INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS

2003 EDITION

ENVIRONMENT, SAFETY, AND HEALTH

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ENVIRONMENT, SAFETY, AND HEALTH

SCOPE

BACKGROUND

The semiconductor industry views responsible performance in environment, safety and health (ESH) as critical to success. Continued ESH improvement is a major consideration for semiconductor manufacturers, whose business approach to ESH employs strategies that are integrated with manufacturing technologies, products, and services. This approach is structured around the belief that good business stewardship includes an active awareness and commitment to responsible environmental, safety, and health practices. Addressing these areas aggressively has resulted in the industry being an ESH leader as well as a technology leader.

EXPECTATIONS

For both engineers and research scientists, this roadmap identifies ESH R&D challenges that occur as new wafer processing and assembly technologies are designed and created. Technology requirements are listed in Tables 101–106. It also proposes possible technology and management solutions to meet the challenges, as illustrated in Figures 73–75.

By giving direction to research centers, suppliers, and semiconductor manufacturers, this roadmap focuses the search for solutions. ESH integration into manufacturing and business practices is clearly a priority. A high expectation of success and improvement requires that ESH must be integral to the thoughts and actions of process, equipment, and facilities engineers, and to university researchers. Improvements must meet local, national, and international needs, with positive impact on cost, technical performance, and product timing. They must also minimize risk, public and employee health effects, and environmental impact. Solutions must be timely, yet far reaching, to assure long-term success. Integration of international initiatives and other notable ESH-focused entities sponsored by the semiconductor industry, universities and government have made the ESH objectives of this roadmap truly international. Refer to the link to a new chemical screening tool (*Chemical Restrictions Table*).

DIFFICULT CHALLENGES

Five global ESH challenges essential to a synergistic ESH strategy and that must be integrated into the technical thrust areas are: Chemicals, Materials, and Equipment Management; Resource Conservation; Workplace Protection; Climate Change Mitigation; and Design for Environment, Safety, and Health.

Chemicals, Materials, and Equipment Management must provide timely ESH information to equipment design engineers and equipment users regarding the environmental, safety and health characteristics of potential new process chemicals and materials. This information is essential to the selection of optimal chemicals and materials for function and minimal ESH impact with respect to reaction product emissions, health and safety properties, materials incompatibility with both equipment and other chemical components, flammability and reactivity while minimizing unnecessary business impacts after processes are developed and in production.

Resource Conservation (water, energy, chemicals, and materials) will grow in importance with respect to availability, cost reduction, manufacturing location, sustainability, and waste disposal. As teams accumulate knowledge, the derived values and underlying data for water and energy are in a state of flux. These values will be further refined in 2004.

Workplace Protection is always among the top priorities for our industry. As more knowledge is gained about the impact of the work environment on employee health and safety, technology improvements may need to be made in facilities, equipment, personal protective equipment, and training.

Climate Change Mitigation is a major consideration because it potentially could limit the use of energy and chemicals essential to the manufacturing process. To address the above issues in a cost-effective and timely way, *Design for Environment, Safety, and Health (DFESH)* minimizes ESH impacts by systematically considering them in the design process as an integral part of management decision-making.

Table 101a ESH Difficult Challenges—Near-term

Five Difficult Challenges ≥ 50 nm/Through 2009	*Summary of Issues/Needs*
Chemicals, Materials, and Equipment Management	*New Chemical Assessment* Need for quality rapid assessment methodologies to ensure that new chemicals (or those carried over from previous technologies but that now face new restrictions) can be utilized in manufacturing, while protecting human health, safety, and the environment without delaying process implementation. *Chemical Data Collection* Need to document and make available environment, safety, and health characteristics of chemicals *Chemical Reduction* Need to develop processes that meet technology demands while reducing impact on human health, safety and the environment, both through replacement of hazardous materials with materials that are more benign, and by reducing chemical quantity requirements through more efficient and cost-effective process management *Environment Management* Need to develop effective management systems to address issues related to disposal of equipment, and hazardous and non-hazardous residue from the manufacturing process
Resource Conservation	*Natural Resource Conservation (Energy, Water)* Need to implement known (from supplier optimization studies, benchmarking surveys and best known methods) energy and water use reduction solutions Continue to design innovative energy and water efficient processing equipment *Chemicals and Materials Use* Need more efficient utilization of chemicals and materials *Resource Recycling* Increase resource reuse and recycling *Sustainable Growth* Continued expansion of semiconductor manufacturing with reduced impact on natural resources
Workplace Protection	*Equipment Safety* Continue to design ergonomically correct and safe equipment Minimize ergonomic stressors and health and safety risks during maintenance activities *Chemical Exposure Protection* Increase knowledge base on health and safety characteristics of chemicals, materials, and process byproducts in the manufacturing and maintenance processes and design out potential for chemical exposures and need for PPE
Climate Change Mitigation	*Reduce Energy Use of Process Equipment* Need to design energy efficient processing equipment *Reduce Energy Use of the Manufacturing Facility* Need to develop energy efficient facilities systems *Reduce High Global Warming Potential (GWP) Chemicals Emission* Need ongoing improvement in methods that reduce emissions from processes using GWP chemicals
Design for Environment, Safety, and Health (DFESH)	*Evaluate and Quantify ESH Impact* Need integrated way to evaluate and quantify ESH impact of process, chemicals, and process equipment, and to make ESH a design parameter in development of new equipment and processes

Table 101b ESH Difficult Challenges—Long-term

Five Difficult Challenges *<50 nm/Beyond 2009*	*Summary of Issues/Needs*
Chemicals, Materials and Equipment Management	*Chemical Use Information* Need to understand regulatory requirements that set chemical restrictions Need for comprehensive material life cycle analysis of semiconductor products
Resource Conservation	*Reduce Water, Energy, Chemicals and Materials Use* Need resource efficient processing and facility support equipment driving toward resource sustainability and greener fabs
Workplace Protection	*Equipment Safety* Need more emphasis on safety of fab automation systems/robotics and sub-system isolation (e.g., LOTO of components of cluster tools) for tool maintenance
Climate Change Mitigation	*Reduce Energy Use* The importance of reducing energy use to minimize/slow climate change will grow *Reduce High GWP Chemicals Emissions* The international pressures to reduce emissions of GWP chemicals will continue
Design for Environment, Safety, and Health (DFESH)	*Evaluate and Quantify ESH Impact* Need ESH integrated into the design and development of new equipment and processes

ESH TECHNOLOGY REQUIREMENTS AND POTENTIAL SOLUTIONS

ESH INTRINSIC REQUIREMENTS

For making ESH-related technology decisions, the scientists and engineers responsible for new technology development require an explicit set of analysis methodologies, data sets, and implementation methods. Table 102 defines those needs. The intent is to meet the ESH intrinsic requirements in parallel to, but independent of, the mainstream technology objectives. As teams accumulate knowledge, the derived values and underlying data for water and energy are in a state of flux. These values will be further refined in 2004. The water and energy values in this table are not fully developed; these will be worked by the ITWG in 2004.

One important element of the measurement and evaluation methods is risk assessment. It may be possible to apply the results of investigations by the chemical industry to the semiconductor industry, after appropriate modification. A standardized methodology to identify, access, and accept risk is needed.

A methodology to identify the *lowest ESH impact* materials and processes needs to be developed. Measurement and evaluation methods must be easy to use and reliable. Their meaning lessens if their content is not updated in response to new semiconductor technologies and other technical developments. An algorithm to conduct environmentally conscious design during the device/process development stage is needed.

Process analysis is another evaluation element. Process by-products, for example from plasma processes, are an important issue. The elementary chemical reactions in each process must be understood, and new measurement and evaluation methods must be implemented for developing processes that have the lowest ESH impact.

Database establishment—A database is necessary to store the information for accurately conducting risk assessment on the materials and chemicals used. The database should contain information such as safety data, environmental load/impact data, process data, emission distribution factor (dispersion model) and emission treatment methods to use the material in accordance with existing laws and regulations. At present, the general database for chemicals and materials is generated by the chemical/material industry, but the data are not sufficient, especially on the process used or the distribution factor (dispersion model) of the chemical/material to the environment.

Water—Process simulation and cost optimization tools are required to determine the optimum balance of high efficiency rinse processes; recycling of higher quality water process applications; and reuse of lower quality water for non-process applications at different factories and different locations.

CHEMICALS, MATERIALS AND EQUIPMENT MANAGEMENT

Risk assessment—Prior to employing a new chemical or material, it is necessary to accurately and quickly evaluate the safety, health danger, and environmental load/impact. A decision is then made whether to employ the chemical, based on the quantity to be used, the method to be employed, and the risk assessment. Operator and maintenance worker exposure to the chemical or material must be reduced for safety and health reasons, and emissions must be controlled to minimize environmental load/impact. In addition, the risk assessment should include a check of the chemical against the *linked chemical screening tool*, to ensure that the chemical is not banned or under some regulatory watch.

Safety and environmental load/impact evaluation of new materials and new chemicals—The safety, health hazards, and environmental load/impact of new materials and chemicals must be evaluated. It is necessary to identify the path by which the environmental load/impact material is emitted (including the control of waste material) to find alternative materials, or to develop recovery/treatment technology.

Reduction of environmental load/impact materials and chemicals—Efforts have been made to find alternative materials, especially for greenhouse gases and ozone-depleting substances. Alternative materials for bromine and antimony used as fire resistant materials in plastic packages, and lead used for soldering and tinning, are being developed.

Environment management—It is necessary to control the chemicals and materials in each plant to reduce the quantity used and their emissions. Therefore, a material balance control system is needed. A system for automatically collecting data will be needed as the number of target chemicals and materials expands.

CLIMATE CHANGE MITIGATION

Energy consumption has increased due to the increased energy consumption of the manufacturing equipment for more complex semiconductors, larger diameter wafers, and the increased air conditioning for higher cleanliness of the cleanroom. Changes in areas such as cleanroom design, equipment design, and wafer transfer/storage methods are needed. In addition to the need for more energy efficient tools, it is necessary to reduce the heat load/impact of the tools on the cleanroom and to develop the capability to put the tools into “sleep-mode” when they are idling and not processing wafers. Also optimization of tool exhaust requirements and cleanroom HEPA velocities are required to reduce overall fab energy consumption. Potential solutions for energy are shown in Figure 75.

Global climate change concerns are driving international efforts to reduce emissions of greenhouse gases, such as PFCs used in semiconductor manufacturing.

WORKPLACE PROTECTION

For equipment, processes, maintenance, factory design, and factory integration, the industry must accept and fully employ a standard protocol for hazard control utilizing the following ranking for solutions: 1) hazard elimination, 2) engineering controls, 3) administrative controls, and 4) personal protective equipment (PPE).

Increases in wafer size and throughput will require wafer-handling systems that may increase worker risk during operation and maintenance. The movement of automated wafer transport systems and their interface with manufacturing equipment are potentially dangerous to nearby workers. Design controls and procedures comprehending ergonomics and robotics to improve equipment operability and prevent incorrect operation need to be established.

An industry need exists for safe, cost-effective materials of construction. Fire-resistant, process-compatible materials that meet the needs of manufacturing and the expectations of insurers are necessary for both tools and wafer carriers.

Electromagnetic waves exhibit various wavelength-dependent characteristics. When the wavelength used for pattern exposure is shortened to the X-ray region, the health effects must be evaluated.

RESOURCE CONSERVATION

The increase in wafer size and the number of process steps as well as the need for higher purity water and chemicals indicates a potential trend for higher resource (water, energy, and chemicals) usage per wafer. This trend can be reversed by development of higher efficiency processes and tools and by a combination of strategies including recycling of spent chemicals, water, and waste for process applications and reuse for non-process applications. Resource usage efficiency in semiconductor tools can be greatly improved. For example, in the photolithography process a significant amount of the photoresist applied to the wafer is slung off during the spin-on process step and becomes waste

*Wate*r—Water used in semiconductor manufacturing is mostly ultrapure water (UPW). Since the production of UPW requires large quantities of chemicals, an increase in UPW consumption and quality results in greater chemical consumption (and ultrapure water production cost). A decrease in UPW consumption will reduce environmental effects caused by the chemicals as well as reduce manufacturing costs. Recycling of higher quality water for process applications and reuse of lower quality water for non-process applications is important. In areas where water is plentiful, wastewater recycling will depend on local water reuse options and associated recycling costs. The water values in Table 102 are not fully developed; these will be worked by the ITWG in 2004.

*Energ*y—Limits on sources of energy could potentially limit industry’s ability to expand existing factories or build new ones. While the semiconductor manufacturers have demonstrated improved energy efficiencies over the past decade, potential resource limitations require the industry to continue the trend.

Chemicals—New chemicals and materials will be used and their usage will be rapidly increased with introductions and development of new technologies to satisfy technology requirements. Whereas in the past the same materials would easily support four to five technology generations, today nearly each technology generation requires introduction of one or more new materials. Though total quantity of chemicals and materials usage in semiconductor industry is quite small compared to other industries, resource efficient processing and production equipment are needed.

Zero Waste—In consideration of the items mentioned above, the semiconductor manufacturers should aim at realizing a “zero waste” plant like other industries. To achieve that objective the waste recycle rate must be improved and cooperation with the recycling industry and governments will be necessary.

DESIGN FOR ENVIRONMENT, SAFETY, AND HEALTH

Design for Environment, Health and Safety (DFESH) is the term applied to the integration and proliferation of ESH improvements into the technology design. It allows for the early evaluation of ESH issues related to critical technology developments and ensures that there are no ESH-related “showstoppers.” It requires a comprehensive understanding of tools and materials development, facility design, waste and resource management and the way they affect ESH results. DFESH allows us to build ESH improvements into the way products are manufactured, while maintaining desirable product price/performance and quality characteristics.

Table 102a ESH Intrinsic Requirements—Near-term

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*DRIVER*
Technology Node		*hp90*			*hp65*			
Dram ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*	
Chemicals, Materials, and Equipment Management Technology Requirements								
Assessment of Chemical and By-product Properties								
Data accumulation	**Data Matrix**		**Agreed upon data matrix**					*New restrictions*
New chemicals (include by-product materials)			**50% of data per chemical two years after market introduction**		**100% of data per chemical two years after market introduction**			*New processes*
Resource Conservation Technology Requirements								
Energy Consumption								*Sustainable growth and cost*
Total Fab tools (KWh/cm^2)	**0.5–0.7**			**0.4–0.5**		**0.3–0.4**		
Total Fab support systems (kWh/cm^2)	**0.5–0.7**			**0.4–0.5**		**0.3–0.4**		
Tool energy usage per wafer pass (300 mm versus 200 mm); baseline 1999	**1.5**		**1**					
Water Consumption								*Sustainable growth and cost*
Net feed water use (liters/cm^2)	**8–10**		**8–10**					
Fab UPW use (liters/cm^2)	**5–7**		**4–6**					
Wet bench UPW use (liters/300 mm -wafer pass)	**53**		**42**					
Chemical Consumption and Waste Reduction								*Environmental stewardship and cost*
Chemical use (liters/cm^2/mask layer)	**Reduced 5% per year**			**Reduced 5% per year**				
Recycle/reuse systems	**Expanded Implementation**				**Innovative recycling technologies**			
Waste recycle/reuse rate (%)	**65%**		**70%**					
Climate Change Mitigation Technology Requirements								
Reduce PFC emission	**10% absolute reduction from 1995 baseline by 2010 as agreed to by the World Semiconductor Council (WSC)**							*Voluntary agreement*

Manufacturable solutions exist, and are being optimized ⬜
Manufacturable solutions are known 🟨
Interim solutions are known ◆
Manufacturable solutions are NOT known 🟥

Table 102a ESH Intrinsic Requirements—Near-term (continued)

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*DRIVER*
Technology Node		*hp90*			*hp65*			
Dram ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*	
Workplace Protection Technology Requirement								
Equipment safety, gases and chemical leaks, and equipment stability during an earthquake	**Conformance to International ESH standards and guidelines such as SEMI S2[1] and European CE Mark requirements[2]**							*Worker safety and fab protection*
Safe interface of automated material handling systems (AMHS) and manufacturing equipment	**SEMI S2 guidelines and CE Mark directives**							*Worker safety*
Safe robotics	**SEMI S2 guidelines and CE Mark directives**							*Worker safety*
Comprehensive exposure data	**Collaboration among government, industry, academia, and companies regarding new exposure data**							
Personal protection equipment (PPE)	**Reduced dependence on PPE**							
Material Safety Data Sheets (MSDS)	**Standardized format**			**Comprehensive data**				
Equipment risk assessment (health and safety)	**Common algorithm**			**Common application**				
Potential chemical exposure	**Design out potential for any chemical exposure and reduce dependence on PPE**							
Ergonomic improvement	**Minimized physiological stressors**			**Minimized/eliminated physiological stressors**				
Design for ESH (DFESH)								
Environmental load/impact assessment (LCA)	**Common algorithm to identify and access risk**							*Green Fab*
Chemical risk assessment (health and safety)	**Common algorithm to identify and access risk**							
Material balance	**Pollutant release and transfer disclosure (PRTR)**	**PRTR data acquisition system**						*New materials and restrictions*
	Common test methods, protocol, and application							
Regulatory requirements	**Collection of requirements, guidelines and policy trends**							*Compliance*

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

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[1] *SEMI. S2-93A—Safety Guidelines for Semiconductor Manufacturing Equipment.*
[2] *European CE Mark Safety Requirements.*

Table 102b ESH Intrinsic Requirements—Long-term

Year of Production	*2010*	*2012*	*2013*	*2015*	*2016*	*2018*	*Driver*
Technology Node	*hp45*		*hp32*		*hp22*		
DRAM ½ Pitch (nm)	*45*	*35*	*32*	*25*	*22*	*18*	
Chemicals, Materials, and Equipment Management Technology Requirements							
Assessment of Chemical and By-product Properties							
Data accumulation							
New chemicals (including by-product materials)	**100% of data per chemical two years after market introduction**						
Resource Conservation Technology Requirements							
Energy Consumption							
Total Fab tools (KWh/cm^2)	**0.3–0.4**						
Total Fab support systems (kWh/cm^2)	**0.3–0.4**						
Tool energy usage per wafer pass (300 mm versus 200 mm); baseline 1999	**0.8**						
Water Consumption							*Cost and sustainable growth*
Net feed water use (liters/cm^2)	**3.5**						
Fab UPW use (liters/cm^2)	**4.6**						
Wet bench UPW use (liters/300 mm-wafer pass)	**42**						
Chemical Consumption and Waste Reduction							*Environmental stewardship*
Chemical use (liters/cm^2/mask layer)	**Reduced 5% per year**						
Recycle/reuse systems	**Innovative recycling technologies**						
Waste recycle/reuse rate (%)	**80%**		**90%**				
Climate Change Mitigation Technology Requirements							
Reduce PFC emission	**10% absolute reduction from 1995 baseline by 2010 as agreed to by the WSC**						*Voluntary agreement*

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

Table 102b ESH Intrinsic Requirements—Long-term (continued)

Year of Production	*2010*	*2012*	*2013*	*2015*	*2016*	*2018*	*Driver*
Technology Node	*hp45*		*hp32*		*hp22*		
DRAM ½ Pitch (nm)	*45*	*35*	*32*	*25*	*22*	*18*	
Workplace Protection Technology Requirement							
Equipment safety, gases and chemical leaks, and equipment stability during an earthquake	**Conformance to international ESH standards and guidelines such as SEMI and CE Mark requirements**						
Safe interface of automated material handling systems (AMHS) and manufacturing equipment	🟨 **SEMI guidelines and CE directives**						
Safe robotics	🟨 **SEMI guidelines and CE directives**						
Comprehensive exposure data	**Collaboration among government, industry, academia, and companies regarding new exposure data**						
Personal protection equipment (PPE)	🟥 **Eliminated need for PPE**						
Material Safety Data Sheets (MSDS)	🟥 **Comprehensive data**						
Equipment risk assessment (health and safety)	🟨 **Common application for new equipment**						
Potential chemical exposure	🟥 **Eliminated potential for any chemical exposure and eliminated need for PPE**						
Ergonomic improvement	🟥 **Eliminated physiological stresses for new equipment**						
Design for ESH (DFESH)							
Environmental load/impact assessment (LCA)	🟥 **Lowest environmental load/impact materials in production**						
Chemical risk assessment (health and safety)	🟥 **Lowest chemical risk (health and safety) materials in production**						
Material Balance							*New materials/ restrictions*
Regulatory requirements	**Collection of requirements, guidelines, policy trends, and others**						

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

*Table 103a Chemicals, Materials and Equipment Management Technology Requirements—Near-term**

**Link to the* Environment, Safety, and Health *new chemical screening tool (Chemical Restrictions Table).*

<table>
<tr><td><i>Year of Production</i></td><td><i>2003</i></td><td><i>2004</i></td><td><i>2005</i></td><td><i>2006</i></td><td><i>2007</i></td><td><i>2008</i></td><td><i>2009</i></td><td><i>Driver</i></td></tr>
<tr><td><i>Technology Node</i></td><td></td><td><i>hp90</i></td><td></td><td></td><td><i>hp65</i></td><td></td><td></td><td></td></tr>
<tr><td><i>DRAM ½ Pitch (nm)</i></td><td><i>100</i></td><td><i>90</i></td><td><i>80</i></td><td><i>70</i></td><td><i>65</i></td><td><i>57</i></td><td><i>50</i></td><td></td></tr>
<tr><td colspan="9"><i>Interconnect</i></td></tr>
<tr><td>Low-κ materials—spin-on and CVD</td><td colspan="2">🟨 Lowest ESH impact solvent/CVD precursors</td><td colspan="2">🟨 Minimum emission/waste processes</td><td colspan="3">🟥 75% raw material (chemical) utilization</td><td><i>Speed, signal loss</i></td></tr>
<tr><td>Copper processes</td><td colspan="2">🟨 50% copper reclaimed/recycled</td><td colspan="3">🟨 75% copper reclaimed/recycled</td><td colspan="2">🟥 100% copper reclaimed/recycled</td><td><i>Speed, reliability</i></td></tr>
<tr><td>Advanced metallization</td><td colspan="2">🟨 Lowest ESH impact precursors</td><td colspan="5">🟥 Minimum emission/waste processes</td><td></td></tr>
<tr><td>Planarization</td><td colspan="3">🟨 5% reduction in consumables per year</td><td colspan="4">🟥 5% reduction in consumables per year</td><td><i>Planarity</i></td></tr>
<tr><td rowspan="2">Plasma processes</td><td colspan="3">🟨 Alternative etch chemistries</td><td colspan="4">🟥 Lowest ESH impact etch chemistries</td><td rowspan="2"><i>Etch/clean</i></td></tr>
<tr><td colspan="2">Characterization of plasma by-products</td><td colspan="5">🟥 Lowest ESH impact etch chemistries</td></tr>
<tr><td colspan="9"><i>Front end Processes</i></td></tr>
<tr><td rowspan="3">High-κ materials</td><td colspan="2">🟨 Minimum emission/waste processes</td><td colspan="3">🟨 Lowest ESH impact high-κ materials</td><td colspan="2">🟥 ESH benign processes</td><td rowspan="3"><i>Transistor performance and device development</i></td></tr>
<tr><td colspan="2" rowspan="2">ESH characterization of deposition, etch, and cleans processes</td><td colspan="2">🟨 Low-hazard deposition, etch, and cleans processes</td><td colspan="3">🟥 ESH benign processes</td></tr>
<tr><td colspan="2">🟨 High-κ materials without potentially toxic/bioaccumulative metals (Pb, Ni)</td><td colspan="3">🟥 Lowest hazard metal compounds</td></tr>
<tr><td rowspan="2">Doping</td><td colspan="2">Reduced usage of high pressure dopant delivery systems</td><td colspan="5">🟥 Safe delivery of dopants (zero ESH impact)</td><td></td></tr>
<tr><td colspan="2">ESH characterization of new doping materials and processes</td><td colspan="5">🟥 Lowest hazard dopant materials and processes</td><td></td></tr>
<tr><td rowspan="2">Surface preparation</td><td colspan="2">Ongoing research and integration of solutions</td><td colspan="5">🟥 Optimized surface preparation processes</td><td></td></tr>
<tr><td colspan="3">ESH-friendly wafer clean and rinse processes and tools evaluated</td><td colspan="4">🟨 ESH-friendly wafer clean and rinse processes and tools incorporated into manufacturing</td><td></td></tr>
<tr><td>Front-end etch</td><td colspan="2">ESH characterization of etch processes</td><td colspan="3">🟨 ESH-friendly etch processes</td><td colspan="2">🟥 Etch process hazards eliminated (zero ESH impact)</td><td></td></tr>
</table>

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

*Table 103a Chemicals, Materials and Equipment Management Technology Requirements—Near-term (continued)**

**Link to the* Environment, Safety, and Health *new chemical screening tool (Chemical Restrictions Table).*

<table>
<tr><td><i>Year of Production</i></td><td><i>2003</i></td><td><i>2004</i></td><td><i>2005</i></td><td><i>2006</i></td><td><i>2007</i></td><td><i>2008</i></td><td><i>2009</i></td><td><i>Driver</i></td></tr>
<tr><td><i>Technology Node</i></td><td></td><td><i>hp90</i></td><td></td><td></td><td><i>hp65</i></td><td></td><td></td><td></td></tr>
<tr><td><i>DRAM ½ Pitch (nm)</i></td><td><i>100</i></td><td><i>90</i></td><td><i>80</i></td><td><i>70</i></td><td><i>65</i></td><td><i>57</i></td><td><i>50</i></td><td></td></tr>
<tr><td colspan="9"><i>Lithography</i></td></tr>
<tr><td colspan="8"><i>New Equipment</i></td><td><i>Reduced feature size</i></td></tr>
<tr><td>Optical</td><td colspan="3">Characterization of ESH impacts</td><td colspan="4">Minimal ESH impact from radiation, ergonomics, chemical consumption, and disposal</td><td rowspan="7"><i>Next generation lithography</i></td></tr>
<tr><td>e-Beam</td><td colspan="4">Characterization of ESH impacts</td><td colspan="3">Minimal ESH impact from radiation, ergonomics, chemical consumption, and disposal</td></tr>
<tr><td rowspan="3">EUV</td><td colspan="4">Characterization of ESH impacts</td><td colspan="3">Minimal impact from ionizing radiation, ergonomics, energy/chemical consumption, and disposal</td></tr>
<tr><td colspan="2"></td><td colspan="5">Non-PFOS PAG for EUV resist</td></tr>
<tr><td colspan="7">Requirements for PPE and/or equipment defined</td></tr>
<tr><td rowspan="2">New materials</td><td colspan="2">Characterization of ESH impacts</td><td colspan="5">Minimal ESH impact for new chemicals, purification requirements, wastes, and emissions</td></tr>
<tr><td colspan="2">PFOS alternatives for non-critical uses*</td><td colspan="5">PFOS alternatives for critical uses**</td></tr>
</table>

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

Notes for Table 103a:

***Critical uses of PFOS includes use in a photo-microlithography process to produce semiconductors or similar components of electronic or other miniaturized devices as a:*

–Component of a photoresist (including PAGs and surfactants)

–Component of an anti-reflective coating

*Table 103b Chemicals, Materials, and Equipment Management Technology Requirements—Long-term**

**Link to the* Environment, Safety, and Health *new chemical screening tool (Chemical Restrictions Table).*

Year of Production	*2010*	*2012*	*2013*	*2015*	*2016*	*2018*	*Driver*
Technology Node	*hp45*		*hp32*		*hp22*		
DRAM ½ Pitch (nm)	*45*	*35*	*32*	*25*	*22*	*18*	
Interconnect							
Low-κ materials—spin-on and CVD	**90% raw material (chemicals) utilization**						*Speed, signal loss*
Copper processes	**100% copper reclaimed/recycled**						*Speed, reliability*
Advanced metallization	**Minimum emission/waste processes**						
Planarization	**5% reduction in consumables per year**						*Planarity*
Plasma processes	**Lowest ESH impact etch chemistries**						*Etch/clean*
Front end Processes							
High-κ materials	**Lowest hazard metal compounds**						*Transistor performance* *Transistor performance and device development*
Doping	**Safe delivery of lowest hazard dopants (zero ESH impact)** **Self-cleaning dopant tools *(in situ* clean)**						
Surface preparation	**ESH-friendly rinse processes and tools incorporated into manufacturing**						
Front end etch	**Etch process hazards eliminated (zero ESH impact)**						
Lithography							
New Equipment							*Reduced feature size*
Optical	**Minimal ESH impact for ionizing radiation, ergonomics, chemical consumption, and disposal**						*Next generation lithography*
e-Beam	**Minimal ESH impact for ionizing radiation, ergonomics, chemical consumption, and disposal**						
EUV	**Minimal impact from ionizing radiation, ergonomics, energy/chemical consumption, and disposal**						
New materials	**Minimal ESH impact for new chemicals, purification requirements, wastes, and emissions**						*Reduced feature size*

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

Table 104a Climate Change Mitigation Technology Requirements—Near-term

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Technology Node		*hp90*			*hp65*		
DRAM ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*
Interconnect							
Reduce PFC emissions for CVD equipment	**Optimized chamber clean processes, alternative chemistries, and cost-effective abatement**	**Optimized chamber clean processes, alternative chemistries, and cost-effective abatement for new technologies**					
Chamber clean gas utilization*	**95%**		**98%**				
Front End Processes							
Reduce PFC emissions (etch)	**Develop optimized etch processes and cost-effective abatement**	**Optimized etch processes, alternative chemistries, and cost-effective abatement for new technologies**					
			New alternative etch chemistries identified				

**Utilization = (PFCin-PFCout)/PFCin*100*

Table 104b Climate Change Mitigation Technology Requirements—Long-term

Year of Production	*2010*	*2012*	*2013*	*2015*	*2016*	*2018*
Technology Node	*hp45*		*hp32*		*hp22*	
DRAM ½ Pitch (nm)	*45*	*35*	*32*	*25*	*22*	*18*
Interconnect						
Reduce PFC emissions for CVD equipment	**Optimized chamber clean processes, alternative chemistries, and cost-effective abatement for new technologies**					
Chamber clean gas utilization*	**98%**					
Front End Processes						
Reduce PFC emissions (etch)	**Optimized etch processes, alternative chemistries, and cost-effective abatement for new technologies**					

**Utilization = (PFCin-PFCout)/PFCin*100*

Manufacturable solutions exist, and are being optimized	☐
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

Table 105a Resource Conservation Technology Requirements—Near-term

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*Driver*
DRAM ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*	
Interconnect								
Copper processes	**Minimum rinse water, consumables and chemical consumption**		**Copper processes optimized for ESH**					*Increasing number of interlayers*
Planarization	**Reduced water consumption**	**Water recycle/reclaim**						
Plasma processing	**Reduced tool idle energy use**							
Front End Processes								
High-κ	**Energy-efficient deposition processes**							
Doping	**More efficient heat removal (PCW) from implanters**		**Minimum energy use for future doping technologies**					
Surface preparation	**Energy efficient clean processes (reduced exhaust flow rates)**							
	Incorporation of novel rinse methods in wet tools	**Novel water reduction techniques derived from surface/interface science**						
Front-end etch	**Reduced tool idle energy**							
Starting materials	**Quantified energy/water reduction from SOI-based process flows**							
Lithography								
Equipment resource consumption: optical, e-beam, and EUV	**Optimized energy consumption, equipment related chemicals/ gases/materials, and water consumption**							*Reduced feature size*
Factory Integration								
Net feed water use (liters/cm^2)	**3.5**		**3.5**					
Fab UPW use (liters/cm^2)	**5–7**		**4–6**					
Wet bench UPW use (liters/300 mm-wafer pass)	**53**	**42**						
Assembly and Packaging								
Eliminate waste from molding process	**Zero waste from molding technologies**							
Reduce water use	**0.8X (X = 1999 baseline)**							
Reduce chemical use and consumption	**0.8X (X = 1999 baseline)**							

Manufacturable solutions exist, and are being optimized ⬜
Manufacturable solutions are known 🟨
Interim solutions are known ◆
Manufacturable solutions are NOT known 🟥

Definitions:
Net feed water use—Source water consumed in support of the operation of the wafer fabrication facility, including sanitary, irrigation, and facilities infrastructure. Net feed water may be obtained from a city supply, surface or ground water body.
UPW use—Water used in wafer contact processes, including water recovered from any source.
Tool UPW use reduction—A percentage reduction versus 200mm UPW usage. The baseline value is set at (0.83 gal per in^2 per mask layer).

Table 105b Resource Conservation Technology Requirements—Long-term

Year of Production	*2010*	*2012*	*2013*	*2015*	*2016*	*2018*	*Driver*
Technology Node	*hp45*		*hp32*		*hp22*		
DRAM ½ Pitch (nm)	*45*	*35*	*32*	*25*	*22*	*18*	
Interconnect							
Copper processes	**Copper processes optimized for ESH**						*Increasing number of interlayers*
Planarization	**Water recycle/reclaim**						
Plasma processing	**Reduced tool idle energy usage**						
Front End Processes							
High κ	**Energy efficient deposition processes**						
Doping	**Minimum doping energy for future technologies**						
Surface preparation	**Energy efficient clean processes (optimized exhaust flow rates)**						
Front end etch	**Reduced tool idle energy usage**						
Starting materials	**Quantified energy/water reduction from SOI-based process flows**						
Lithography							
Equipment resource consumption: optical, e-beam, and EUV	**Optimized energy consumption, equipment related chemicals/ gases/materials, and water consumption**						*Reduced feature size*
Factory Integration							
Net feed water use (liters/cm^2)	**3.5**						
Fab UPW use (liters/cm^2)	**3–5**						
Wet bench UPW use (liters/300 mm wafer pass)	**35**						
Assembly and Packaging							
Eliminate waste from molding process	**Zero waste from molding technologies**						
Reduce water use	**0.5X (X = 1999 baseline)**						
Reduce chemical use and consumption	**0.5X (X = 1999 baseline)**						

Table 106 Design for Environment, Safety, and Health Technology Requirements

Year of Production	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Technology Node		*hp90*			*hp65*		
DRAM ½ Pitch (nm)	*100*	*90*	*80*	*70*	*65*	*57*	*50*
Factory Integration							
Improved factory design and equipment integration for ESH	**Incorporate ESH design guidelines, methodology, and criteria into tool and factory design**			**Safe, "green" Fab**			

Manufacturable solutions exist, and are being optimized	⬜
Manufacturable solutions are known	🟨
Interim solutions are known	◆
Manufacturable solutions are NOT known	🟥

ESH INTRINSIC REQUIREMENTS

ESH requirements were established based on mapping of the technical thrust needs against the ESH Difficult Challenges. The specific technical thrust influences are discussed below.

INTERCONNECT

The interconnect area poses several unique environment, safety, and health (ESH) challenges. Because of the new processes being developed to meet the technology demands, the industry is evaluating new materials in the area of advanced metallization, low κ, CMP, supercritical fluid wafer cleaning and post-copper/low-κ interconnect schemes. The ESH impacts of these new materials, processes, and subsequent reaction by-products must be determined as early as possible, ideally in the university and early supplier research stages, to ensure that the ESH information is available to the users. This determination will allow selection of optimal process materials based on both function and lowest ESH impact with respect to reaction product emissions, health and safety properties, materials compatibility with both equipment and other chemical components, flammability, and reactivity. This will minimize undesirable business impacts after processes are developed and used in large-scale production. The near-term technology requirements for Chemicals, Materials, and Equipment Management (Table 103a) include the development of the lowest impact materials and processes for all areas of interconnect. This includes solvents and polymers for spin-on processes, CVD precursors, low-κ pore sealers and barrier materials, planarization chemistries and pads, and etch chemistries. It also calls for reduced chemical requirements and reduced waste in these areas, which may be achieved by increasing chemical utilization efficiency in CVD processes; extending bath life or recycling in copper plating; and decreasing slurry requirements or recycling slurry in CMP. The long-term technology requirements (Table 103b) include zero-waste deposition processes for both dielectrics and metals and non-chemical consuming processes for planarization.

The use of supercritical fluids such as supercritical carbon dioxide for removing etch residues from low-κ materials is a promising emerging technology that will significantly reduce chemical and water waste. Since there are currently no suitable cleaning methods for low-κ dielectrics, supercritical fluid processes promise to become the enabling technology for via veil and post-etch low-κ cleans. This is a good example of how a more environmentally benign process can also have significant process advantages.

Global warming resulting from the emission of greenhouse gases has been identified as one of the possible causes of climate change. Perfluorocompounds (PFCs), one type of high global warming potential chemicals, are used almost exclusively in interconnect in dry etch and chamber cleaning applications. Both the near- and long-term technology requirements for Climate Change Mitigation (Table 104) are for a 10% absolute reduction of PFC emissions from the 1995 baseline, the goal established internationally by the semiconductor industry. To achieve this aggressive goal and to ensure that these chemicals remain available for industry use, the industry must strive to reduce emissions of PFCs compounds via process optimization, alternative chemistries, recycle, and/or abatement. The development of new materials results in the implementation of new etch chemistries; the lowest ESH impact etch processes should be developed that do not emit high global warming potential by-products. This concept also applies to CVD chamber cleaning.

The increased requirement for CMP will result in interconnect becoming a major user by volume of both chemicals and water. As indicated in the short term technology requirements for Resource Conservation (Table 105a), efforts must be made to develop the lowest ESH impact CMP and post-CMP clean chemistries while reducing overall water requirements. Rinse water minimization in copper electroplating and post-CMP cleaning is necessary. Water recycle and reclaim for CMP and post CMP cleans is also a potential solution for water use reduction. With increased focus on energy conservation, the power requirements of plasma processing and CMP tools and related infrastructure must be minimized. RF generators are energy-intensive. Plasma processes are neither energy-efficient nor efficient in the way they utilize the input chemistries (10–70% dissociation). Waste heat from the plasma systems could possibly be recovered for reuse. Future generation tools would require R&D in low-energy consuming plasma systems. Etchers and CVD tools use point-of-use (POU) chillers and heat exchangers to maintain wafer and chamber temperatures in a vacuum. More efficient heating and cooling control systems could help decrease energy use. New research is needed for improved heat transfer in vacuum systems. Greater use of cooling water for heat removal from tools versus heat dissipation to the clean room results in fab energy savings.

The near-term technology requirements for Workplace Protection (Table 102a) call for the development of tools with reduced employee exposure. This applies to the development of new copper plating tools as well as tools that may be developed for optical interconnect in the long term.

FRONT END PROCESSING

Key ESH concerns for Front End Processes center on development of new materials for gate dielectrics and electrodes; natural resources use (especially water); management of potential physical and chemical hazards to ensure worker protection; and optimization of processes to reduce chemical use and the generation of wastes that require abatement. New materials for 100 nm technologies and beyond (and corresponding precursors, clean techniques and etch gases) will require thorough ESH review.

The global ESH challenges affect all areas of Front End Processes. The primary chemical management strategy should be to optimize processes to maximize chemical use efficiency, including consideration of chemical throughput, waste generation, recovery of hazardous materials, and tool utilization factors. On-demand, *in situ* chemical generation can contribute to improved efficiency. Energy needs (tool and facility systems) must be evaluated for new technologies. Worker protection measures should address potential physical (such as thermal, non-ionizing radiation, laser, and robotics hazards) as well as chemical hazards, especially during equipment maintenance. Factory planning and layout should include ergonomic design criteria for wafer handling (especially for 300–450 mm wafers. ESH cost-of-ownership (CoO) and risk assessment tools should be utilized to evaluate process improvements and identify potential risks of new materials.

In addition, key ESH issues apply to specific areas of Front End Processes:

Surface preparation—ESH concerns for surface preparation focus on new clean techniques, chemical use efficiency, and consumption of water and energy. Surface preparation methods will undergo fundamental changes to accommodate new materials after the 2005 timeframe for expected adoption of new gate dielectrics and electrodes. There is a need for improved understanding of surface and interface science with the potential for significant reductions in chemical or water use.

Chemical use optimization should be applied to conventional and alternative cleaning processes. Several alternative clean processes have potential for significant chemical use reduction (supercritical fluids, dilute chemistries, sonic solvent cleans, simplified process flows, O_3 cleans). Fluid flow optimization and sensor-based process control should be evaluated. Potential increased use of anhydrous gases (HF/HCl and alternatives) should be reviewed through process hazards analysis.

Sustainable, optimized water use strategies utilizing improved UPW production efficiency, reduced tool consumption, and efficient rinsing are being developed. However, the impact of alternative cleaning methods (such as cryogenic wafer and parts cleaning and hot-UPW wafer cleaning) or UPW production methods (such as continuous electrolytic ion-exchange) on energy consumption needs to be considered. Alternative solvent-based cleans need development. Development of reliable, on-line, quick-response sensors to speciate low-level organics is needed to mitigate the process risk of UPW recycling. The optimization of test wafer usage can reduce chemical, water, and energy consumption. Wet-tool designs should continue to incorporate enclosed processes, ergonomic and robotics safety principles.

Starting materials—Current materials are primarily Czochralski (CZ) polished silicon wafers with an epitaxial (Epi) silicon layer. Silicon-on-insulator (SOI) materials expected in conjunction with the 130 nm node may offer ESH advantages of fewer process steps—less chemicals and less energy than other materials. Larger wafers (300–450 mm) will require more chemicals, energy and water, although industry initiatives have been advanced to hold usage flat.

Thermal/thin films—The evaluation of alternative higher-κ materials must include thorough assessment of potential process hazards associated with both the materials and associated deposition processes. Alternative silicides (such as Co, Ni, others) present potential hazards requiring mitigation through engineering controls and appropriate personal protective equipment. Chemical use efficiency can be optimized through improved delivery systems and tool designs (such as small batch furnaces, single-wafer tools). Energy use, for diffusion and implant tools and associated facility systems (exhaust) should be evaluated and optimized.

A wide variety of organic ligands (potentially including halogens) are proposed as high-κ precursors. The resulting metallorganic compounds may pose potential toxicity or flammability hazards. Anneals are probably necessary, utilizing N_2, FNO_2, O_2, NH_3, H_2 (forming gas).

Various metals and sources (gas phase, solution, and solid) are being considered for gate electrodes. Gate metals will range from doped-polysilicon to metals (Ta, Ti, Nb, Al, Mo, Zr, V, Co W, Ru, Rh, Ni, Re, Ir, Pt) and various silicides and nitrides. Most CVD precursors will be organometallics, but they may be dissolved in a matrix solution with stabilizers, and carrier liquid that will be injected as a liquid.

Doping—The potential physical and chemical hazards of alternate technologies (a variety of new techniques are being considered) need to be evaluated and mitigated. Process hazards analysis tools will assist in managing hydrides (SiH_4, B_2H_6, PH_3, SbH_3, AsH_3, possibly others), metal alkyls and laser sources. Sub-atmospheric delivery stems should be developed for a wider variety of dopant materials.

Front-end plasma etch—Continued use of PFCs will necessitate near-term process optimization/increased gas utilization (conversion efficiency within the process). Over the longer term, alternative chemistries for PFCs that do not emit PFCs as by-products need to be developed. Changes in gate dielectric materials will drive corollary changes in etch chemistries, necessitating review of potential ESH impacts. High-κ materials will require an anisotropic selective etch over doped Si. The chemistry for these etches have not been determined but will most likely include Cl-based chemistries.

LITHOGRAPHY

From the perspective of ESH, lithography is represented by four subject areas. These are lithography and mask manufacturing chemicals (photoresists, ARCs, adhesion promoters, edge bead removers, thinners, developers, rinses, and strippers); processing equipment (spin coaters, vapor-phase deposition systems, and silylation ovens); exposure equipment (EUV, E-beam, X-ray, and ion beam); and equipment cleaning. Of critical concern with respect to these areas and the implementation of new lithography technologies is the avoidance of showstopper problems. In particular, the ESH impact of the new process chemicals, compliance with environmental regulations, equipment safety, and worker protection must be considered before changes are made.

Photolithography and mask manufacture chemicals—The first critical need in this category is the need for information related to properties and availability of new chemicals used in photolithography and mask manufacture. Among the information required are chemical toxicity, health risk assessment data, status under TSCA, ability to monitor potential exposures, process emissions (HAPs and VOCs) including etch, strip, etc. The second critical need is for better materials management. This would include integration of new materials into patterning, maintaining performance and cost while, at the same time, promoting recycling and minimum use. Another critical need is the identification of alternatives to the traces of PFOS contained in developers, surfactants, photoacid generators (PAGs) and resists. Also the development of immersion technology must be closely monitored for any potential ESH impacts.

Potential solutions for these critical needs include preparation of a list of acceptable lithography chemicals based on evaluation of TSCA conformance, development of analytical protocols that enable monitoring of new chemicals, robust chemical selection criteria, risk assessment, and the use of pollution prevention principles. Additional potential solutions include alternative materials and chemistries, life cycle analysis of new materials and chemistries, use of additive technologies, and use of benign materials.

Processing equipment—Critical needs for processing equipment include understanding potential exposure to toxic materials, emission of HAPs and VOCs, hazardous waste disposal, cost of ownership, and energy consumption. Additional needs are ergonomic design of equipment, controlling emissions from PFC usage, and plasma byproducts. Lastly, there is a need to minimize waste, for example, waste resulting from spin-on processes and assorted "wet" processes.

Among the potential solutions are effective point-of-use abatement, optimization of tool exhaust, use of pollution prevention and DFESH principles, and supplier use of S2 and S8 standards[3]. Further potential solutions include deployment of zero impact processes, elimination of the need for materials with significant global warming potentials, and utilization of DFESH tools in design of new tools.

Exposure equipment—Critical needs with respect to new exposure equipment include understanding toxicity of required chemicals, control of potential exposure to radiation, risk assessment, cost-of-ownership, hazardous energies, and beam shielding.

Potential solutions include performing risk assessments, analysis of cost-of-ownership and establishing radiation protection programs, as necessary.

Equipment cleaning—Critical needs relate to understanding solvent usage, emission of HAPs and VOCs, hazardous waste disposal, and required personal protective equipment. It will also be important to understand the proper selection of cleaners and cleaning methodologies.

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[3] *SEMI. S2-93A—Safety Guidelines for Semiconductor Manufacturing Equipment.*
SEMI S8—Safety Guidelines for Ergonomics/Human Factors Engineering of Semiconductor Equipment.

Potential solutions include cryogenic cleaning, solvent-free cleaning, dry resist technology, point-of-use abatement, pollution prevention, and optimization of tool design. Additionally, redesign of processes and equipment to achieve minimal environmental impact will be required.

FACTORY INTEGRATION

Responsible safety, health, and environmental performance for the semiconductor industry begins with factory pre-design (training and planning), design and construction. Standardization of safety and environmental systems, apparatus, procedures, and methodologies when applicable, will prove to be an efficient and cost effective approach. Sharing of these practices can reduce start-up schedules and will result in greater cooperation by equipment suppliers for interfacing their products into factories. Factory design, manufacturing equipment, the interface between these elements and their interaction with the people who work in this environment strongly influence ESH performance for the industry.

Early comprehension of safe and environmentally responsible design coupled with an understanding of code and regulatory requirements is essential for designers to develop factories that meet ESH expectations, reduce start up schedules, and avoid costly retrofits and changes.

Accepted protocol and order of selection for risk management are hazard elimination, design controls (isolation or engineering design), administrative controls (procedural), and personal protective equipment.

One opportunity for greater standardization exists with manufacturing and assembly/test equipment. Standardization in ESH aspects of equipment design, design verification, ESH qualification and signoff will greatly improve ESH performance, start up efficiency, and cost. Additionally, standardization of ESH practices in equipment maintenance, modification, migration, decommissioning, and final disposition will also reap substantial performance improvements in ESH and cost over the life of equipment and factories.

Standardization of building safety systems and interface to tools will improve safety and also increase efficiency of installations and reduce start-up times. This would include but is not limited to fire detection and suppression systems and their monitoring interface, gas detection systems, electrical and chemical isolation devices, emergency shut off systems, and safety related alarms. These include building systems as well as those that are integral to manufacturing and assembly/test equipment.

Additionally, the careful selection of process and maintenance chemicals addressed in other sections of this roadmap should be complemented by designs that serve to isolate personnel from equipment and product during operation and maintenance of equipment and systems.

The safety issues associated with factory processing support systems must also be aggressively improved in future factories. As more is known about potential impacts of the work environment on the health and safety of workers, protection improvements must be incorporated into factory systems. Improved risk assessment methodologies and their consistent utilization during the design phase will enhance this effort.

A thorough understanding of the potential safety risks associated with automated equipment will drive development of standards that assure safe working conditions for both people and product. These standards and guidelines must be integrated into the automated systems, the tools with which they interface, and the interface between them.

The industry faces increasing permit, code, and emissions limitations. Planning for future factories and modifications to existing factories should involve cooperative efforts with code entities and government bodies to ensure that advancements in technology of tools and factories are comprehended and utilized in new regulations and amendments. These actions must be driven on a global level. The semiconductor industry should move to establish basic ESH specifications that apply to all equipment and factory practices that are recognized around the world.

Factory design defines the systems that deliver process materials to tools, manage by-products, and control work place environments. Future factory design must balance resource conservation, reduction, and management. These conservation and reduction programs are driven by increasing competition for limited water and energy resources, pollution concerns, and industry consumption of these limited resources.

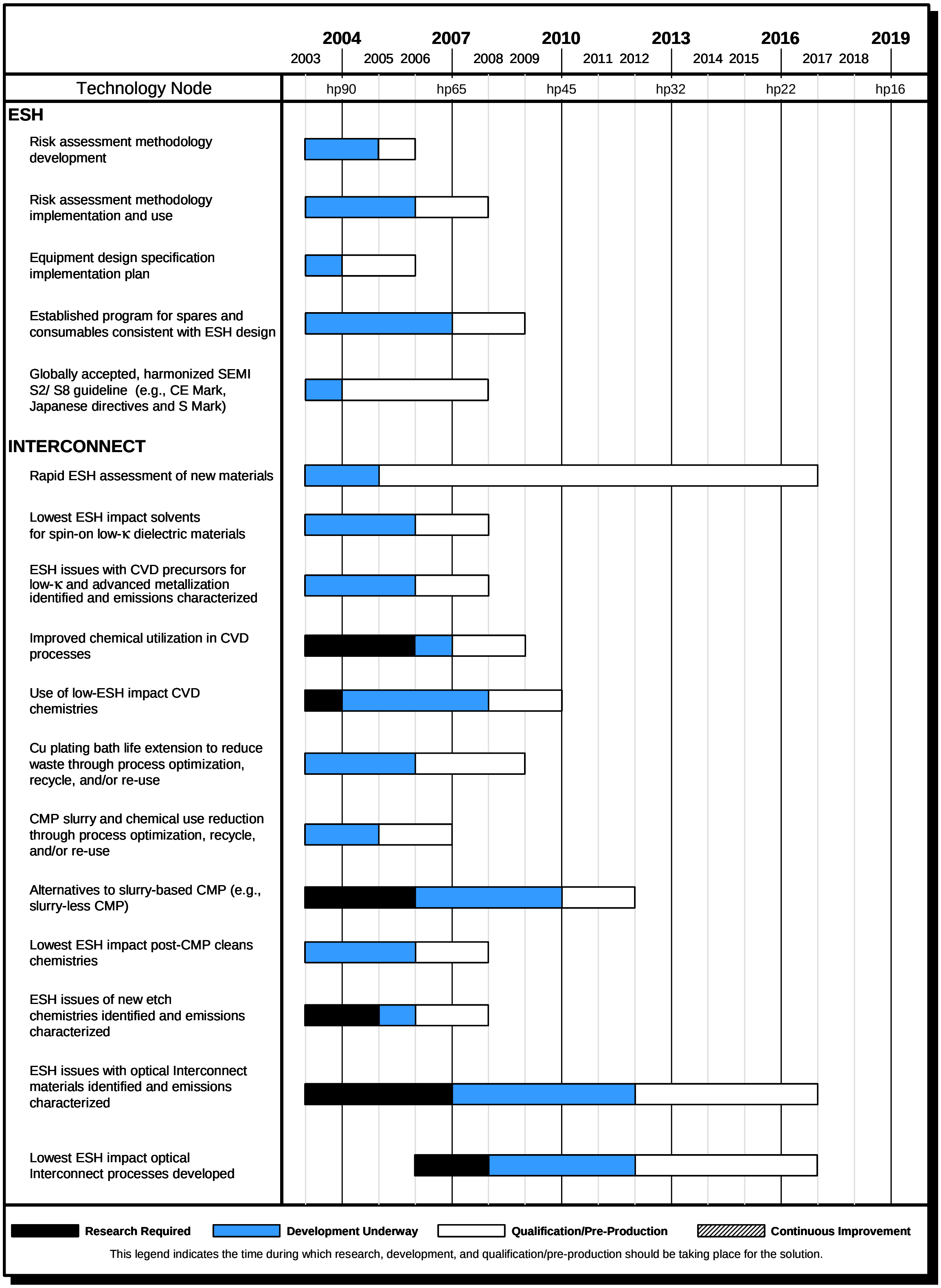
ESH standardization and design improvements for factories and equipment can be greatly enhanced through training programs established for and by the industry. Technology now allows for computer based training (CBT) programs to be developed to address all of the design and procedural challenges noted in this section.

While much of the responsibility for reduction in use of limited resources and waste minimization rests with the tool suppliers and process technologists, application of advanced resource management programs to factory systems will have a significant impact. The goal of these future programs is to build factories that minimize resource consumption and maximize reuse, recycle, or reclaim of by-products to produce near-zero discharge factories. Key factory-related ESH programs require water reuse in process and non-process applications, energy efficient facilities equipment, improved facilities system design, and new facilities operating strategies.

ASSEMBLY AND PACKAGING

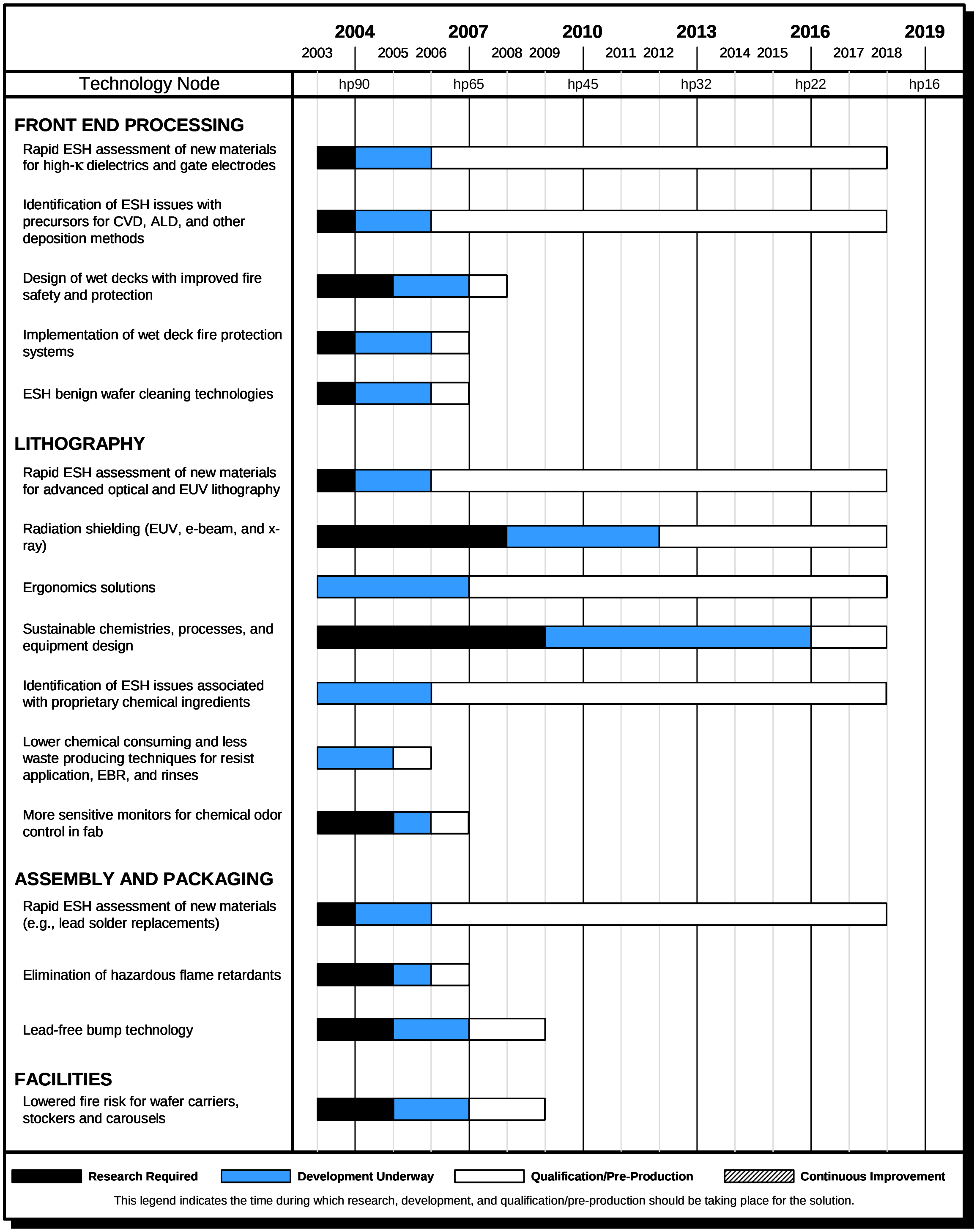
The drive towards flip-chip and chip-scale packaging will change the ESH needs for assembly and packaging eventually completely, as these technologies eliminate the application of leadframes, conventional molding and substrates. However, the use of environmentally hazardous materials, such as lead, chromium, beryllium, antimony, and brominated flame retardants is under increasing international regulatory pressure. Restrictions on the use of these materials in the European market are expected soon. For example, the ban on the use of lead goes into effect on July 1, 2005. Lead (Pb) has special significance since alternative soldering processes will cause numerous problems in the electronics industry, where the current process is widely used and integrated in equipment assembly lines. *Alternatives may cause a technology problem, as the soldering temperature of semiconductors has to be increased, leading to reduction of chip lifetime and quality*. For power devices, an additional complication is the use of a lead-containing alloy to attach the chip to the leadframe.

The reduction of energy consumption is important from a global warming as well as resource conservation point of view. The needs for assembly and packaging are not tied to the nodes of the wafer production, but to the requirements and technologies of our customers. However, to maintain the roadmap format, the same tables have been used.



This legend indicates the time during which research, development, and qualification/pre-production should be taking place for the solution.

Figure 73 Potential Solutions for ESH:
Chemicals, Materials, and Equipment, and Worker Protection



This legend indicates the time during which research, development, and qualification/pre-production should be taking place for the solution.

Figure 73 Potential Solutions for ESH:
Chemicals, Materials, and Equipment and Worker Protection (continued)

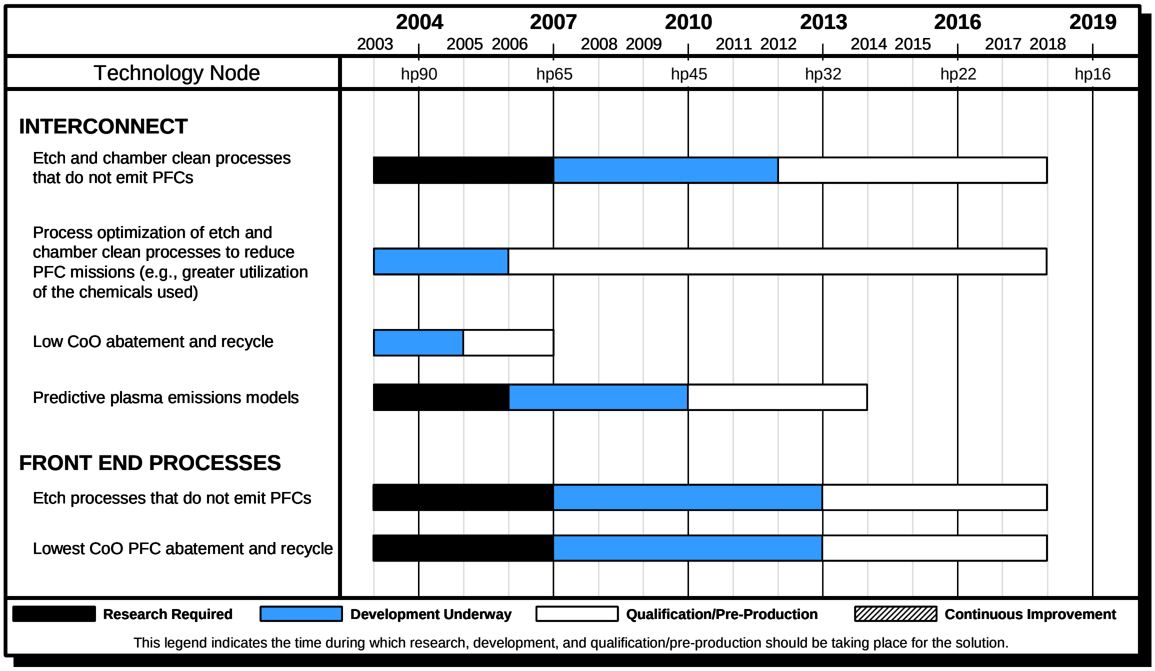


Figure 74 Potential Solutions for ESH: Climate Change Mitigation

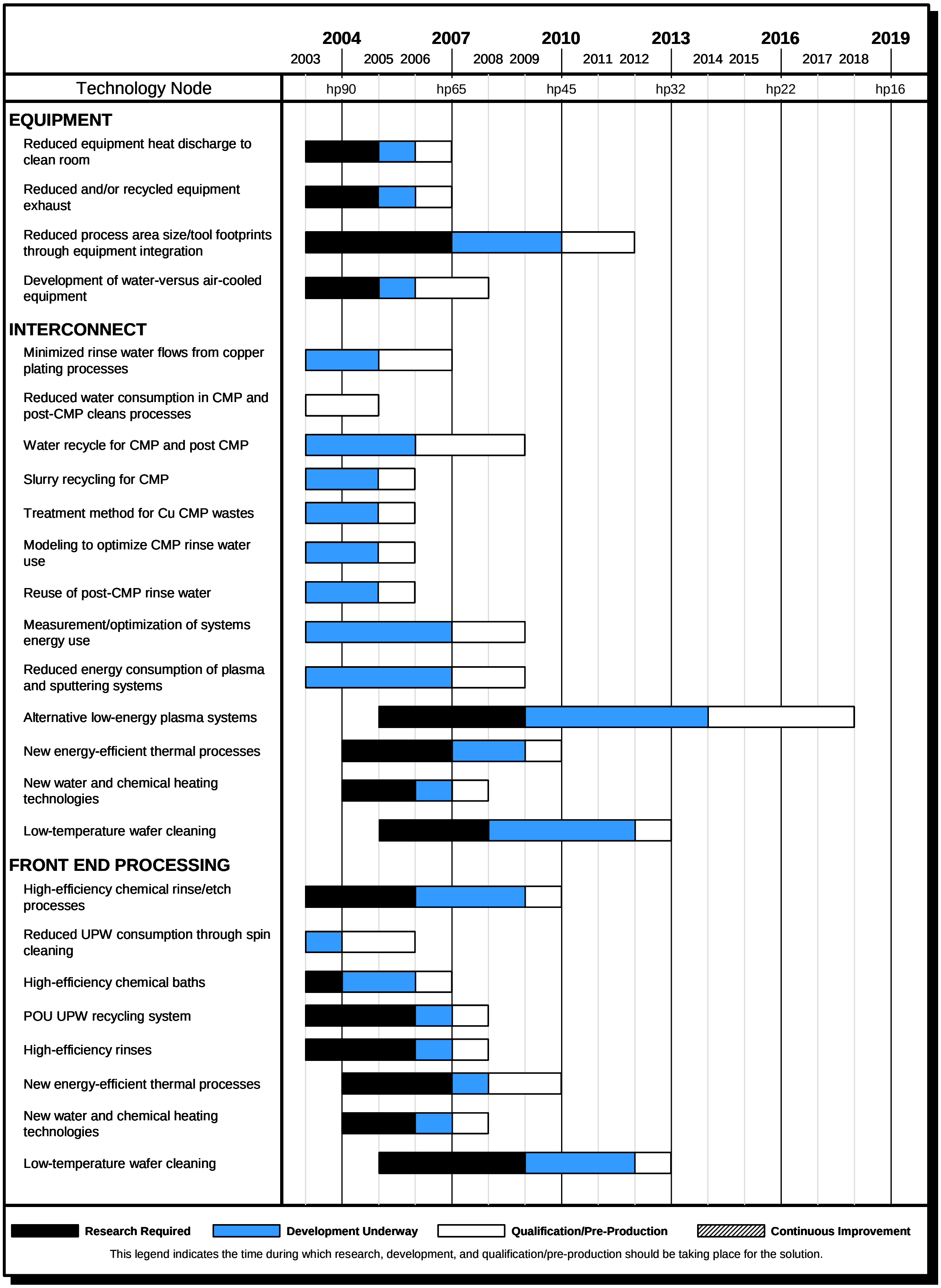


Figure 75 Potential Solutions for ESH: Resource Conservation

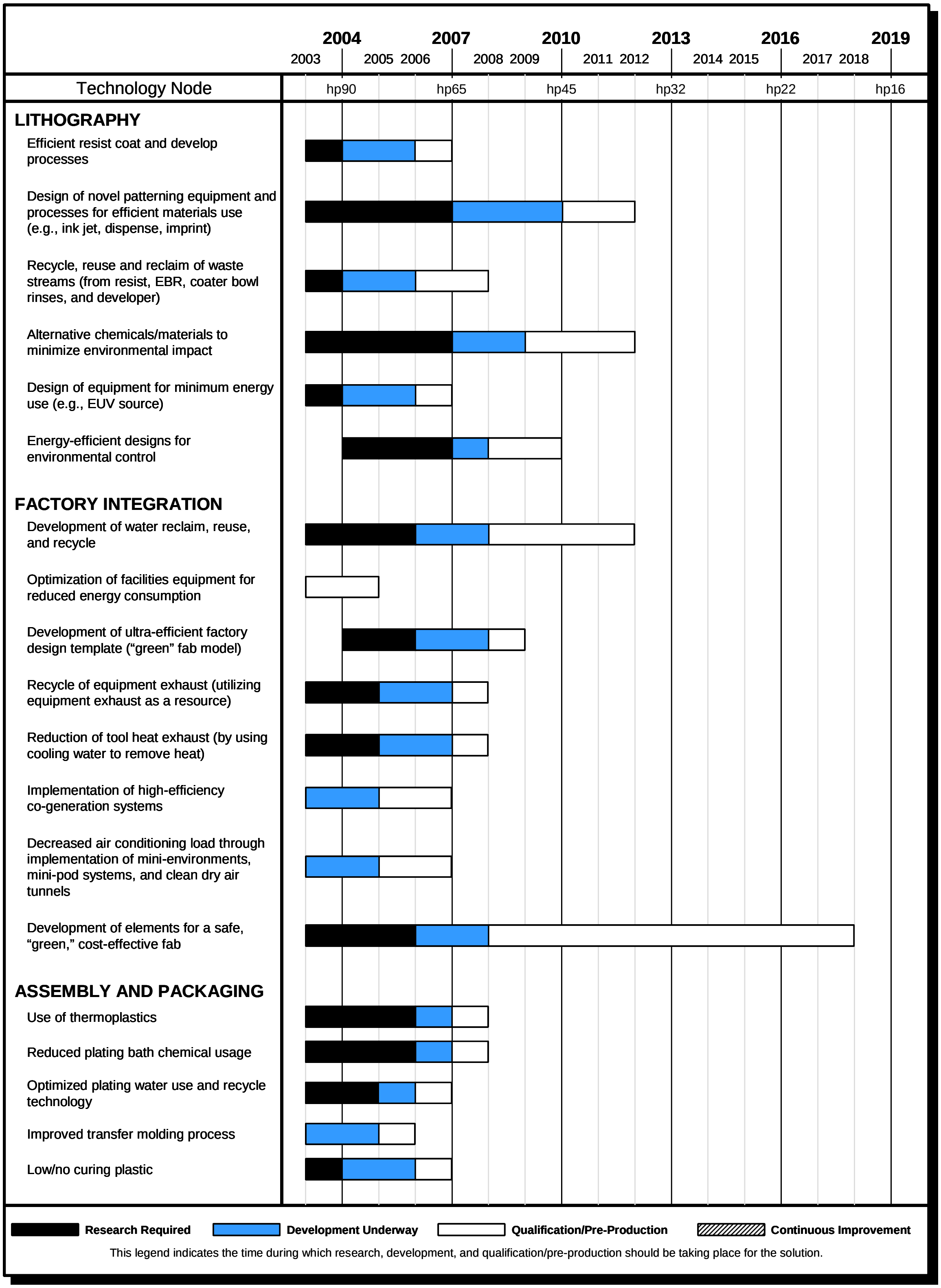


Figure 75 Potential Solutions for ESH: Resource Conservation (continued)