and local exhaust abatement versus electrical energy
- Water management system: chemical purity of raw water, need for high recycling rates due to cost, scarcity or regulations
- Specific process requirements, e.g. quantity and temperature of hot UPW
- Special conditions, e.g. use of river water for cooling.

Figure 1 gives some ideas where energy can be saved, but it still does not reveal enough.
ENERGY CONSUMPTION IN A FAB
A better model to determine actual energy and resource savings potential is shown in Figure 2 and Figure 3. This model uses the equivalent energy consumption concept according to SEMI S23 (6). It starts with the process and considers indirect energy consumption by process utilities, such as UPW, nitrogen, compressed air, and exhaust, among others. Secondarily, it considers energy consumption of infrastructure systems, such as cleanroom, make-

up and recirculating air handling systems, boilers and chillers. It differentiates between the consumption directly from the tool and the consumption of subfab equipment, such as vacuum pumps, local exhaust abatement, chillers, RF generators, etc. Figure 4 shows a breakdown of the equivalent energy. About 50% is consumed as power, but an additional 50% of the equivalent energy is consumed as process utilities. This does not include the natural gas consumption for abatement.
Power and utility consumption is further broken down by process area. Figure 5 summarizes the results. The first column shows direct equipment power consumption. The second column shows indirect power consumption from compressed air, nitrogen, hot and cold UPW, exhaust (including required make-up air), heat emitted to the cleanroom and process cooling water (including the energy needed for the chiller). Indirect energy consumption was converted into power consumption by using the energy conversion factors (ECF) defined in SEMI S23, which are listed in Table 1. The third column shows the total equivalent energy as defined by SEMI S23.

To identify complete energy saving potential, another step is required: understanding how much energy is consumed by equipment sub-parts. Figure 6 shows the results of a fabwide analysis, breaking down power consumption of mainframe and subfab components. The local exhaust abatement is considered part of tool consumption.

**HOW CAN THE ENERGY CONSUMPTION BE REDUCED?**

Energy savings can be achieved in three main areas:

1. In the facility and infrastructure system
2. In the process itself
3. At the interface between facility and infrastructure systems

### 1 Facility system improvements

Over the years, a lot of focus has been placed on improving facility systems since changes usually have no or little impact on process results.

#### General mechanical systems

Sound engineering practices and well-designed piping architecture help curtail energy consumption. Better management of pressure drops reduces operational costs and improves efficiency of motors, pumps, blowers and fans. Success has been reported in many publications (7), (8), (9). Additionally, the investment cost for variable frequency drives, which help control electrical power, has dropped over the years and therefore new fabs are using them extensively for pumps, compressors and large fans.

#### Cleanroom and air handling systems

The energy consumption of the cleanroom depends on many factors:

- Cleanroom class/filter coverage
- Cleanroom concept and associated pressure drop
- Fan efficiency
- Temperature and humidity specifications

300mm fabs and 200mm Standard Mechanical Interface (SMIF) fabs have much lower filter coverage and total recirculation air volume than older, traditional fabs. This alone has reduced power consumption drastically. Today, power consumption of recirculation air handling systems can be in the same range as cleanroom lighting systems.
Compressed air and bulk gas systems

Progress has been made on improvements to compressed air systems. Most manufacturers offer energy saving control systems which optimize the operation of variable frequency drives. Today, fabs are using more turbo compressors compared to oil free screw and similar compressors.

2 Improvements to the process

Process requirements drive overall energy and resource consumption. Certainly, the equipment itself is under tight scrutiny. On one hand, changes are difficult to implement since they require process re-qualifications: on the other hand, during process development optimization, processes are used to drive down the cost of ownership or cost per layer. By using energy efficient equipment right from the beginning, inefficient processes are replaced. The semiconductor industry is continuously driving process efficiency in all areas and this is constantly changing and improving.

Equivalent energy consumption fabwide according to SEMI S23

SEMI S23 allows tool characterization according to their overall impact on the energy balance of a fab. Semiconductor companies and equipment suppliers are driving energy savings for manufacturing equipment with aggressive roadmaps (10), (11).

Another way to generate energy savings is to increase equipment throughput. Many facility consumptions, such as exhaust, heating, etc., are constant over time. Therefore an increase in wafer throughput can reduce specific energy consumption.

Another important driver for energy savings is reduction of idle consumptions. This can range from optimized lamp configurations in RTP tools to modulating transfer chamber gas flows or UPW bypass flows in wet equipment.

Energy efficient components

There is a continuous drive to improve component efficiencies. Recently, dry vacuum pumps have significantly reduced energy consumption. Today, most pumps can vary speed and nitrogen purge. But new designs have been introduced which improve pumping efficiency under vacuum conditions without impacting reliability and lifetime of the vacuum pumps.

Solid state chillers have replaced only a small percentage of traditional refrigeration chillers due to high investment cost and availability for small loads only. The good news is traditional refrigeration chillers are much more efficient than before. They can be equipped with variable frequency drives and many other energy saving features.

Resource reduction by tool/chamber matching

Resource consumption matching is one of the basic methods of eco-efficiency engineering widely used in the chemical and pharmaceutical industry. Resource consumption between similar tools and chambers running the same processes should be equal. In the semiconductor industry, resource consumption matching methods are gaining more attention. With state-of-the-art software and data mining techniques, this can be achieved much more easily than previously. The detailed concept is explained in (12) and (13).

Reduction of idle consumptions

Many resources such as purge or cleaning gases are actually unproductive and also pose a certain risk to the process, if not used properly.

- Reasons for purging or cleaning gases:
  - Purge gases prevent intrusion of particles, oxygen and other impurities
  - Gases such as Helium are used to cool down wafers; variations may impact the temperature profile in the reactor/equipment
  - Heating to maintain temperature levels in reactors, since variations may cause particle bursts, impacting layer uniformity

Dry vacuum pumps and abatement are running in a fab all the time independently from the status of the tool. During the tool idle state, pumps cannot be switched off, but can run at a lower pump speed and with reduced Nitrogen purge rate. Additionally, a burn/wet exhaust abatement could reduce fuel gas and oxygen.

Fab/subfab synchronization

The fab/subfab synchronization concept goes one step further than just using idle mode energy and resource reductions. Understanding all process steps enables a full synchronization of the subfab tool operation.

<table>
<thead>
<tr>
<th>Unit</th>
<th>ECF</th>
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<tbody>
<tr>
<td>Power</td>
<td>kW/</td>
</tr>
<tr>
<td>Exhaust</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>Heat released to the cleanroom</td>
<td>kW/ kW</td>
</tr>
<tr>
<td>Ultrapure water (UPW)</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>Hot UPW</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>Process cooling water (PCW)</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>Nitrogen (N²)</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>Compressed air (CDA)</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>High temperature (HT) PCW</td>
<td>kWh/ m3</td>
</tr>
<tr>
<td>House vacuum</td>
<td>kWh/ m3</td>
</tr>
</tbody>
</table>

▲ TABLE 1. Standard energy conversion factors (ECF) by SEMI S23 (6).
3 Improvements at the interface between process and facility systems

The biggest savings potential, besides idle mode and fab/subfab synchronization, can be found at the interface between facilities and process.

Several examples are discussed below.

High temperature process cooling water

Direct process cooling from the cooling tower is not the standard system used in today’s semiconductor manufacturing facilities, as illustrated in Figure 7. The process cooling water temperature level is usually set to the strictest (coldest) requirements of the fab equipment (e.g. dehumidification in litho for environmental chamber) and depends on the facility chillers to cool down the recirculating water. However, many applications do not require such low water temperatures, requiring water to be partly heated up again. At the same time, the needed process cooling water capacity is so large in most semiconductor manufacturing facilities that a second cooling water loop is economically feasible, especially since energy costs are continuously increasing.

Since not all users could change to more efficient cooling systems without extensive re-qualification, the idea is to install a second process cooling water system called high temperature process cooling water system. The current recommendation is to use the high temperature process cooling water only on the secondary site of local chillers and for applications where there is no impact to the process, minimizing need for re-qualification. This concept has been discussed multiple times (7), (15), but not implemented widely since it requires a lot of detailed work.

Exhaust recycling

Another major opportunity for savings is the reuse of uncontaminated exhaust air. It is more energy effective to cool this air than to extract it to the outside and replace with fresh make-up air, especially in the summer when air needs to be cooled down to less than 10°C, consuming a lot of energy. Specific examples have been discussed by many authors (9), (16).

Others

Other major improvement potentials can be found at interface specifications (7), such as for compressed air. Only a few applications require air to be compressed to 10 bar g+. Most applications require a pressure regulator, destroying most of the energy, before it can be used. Other examples are the humidity specification for compressed air or the pressure specification for Nitrogen (7).

ENERGY SAVING ROADMAP

Table 2 shows the targets set by ITRS in 2010 (1) in comparison with the 25% reduction target for a five-year cycle, which most companies follow. The question is whether these targets are achievable. Table 3 lists energy saving measures for a new 300mm fab, as outlined in the previous section, with assumptions on their implementation level.

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<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Power Eq/cm² Si kWh/cm² Si</td>
<td>0.5</td>
<td>0.43</td>
<td>0.36</td>
<td>0.30…0.25</td>
</tr>
<tr>
<td>Power Total site/cm² Si kWh/cm² Si</td>
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<td>0.85</td>
<td>0.7</td>
<td>0.6…0.5</td>
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<tr>
<td>Reduction 25%/5 yr</td>
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<td>0.85</td>
<td>0.72</td>
<td>0.54</td>
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<tr>
<td>Power Eq/cm² Si kWh/cm² Si</td>
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<td>0.43</td>
<td>0.36</td>
<td>0.27</td>
</tr>
<tr>
<td>Power Total site/cm² Si kWh/cm² Si</td>
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<td>0.85</td>
<td>0.72</td>
<td>0.54</td>
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▲ TABLE 2. ITRS Energy reduction targets set by ITRS in comparison with 25% reduction target over 5 years.
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<td></td>
</tr>
<tr>
<td>Idle mode</td>
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<td>100%</td>
</tr>
<tr>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>% of pumps with idle mode</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
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<td>20%</td>
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<td></td>
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<td>20%</td>
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<td></td>
</tr>
<tr>
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<td>20%</td>
<td>30%</td>
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</tr>
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<td>30%</td>
</tr>
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<td>RF Generators</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency, idle mode</td>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
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<td>30%</td>
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<td>30%</td>
</tr>
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<td>UPS Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
</tr>
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<td>30%</td>
<td>30%</td>
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<td>Remote Plasma Clean</td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
</tr>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Mini Environments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>10%</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Others (Local abatement)</td>
<td>25%</td>
<td>40%</td>
<td>75%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Efficiency improvement</td>
<td>10%</td>
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<td>30%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Chilled Water</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Equipment</td>
<td>HTPCW</td>
<td>40%</td>
<td>50%</td>
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<td>90%</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrubbed and General Exhaust</td>
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<td>20%</td>
<td>30%</td>
<td>40%</td>
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<td>10%</td>
<td>20%</td>
<td>30%</td>
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<td>Recirculating Air Handing</td>
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<td>5%</td>
<td>10%</td>
<td>15%</td>
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<td>10%</td>
<td>15%</td>
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</tr>
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<td></td>
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<td>Process Cooling Water</td>
<td>See HTPCW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DI/UPW</td>
<td>Eco efficiency</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>UPW Hot</td>
<td>Eco efficiency</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Compressed Air</td>
<td>Eco efficiency</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Bulk Gases</td>
<td>Eco efficiency</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
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<td>Process Vacuum</td>
<td>Eco efficiency</td>
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<td>6%</td>
<td>8%</td>
<td>8%</td>
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<td>Industrial Waste Collection and Treatment</td>
<td>Eco efficiency</td>
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<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
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<td>Chemical Dispense</td>
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<td>6%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Automated Material Handling System (AMHS)</td>
<td>Eco efficiency</td>
<td>4%</td>
<td>6%</td>
<td>10%</td>
<td>15%</td>
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</table>

▲ TABLE 3. Energy saving measures by main user and implementation level (assumption).
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<thead>
<tr>
<th>Category</th>
<th>300mm</th>
<th>Power in kW</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Delta in kW</th>
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<td>47.2%</td>
<td>11,213</td>
<td>10,692</td>
<td>10,396</td>
<td>9,630</td>
<td>8,965</td>
<td>8,965</td>
<td>2,248</td>
</tr>
<tr>
<td>Dry Pumps</td>
<td>19.1%</td>
<td>4,535</td>
<td>4,308</td>
<td>4,172</td>
<td>3,855</td>
<td>3,628</td>
<td>3,628</td>
<td>907</td>
</tr>
<tr>
<td>Turbo Pumps</td>
<td>4.3%</td>
<td>1,019</td>
<td>1,009</td>
<td>999</td>
<td>978</td>
<td>958</td>
<td>958</td>
<td>61</td>
</tr>
<tr>
<td>Heaters</td>
<td>5.9%</td>
<td>1,391</td>
<td>1,321</td>
<td>1,252</td>
<td>1,113</td>
<td>974</td>
<td>974</td>
<td>417</td>
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<tr>
<td>Misc.</td>
<td>5.4%</td>
<td>1,284</td>
<td>1,220</td>
<td>1,156</td>
<td>1,027</td>
<td>899</td>
<td>899</td>
<td>385</td>
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<tr>
<td>Non-process Pumps</td>
<td>4.1%</td>
<td>963</td>
<td>867</td>
<td>867</td>
<td>770</td>
<td>674</td>
<td>674</td>
<td>289</td>
</tr>
<tr>
<td>RF Generators</td>
<td>2.7%</td>
<td>642</td>
<td>629</td>
<td>629</td>
<td>616</td>
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<td>603</td>
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<td>UPS Control</td>
<td>1.8%</td>
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<td>419</td>
<td>419</td>
<td>411</td>
<td>402</td>
<td>402</td>
<td>26</td>
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<td>Remote Plasma Clean</td>
<td>1.4%</td>
<td>321</td>
<td>315</td>
<td>315</td>
<td>308</td>
<td>302</td>
<td>302</td>
<td>19</td>
</tr>
<tr>
<td>Mini Environments</td>
<td>0.5%</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
<td>107</td>
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<td>Others (Local abatement)</td>
<td>2.2%</td>
<td>523</td>
<td>497</td>
<td>481</td>
<td>445</td>
<td>418</td>
<td>418</td>
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<td>Chilled Water</td>
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<td>1,546</td>
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<td>Recirculating Air Handling</td>
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<td>808</td>
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<td>Lighting</td>
<td>2.2%</td>
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<td>497</td>
<td>471</td>
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<td>445</td>
<td>445</td>
<td>78</td>
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<td>Make-up Air</td>
<td>3.0%</td>
<td>713</td>
<td>713</td>
<td>713</td>
<td>713</td>
<td>713</td>
<td>713</td>
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</tr>
<tr>
<td>Steam/Hot Water</td>
<td>0.3%</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>71</td>
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<tr>
<td>Process Cooling Water</td>
<td>2.9%</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>690</td>
<td>0</td>
</tr>
<tr>
<td>DI/UPW</td>
<td>3.1%</td>
<td>737</td>
<td>708</td>
<td>693</td>
<td>663</td>
<td>627</td>
<td>590</td>
<td>147</td>
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<tr>
<td>UPW Hot</td>
<td>0.5%</td>
<td>119</td>
<td>114</td>
<td>112</td>
<td>107</td>
<td>101</td>
<td>95</td>
<td>24</td>
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<tr>
<td>Compressed Air</td>
<td>4.2%</td>
<td>799</td>
<td>959</td>
<td>939</td>
<td>899</td>
<td>849</td>
<td>799</td>
<td>200</td>
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<tr>
<td>Bulk Gases</td>
<td>7.9%</td>
<td>1,878</td>
<td>1,803</td>
<td>1,766</td>
<td>1,691</td>
<td>1,597</td>
<td>1,503</td>
<td>376</td>
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<tr>
<td>Process Vacuum</td>
<td>0.4%</td>
<td>95</td>
<td>91</td>
<td>89</td>
<td>88</td>
<td>88</td>
<td>86</td>
<td>10</td>
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<tr>
<td>Industrial Waste Collection and Treatment</td>
<td>1.6%</td>
<td>380</td>
<td>365</td>
<td>358</td>
<td>342</td>
<td>323</td>
<td>304</td>
<td>76</td>
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<tr>
<td>Chemical Dispense</td>
<td>0.0%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Automated Material Handling System (AMHS)</td>
<td>0.4%</td>
<td>95</td>
<td>91</td>
<td>89</td>
<td>86</td>
<td>81</td>
<td>76</td>
<td>19</td>
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<tr>
<td>TOTAL</td>
<td>100.0%</td>
<td>23,768</td>
<td>21,708</td>
<td>20,912</td>
<td>19,160</td>
<td>17,560</td>
<td>17,348</td>
<td>6,420</td>
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<td>Reduction</td>
<td>100%</td>
<td>91.3%</td>
<td>88.0%</td>
<td>80.6%</td>
<td>73.9%</td>
<td>73.0%</td>
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<tr>
<td>Power Cost Reduction $M (US)</td>
<td>1.8</td>
<td>2.5</td>
<td>4.0</td>
<td>5.4</td>
<td>5.6</td>
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</table>

▲ TABLE 4. Saving results for a 300mm fab.
Table 4 shows the results of the simulation, showing 25% energy savings over five years is achievable, but requires the implementation of multiple concepts. A single activity alone will not achieve the target. Additionally, the savings achieved are in the $5M USD range for a 300mm fab with a 10,000 m² manufacturing area.

Key activities to achieve the 25% target in the next 5 years include:

- Reduction of resource consumption using eco-efficiency engineering methods such as eliminating idle flows as much as possible as well as chamber and equipment matching of idle and operational flows
- Application of smart idle operation of subfab components and fab/subfab synchronization of vacuum pump, heater and local abatement operation
- Heat recovery from any source, such as hot UPW, compressor cooling water and others.
- Exhaust recycling for uncontaminated exhaust and optimization of exhaust segregation
- High temperature process cooling water (free cooling instead of facility chiller) all year long by optimizing process cooling water temperatures and use of multiple temperature levels.

SUMMARY AND OUTLOOK

The return on investment of the alternatives proposed here is typically in the two to three year range for power rates of approximately 0.1 US$/kWh. Not all of them have been implemented widely, but no major obstacles can be seen for new fabs. In existing fabs, not all of the proposals can be implemented with reasonable return on investment. However, government funding is sometimes available to improve existing fabs.

Savings beyond the current 5-year horizon will require a lot of effort, such as:

- Implementation of high temperature process cooling water for all equipment (7)
- Minimized inlet pressure e.g. for N², CDA, UPW: system pressure at less than 4 bar g (15)
- Reduction of heat load to cleanroom (at the same time use of high temperature process cooling water)
- Use of green chemistries, which reduce required temperatures

Implementation will require major changes in process equipment and require a lengthy process development cycle. Because the return on investment is not clear, it will require close cooperation between all stakeholders (engineering, manufacturing, operations, etc.) to make sure the economics make sense. This is the reason why the ITRS has marked the expected energy savings in this time horizon as red. (Table 2).

Energy and resource savings will continue to be a major goal for fabs and suppliers in the semiconductor industry but it will require a lot of cooperation and effort to ensure that it does not impact process results.

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Greenhouse Gas Reporting: Q&A

What is the Greenhouse Gas Reporting Program (GHGRP)?

In April 2009, the U.S. Environmental Protection Agency (EPA) issued a finding that greenhouse gas emissions posed a public health risk under the Clean Air Act. Since that time, the agency has moved forward with regulatory rule-making procedures, including the Greenhouse Gas Reporting Program (GHGRP). This program proposed a mandate that industries emitting 25,000 or more metric tons of carbon dioxide equivalent (mtCO₂e) per year, which includes electronic manufacturing, must annually report their GHG emissions to the EPA. The purpose of annual reporting is to provide a basis for future GHG policy decisions.

What does GHGRP mean to electronics manufacturers?

Large manufacturers of electronic components such as semiconductors, photovoltaic cells (PV), liquid crystal display (LCDs), light emitting diodes (LEDs) and micro-electro-mechanical systems (MEMS) manufacturing in the United States fall under the “Mandatory Reporting Rule for Additional Sources of Fluorinated Greenhouse Gases,” which defines GHG sources and specifies procedures for collecting and calculating GHG emissions. The sources of fluorinated GHGs in the electronics manufacturing industry include:

- Etch and chamber clean gases that create plasma-generated fluorine atoms or other reactive fluorine species.
- CVD processes using nitrous oxide (N₂O) gas, and heat transfer fluids (HTFs), which are utilized in chillers and other temperature control equipment.

Under the GHGRP manufacturers will be required to catalog all incoming and stored GHG gases and fluids, and account for usage, abatement, recycling and return throughout the reporting year using best available monitoring methods (BAMM). BAMM varies in complexity depending on manufacturer-type and production capacity. Some facilities will be able to estimate emissions based on default emission factors for limited processes; others will be required to measure actual emissions from process-type, sub-type or recipe. The measurement, data collection and reporting of GHG emissions will be a resource-intensive endeavor.

What are the latest developments?

Mandatory reporting has not yet been implemented. However, major GHG-emitting industries, such as power plants and oil refineries, are required to limit future GHG emissions in new or modified facilities. Developments specific to the electronics industry include the 3-month extension of submissions for approval of BAMM for directly measured recipe-specific emissions factors in 2011, and an extension to utilize BAMM without EPA approval.

What are other countries doing about greenhouse gas reporting?

Mandatory GHG reporting is a US-based initiative only. However, methods for reducing GHG emissions are defined by the Kyoto Protocol, adopted in 1997 and put into effect in 2005. The parties to the Kyoto Protocol are 41 industrialized nations with reporting obligations under the United Nations Framework Convention on Climate Change. One party, the European Union (EU), has a regulated Emissions Trading System based on the “cap and trade” principle. This means that there is a “cap,” or limit, on the GHG emissions allowed from a facility in the system. A facility that does not reach its cap can sell its unused allowance to a facility that has exceeded its limit. The finite number of allowances ensures that they maintain value.
How is Applied Materials responding?

Applied Materials has developed two cost-effective products that enable the automated abatement, monitoring and reporting of GHGs. The Applied iSYS™ subfab controller monitors the process tool and adjusts the tool’s abatement system parameters to achieve maximum destruction removal efficiency (DRE) for GHGs and N₂O, ensuring minimal emissions. The parameters affecting DRE, such as fuel flow rate or thermal energy, are recorded and utilized to trace an emissions excursion back to the source, if necessary. iSYS monitors and records data from individual tools, and, when interfaced with Applied’s E3™ fab-wide monitoring system, can provide centralized data collection and reporting of GHGs. The E3 system collects the data from each iSYS controller in the facility and calculates emissions using the process tool's GHG BE% (breakdown efficiency), the abatement system DRE%, and process tool and abatement system uptimes. In addition to fab-wide process tool monitoring, the E3 system can store records of all incoming and spent GHGs and HTFs, thus providing a comprehensive record of greenhouse gas emissions that can be uploaded annually to the EPA’s electronic reporting tool.

Besides GHG reporting, what other value does iSYS bring to electronic manufacturers?

You can’t measure or manage processes if you don’t monitor them. In addition to its GHG reporting capabilities, the iSYS Subfab controller monitors and controls abatement and pump energy usage by synchronizing with the process tool, reducing utilities expenses up to $20K per tool without purchasing additional equipment.

Where can manufacturers find more information?

Manufacturers can visit the climate change section of the U.S. EPA’s website at www.epa.gov

Information specific to electronics manufacturing can be found in these EPA documents:
http://www.epa.gov/climatechange/emiissions/downloads11/training/webinar_subpart-i-12-7-10.pdf
http://www.epa.gov/climatechange/emiissions/ghgrulemaking.html
http://www.epa.gov/climatechange/emiissions/downloads10/F-gas_EIA.pdf

Information on iSYS can be found at http://www.appliedmaterials.com/technologies/library/applied-isys

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1 Rule 40 CFR Part 98.
2 Rule 74 FR 56260.
3 Fluorinated GHGs for the electronics industry include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆), nitrogen trifluoride (NF₃), and hydrofluoroethers (HFEs).
4 Facilities with annual capacities less than 10,500 m² silicon.
5 Facilities with annual capacities greater than 10,500 m² silicon.
It’s an exciting yet challenging time to be a solar cell manufacturer. A convergence of economic and technological trends has pushed up a notch the always-relentless pressure to increase efficiency and cut costs.

On one hand, many pro-solar tariff and subsidy programs have been reduced. Some of these programs were eliminated because solar prices have come down and are no longer needed, a sign that the industry is maturing. Market growth, although a positive trend, has created a big challenge: Solar projects are larger, and now with more money at stake, investor expectations are higher and manufacturers who fall short may not get a second chance. This pending consolidation is a natural outcome of an industry going mainstream.

At the same time, solar technology is advancing at its fastest pace in decades. Double-printing, selective emitter, back contact and other new designs are moving from development labs and high-end niche products into large-scale mainstream production. To compete, manufacturers must meet the market’s demand for more efficient cells, while also controlling or reducing overall cell costs.

It’s an uncertain time. Businesses that fail to control costs may not survive. But it’s also a thrilling time, too. Solar energy is approaching grid parity, on the verge of establishing itself as a critical component of the world’s energy mix. Businesses that fail to invest in technology upgrades may not be able to take advantage of the tremendous opportunities ahead.

Strong partnering across the supply chain is critical in balancing technological innovation and cost containment. Strong partnering can help each company succeed but weak ones can drag each other down. Materials and consumable suppliers can optimize their products for the needs of a particular cell design and process flow. Innovative equipment suppliers can help cell manufacturers integrate new processes in the most cost-effective, least disruptive way.

For example, many important developments in solar cell technology involve new contact structures: double printing, selective emitters, back contacts, and so forth. As Suketu Parikh, director of Display and Energy Service Technology for Applied Global Services, explained, each technology requires an integrated solution for material paste, screen, printer alignment and film deposition. For example, double printing demands silver paste to form a good contact with a high aspect ratio involving special screens and printers that deliver very precise alignment between the first and second paste layer. Selective emitter technologies require advanced pattern recognition and alignment to print metal over the selective emitter to get high efficiency. Screen printed dopant selective emitters require the optimization of compatible materials including dopant paste screens and squeegees.

It isn’t yet clear if these structures will become the new standard. Some approaches may be more cost effective than others, but pursuing each possibility will likely be manufacturer dependent. Manufacturers need flexible equipment that supports current needs while offering an upgrade path as new designs emerge. Applied Materials is working with paste and print screen suppliers to develop best known methods (BKM)s and recommended consumables for advanced cell designs. On the equipment side, Applied’s Baccini Esatto Technology™ upgrade package adds a printer/dryer unit and a high precision alignment kit, allowing existing lines to implement new cell designs at relatively little cost. Such drop-in upgrades limit the expense and line disruption of technology upgrades.

Strong partnering with equipment suppliers is equally valuable in managing overall factory operations. Key performance indicators for a solar cell factory include absolute efficiency, material cost, utilization, throughput, and yield. Effective monitoring can help manufacturers see how to improve all of these metrics. For instance, conductive paste in cell manufacturing is a major material expense,
second only to the cost of silicon wafers themselves. Comparing paste consumption across shifts and between lines can highlight wasteful consumption patterns. According to Alex Schwarm, senior global product manager for Solar Automation Products, a 400MW factory with 2% paste usage variability from shift-to-shift and line-to-line potentially wastes as much as $210,000 per year on paste alone.

Similar examples can be found throughout the factory. Line bottlenecks cause work-in-progress to accumulate, adding to inventory carrying costs and putting more product at risk when excursions occur. Variations in incoming wafer quality and process quality cause fluctuations in the efficiency of finished cells. One batch of wafers might have more defects, for example, or one line might produce less consistent contacts. Since cell selling prices depend on efficiency, a wider distribution represents lost revenue. Statistical Process Control (SPC) charts help engineers to examine the process and reduce variability. Factory level charts for uptime, utilization and real-time tool states help factory managers to reduce line bottlenecks and optimize each process step to maximize output. Process parameters and performance data allow engineers to set up controls to minimize excursions due to poor print quality. Small increases in bin yield can make a big difference: if responding to product quality excursions more quickly increases yield by just 0.1%, Schwarm said, a 400 MW output factory would realize an additional 4MW of cell output, worth about $3,120,000.

Cell quality variability, yield loss and process bottlenecks all represent “hidden” capacity—improvements to these areas allow the factory to produce more without additional equipment investments. For this reason, investments in productivity improvement tools pay for themselves many times over. Applied Global Services’ c-Si factory productivity services along with the Applied E3™ Baccini Print Process Monitor App puts process and excursion control, wafer and print quality control, yield analysis, and tool uptime and utilization monitoring tools together in one place, helping to improve efficiency distribution, line yield, and overall output. E3 customers can also consult with Applied Global Services’ factory productivity experts. A fab audit can help identify bottlenecks and material waste, and can suggest the most cost effective process flows.

It’s an exciting time to be a solar cell manufacturer. With the right investments and the right equipment and materials partners, manufacturers can position themselves to be first and take advantage of exciting market opportunities ahead, ready to exploit new technologies and challenges.

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New E3 Apps for Semiconductor Equipment Diagnostics Help Increase Yield and Productivity

One of the most trying and time-consuming tasks for equipment and process engineers is troubleshooting their tools and processes. Whether you have Applied Materials or other semiconductor processing systems, Applied’s latest E3™ Apps can dramatically change the way equipment is maintained. These Apps take the difficulty and time out of troubleshooting so repairs and preemptive tasks can be implemented to improve equipment performance, boost tool utilization and yield, and reduce scrap. Below are brief descriptions of four of these recently released applications, developed on the E3 equipment engineering platform.
E3 CHAMBER VARIANCE REPORTING (CVR) FOR APPLIED MATERIALS PROCESSING SYSTEMS

Mismatched chambers can result in reduced yield, lower throughput, suboptimal tool efficiency and increased product variability. Discovering the source of chamber mismatch requires time-consuming root-cause analysis on potentially thousands of sensors and process variables associated with the tools.

Using the E3 CVR App, engineers now have a fast and easy way to identify and solve difficult chamber variance issues. The E3 CVR App is available for Applied Materials equipment and automatically generates web reports comparing chamber performance. If new sources of chamber variance are found across chambers, the tool notifies operators.

**Speed up chamber analysis to tighten process and product results**

The E3 CVR App tracks a virtually unlimited number of tool sensors and recipes, within the tool or across multiple tools, showing high-resolution data and recipe-specific sensor statistics and visualization. It compares a specific chamber to all other chambers running the same recipe, determines and then shows which sensor is most significant.

The App does this by performing a statistical test on all sensors, steps and statistics to determine which are most strongly correlated to the chamber. The web-based E3 CVR user interface allows users to quickly identify contributions to variances across a fleet of chambers, speeding time to determine root-cause for chamber mismatch. As an example, comparing all chambers running a specific recipe may indicate the most significant sensor is RF reflected power for step 6.

Reports are generated for each period (shift, day, or week). By matching equipment or chambers to the best-performing tool (“golden tool”) or chamber, engineers can use the reports to adjust an errant piece of equipment.

E3 App implementation is simple, with most installations up and running in minutes. Communication is established through the high-speed data port (5 Hz) and the Applied Tool Data Dictionary (TDD), a database with predefined data collection plans and a set of interface configurations for Applied Materials process tools. CVR App configuration only requires operators to specify the process type and define the automated statistics calculation by tool, recipe, step and sensor.

**Benefits**

By rapidly identifying chamber mismatch and the sensors that correlate to root causes, often before it becomes a production problem, the E3 CVR App helps fabs reduce troubleshooting and process variability and increase throughput and availability. At the fab level, it can help increase yield by reducing scrap, tightening bin splits, and boosting line throughput. This App can be quickly deployed on site with a minimum of training and no impact on the customer’s MES/automation integration.

**FIGURE 1a.** Report Inputs. To start analysis, user selects Process Type and the most Recent Report from which to pull data. This example shows CVR analysis for poly etch process.

**FIGURE 1b.** Report Outputs. Recipes, Steps, Sensors and Statistics associated with the report are listed in ranked order. This example indicates that Recipe A and Etch Step are the most correlated to chamber variability. Pressure is the most significant sensor, with Median, Mean and Standard Deviation as the most significant statistics. This information is used by the engineer to focus troubleshooting and make corrections to pressure in Recipe A of Etch Step.
FIGURE 2. The E3 CVR App provides users with summarized data and access to trace data. Charts provide a graphical method to identify chambers that are most different in the fleet. In this case, the Box Plot Chart illustrates that pressure in Etch_01 chamber is different from the rest of the chambers running the same recipe. The Scattered Chart illustrates the pressure trend per run for each chamber. The arrows are the points where the full trace data was investigated for one wafer, with results shown in the Trace Chart. The Trace Chart shows the raw pressure over time for selected wafer. The next step for the user is to identify the root cause for the pressure sensor difference on this tool, and determine whether this is a tool or sensor issue.
E3 WAFER ARC DETECTION APP FOR APPLIED ENDURA PVD TaN
Wafer arcing in the process chambers of PVD TaN systems during deposition can go undetected, causing scrapped wafers and unscheduled downtime. In nanometer-scale processing, even micro-arcing on a small scale can significantly reduce yield. Arcing is difficult to detect during processing, so being able to monitor the process for signs of arcing can dramatically improve system economics.

Monitor chamber data to stop arcing before it starts
The E3 Wafer Arc Detection App monitors data from key tool sensors associated with wafer arcing, providing rapid feedback on process variations. It provides intelligence needed to quickly fix a problem when a limit is violated. This E3 App is specifically tuned for Endura PVD TaN tools. It utilizes the expertise of Applied engineering resources around the world to help customers get the right data off their Applied tools, understand which sensors to monitor, and respond appropriately to the information. Predefined data collection plans contain tool-specific monitoring and detection models that trigger an alarm for out-of-spec readings.

Customer Results
The primary production benefits of E3 are twofold: fewer scrapped wafers for increased output and less equipment downtime.

| Increased Output | Operators can significantly improve equipment uptime through early wafer arcing detection, and cut labor costs associated with unscheduled down events. One customer has seen savings of up to 228 hours annually in equipment downtime, along with >100 hours per tool per year in labor costs required to handle unscheduled down events. |
| Improved Equipment Uptime | Initial results from one customer show an increase of 6–9 wafers per month per tool. |

E3 CLEANING MONITOR APP FOR APPLIED CENTURA ULTIMA X HDP-CVD CHAMBER
Periodically, after every xth process wafer, a special process recipe cleans an HDP-CVD chamber and its critical components to prevent fluorine buildup. After this periodic cleaning, Applied Materials recommends a SiH4 pressurization step. This step is critical for maintaining the surface integrity of the electrostatic chuck (ESC). If it is ineffective, fluorine radicals can remain on the surface of the ESC, allowing wafer “sticking and popping” during de-chuck steps in subsequent process runs, potentially damaging the ESC ceramic surface. ESC failures are expensive and time consuming to repair—up to 24 hours of downtime—and possibly scrapped wafers.

Until now, monitoring in-situ cleaning effectiveness has been challenging because current monitoring tools do not help operators take action in real time. With the E3 Centura Ultima X HDP-CVD Chamber Cleaning Monitor App, this situation can be dramatically improved by enabling true predictive maintenance for HDP cleaning issues.
defined limit, the tool issues an alarm and sends email notification to operators.

Statistical process limit calculations such as max, min, standard deviation, etc., are created for each process parameter. This enables data visualization to determine trends, make comparisons from one line to the next, see data over time, and compare runs. When faults are found, the software diagnoses problems such as throttle valve adjustment issues that can lead to wafer sticking and popping during de-chuck steps. The App alerts operators to the need for preventive maintenance before unscheduled downtime occurs, then provides key intelligence needed to quickly fix the problem.

**Customer Results**
The E3 Centura Ultima X HDP-CVD Chamber Cleaning Monitor App improves output by reducing troubleshooting and increases equipment uptime by ensuring that chamber cleanings are within limits to prevent wafer sticking on 300mm HDP systems. In some instances, the App has shown scrap reduction of more than $100,000 per tool per year.

**APPLIED E3 OVERLAY CORRECTION APP FOR LITHOGRAPHY SYSTEMS**
Degradation to critical dimension (CD) or overlay performance in the lithography area can translate into rework, reprocessing, reduced yields, and lower overall factory productivity. While fabs achieve savings by using older lithography equipment alongside state-of-the-art tools, the tradeoff is overlay performance degradation. Manually controlling corrections is difficult because multiple manufacturing lines and devices often run concurrently.

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**Proactive monitoring in HDP-CVD chambers**
The E3 App proactively maps and monitors multiple chambers, collecting chamber readings continuously during process runs and scanning for potentially ineffective chamber cleaning and conditioning. When a chamber parameter range exceeds the

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**Several components are common across these four E3 Apps:**

- **Software** - The equipment adapter quickly connects E3 to the process tools and manufacturing systems; it collects process and event data directly from the tool and stores it in file format data form. By retrieving the data from the system's software, engineers can conduct nearly instant analysis of many different parameters of interest. The E3 fault detection and classification (FDC) module is one of the various backbones to the E3 Apps for collecting and integrating tool data into a common Oracle database. Other E3 modules can then access this data.

- **Predefined Models** - All E3 Apps contain predefined models that monitor and detect issues during a given process, including highly configurable fault and intervention levels. A configurable dashboard assists users in plotting and analyzing real-time data.

- **Training, Maintenance and Support** - All E3 Apps include user training as well as one full year of maintenance and support. Applied's on-site E3 deployment teams can install preconfigured hardware systems quickly and provide a single point of contact for hardware and software components.
Authors: Ben Harry, Scott Bushman. For additional information, please contact Scott_Bushman@amat.com.

**Improve yields and reduce rework by reducing disturbances**

The E3 Overlay Correction App uses patented control algorithms to eliminate disturbances affecting lithography overlay by correcting for run-to-run litho overlay errors and sending a new recipe for this correction. It tracks product data on tools so that engineers can choose to manually or automatically find the optimal recipe settings before processing to keep overlay within spec.

By using data coming from the Manufacturing Execution System (MES), the App recommends the recipe settings that affect overlay for the next run based on measured overlay parameter errors, as well as disturbances due to tool shifts, controller initialization, and erroneous metrology. Generally, no software development or coding is required. With the E3 R2R Lithography Overlay Correction App, manufacturers can maximize process yields and minimize product rework to improve process capability, in some cases by as much as 30% over open-loop control systems.

Overlay correction is a primary contributor to rework. Several types of variation require constant monitoring and correction through changes to overlay parameters:

- **Tool variations** – temperature changes, power fluctuations, stage fluctuations
- **Other variations** – reticle differences, tool mix and match, process variation

By incorporating fundamental process knowledge into the models, product effects can be separated from all other effects to allow a dynamic, automatic determination of model parameters.

**Customer Results**

The key benefit of the E3 R2R Lithography Overlay Correction App is its demonstrated ability to optimize lithography module performance and improve process capability. This can result in improved yield and less product rework. In addition, quickly matching new tools to the fab's standard process can save significant amounts of time in yield-ramping new tools, lines or fabs. Other benefits that customers have seen include improved Cpk (up to 100%), reduction in rework from 1 to 3%, fewer test wafers, and faster tool qualification.

**E3 APPS BOOST EQUIPMENT OPERATION**

The four E3 Apps are easy to use, even by relatively untrained operators. The E3 configurable dashboard lets operators plot real-time data, analyze various data sources, and monitor equipment health. In many cases, a single univariate analysis (UVA) collection strategy can monitor all process recipes. Equipment engineers can access all tool data as overlay collections and views help to make informed decisions based on data or sensor values. Applied is currently working on new E3 Apps for several Applied Materials equipment platforms, including solar and display.