INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS 2006 UPDATE

ENVIRONMENT, SAFETY, AND HEALTH

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ENVIRONMENT, SAFETY, AND HEALTH

SUMMARY

For 2005 the *ESH chapter* has been fully reorganized following a major revision of the ESH Difficult Challenges that now address the four categories: Chemicals and Materials Management, Process and Equipment Management, Facilities Energy and Water Optimization, and Sustainability and Product Stewardship. The revised Difficult Challenges are now more reflective of their multiple functions to be able to incorporate external influences (e.g., regulatory) on semiconductor technology development, serve as a more effective "filter" to evaluate the technology thrust needs, and identify intrinsic needs for ESH R&D. There has been further elimination of repetitive technical requirements that are considered ESH maintenance of business such as tool safety audits, which do not themselves require development, but are a method used to evaluate tools entering the marketplace. Increasing emphasis has been placed on the need to understand and manage materials and material alternatives, given the growth in public policy concern over use of chemicals for which little ESH characterization is available. In addition, Product Stewardship has been formerly identified as an ESH challenge with appropriate technical requirements, as there grows increasing emphasis in the market over reducing hazardous content of products.

The 2006 Update revisions to the Environment, Safety, and Health chapter were minor and are summarized as follows. Roman numerals were added in Tables 104a & b, *ESH Intrinsic Requirements*, to indicate the major headings and distinguish them from sub-section titles. In Tables 105a & b, the word “lowest” (regarding ESH impact) was replaced with “low”, indicative of the ever-changing nature of process materials and their critical process performance requirements. Additionally, a footnote was added to these tables to show mathematically the definition for the word “utilization”, as used in the text. The title of Tables 106a & b was changed to align with the categories in Table 103, *ESH Difficult Challenges.* Also, minor changes were made to the wording around “idle water and energy usage”. The last change worth noting included the addition of “Optimization of CMP Water Use at Idle” as a potential ESH solution in Figure 100.

Table 103a ESH Difficult Challenges—Near-term UPDATED

Difficult Challenges ≥ 32 nm	*Summary of Issues*
Chemicals and materials management	*Chemical Assessment* Lack of quality rapid assessment methodologies to ensure that chemicals can be utilized in manufacturing, while protecting human health, safety, and the environment without delaying process implementation *Chemical Data Availability* Lack of comprehensive ESH data for new, proprietary chemicals and materials to respond to the increasing external and regional requirements on the use of chemicals *Chemical Exposure Management* Lack of information on how the chemicals and materials are used and what process by-products are formed
Process and equipment management	*Chemical Reduction* Need to develop processes that meet technology demands while reducing impact on human health, safety and the environment, both through the use of more benign materials, 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 re-use and disposal of equipment, and hazardous and non-hazardous residues from the manufacturing processes *Water and Energy Conservation* Need to reduce water and energy consumption Need for innovative energy and water-efficient processes and equipment *Consumables Optimization* Need for more efficient utilization of chemicals and materials, and increased reuse and recycling *Byproducts Management* Need to understand ESH characteristics of process by-products to identify the appropriate mitigation *Chemical Exposure Management* Need to design-out potential for chemical exposures and need for personal protective equipment (PPE) *Equipment Ergonomics* Need to design ergonomically correct and safe equipment *Design for Maintenance* Need to design equipment so that maintenance and service may be safely performed by a single person Need to design equipment so that commonly serviced components and consumable items are easily accessed Need to minimize health and safety risks during maintenance activities.
Facilities energy and water optimization	*Conservation* Need to reduce energy and water use *Tool Heat Removal* Need for more efficient thermal management of cleanrooms and facilities systems *Global Warming Emissions Reduction* Need to design energy efficient processing equipment and manufacturing facilities Need to reduce emissions from processes using GWP chemicals
Sustainability and product stewardship	*End-of-Life Disposal/Reclaim* Need to design tools, equipment and products to facilitate disposal at end of life *Design for ESH* Need method to **holistically** evaluate and quantify the ESH impacts of processes, chemicals, and process equipment for the total manufacturing process Need to make ESH a design parameter in development of new equipment, processes and products *Sustainability Metric* Need to identify the elements for defining and measuring the sustainability of a technology generation

Table 103b ESH Difficult Challenges—Long-term UPDATED

Difficult Challenges < 32 nm	*Summary of Issues*
Chemicals and materials management	*Chemical Assessment* Lack of quality rapid assessment methodologies to ensure that chemicals can be utilized in manufacturing, while protecting human health, safety, and the environment without delaying process implementation *Chemical Data Availability* Lack of comprehensive ESH data for new, proprietary chemicals and materials to respond to the increasing external and regional requirements on the use of chemicals *Chemical Exposure Management* Lack of information on how the chemicals and materials are used and what process by-products are formed
Process and equipment management	*Chemical Reduction* Need to develop processes that meet technology demands while reducing impact on human health, safety, and the environment, both through the use of more benign materials, 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 re-use and disposal of equipment, and hazardous and non-hazardous residues from the manufacturing processes *Water and Energy Conservation* Need to reduce water and energy consumption Need for innovative energy and water-efficient processes and equipment *Consumables Optimization* Need for more efficient utilization of chemicals and materials, and increased reuse and recycling *Byproducts Management* Need to understand ESH characteristics of process by-products to identify the appropriate mitigation *Chemical Exposure Management* Need to design-out potential for chemical exposures and need for personal protective equipment (PPE) *Equipment Ergonomics* Need to design ergonomically correct and safe equipment *Design for Maintenance* Need to design equipment so that maintenance and service may be safely performed by a single person Need to design equipment so that commonly serviced components and consumable items are easily accessed Need to minimize health and safety risks during maintenance activities
Facilities energy and water optimization	*Conservation* Need to reduce energy and water use *Tool Heat Removal* Need for more efficient thermal management of cleanrooms and facilities systems *Global Warming Emissions Reduction* Need to design energy efficient processing equipment and manufacturing facilities. Need to reduce emissions from processes using GWP chemicals
Sustainability and product stewardship	*End-of-Life Disposal/Reclaim* Need to design tools, equipment, and products to facilitate disposal at end of life *Design for ESH* Need method to **holistically** evaluate and quantify the ESH impacts of processes, chemicals, and process equipment for the total manufacturing process Need to make ESH a design parameter in development of new equipment, processes and products *Sustainability Metric* Need to identify the elements for defining and measuring the sustainability of a technology generation

ESH Technology Requirements and Potential Solutions

Table 104a ESH Intrinsic Requirements—Near-term Years

Year of Production	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*Driver*
DRAM ½ Pitch (nm) (contacted)	*80*	*70*	*65*	*57*	*50*	*45*	*40*	*36*	*32*	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*90*	*78*	*68*	*59*	*52*	*45*	*40*	*36*	*32*	
I.. Chemicals and Materials Management Technology Requirements										
CPIFs* completed for percent of new chemical candidates	**100%**									
Percent of chemical risk assessments (health and safety) completed	**100%**					**100%**				
II.. Process and Equipment Technology Requirements										
Energy Consumption										
Total fab tools (kWh/cm^2) [3]	**0.3–0.4**						**0.25–0.3**			
Tool energy usage per wafer pass (300 mm versus 200 mm); baseline 1999	**1**	**0.8**		**0.6**			**Functional Area Goals TBD**			
Water Consumption										*Sustainable growth and cost*
Wet bench UPW use (liters/300 mm wafer pass)	**42**					**TBD**				
Chemical Consumption and Waste Reduction										*Environ-mental stewardship and cost*
Improvement in process chemical utilization (liters [liquid] or grams [gas]/cm^2/mask layer)	**3% per year**					**3% per year**				
Worker and Workplace Protection										
Conformance of new tools to latest International ESH standards and guidelines such as SEMI S2 [1] and European CE mark requirements [2]	**100%**					**100%**				
Conformance of AMHS/tool interface to latest SEMI S2 Guideline and CE mark directive.	**100%**					**100%**				
III.. Facilities Energy and Water Optimization Technology Requirements										
Energy Consumption										
Total fab support systems (kWh/cm^2) [3]	**0.5–0.6**					**0.35–0.5**				
Water Consumption										
Net feed water use (liters/cm^2) [3]	**8–10**					**3–5**				
Fab UPW use (liters/cm^2) [3]	**4–6**					**4–6**				
Chemical Consumption and Waste Reduction										
Hazardous liquid waste recycle/reuse	**80%**					**80%**				
Solid waste recycle/reuse	**85%**					**90%**				
Reduce PFC emission	**10% absolute reduction from 1995 baseline by 2010 as agreed to by the World Semiconductor Council (WSC)**						**Maintain 10% absolute reduction from 1995 baseline**			
IV. Sustainability and Product Stewardship Requirements										
Process environmental load/impact assessments for (%) of new materials	**75%**			**100%**						

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

Notes for Table 104a:

[1] SEMI. S2-93A—Safety Guidelines for Semiconductor Manufacturing Equipment

[2] European CE Mark Safety Requirements

[3] cm^2 per wafer out.

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.

** CPIF = Chemical Properties Information Form*

Table 104b ESH Intrinsic Requirements—Long-term Years

Year of Production	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Driver*
DRAM ½ Pitch (nm) (contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*	
I. Chemicals and Materials Management Technology Requirements								
CPIFs completed for percent of new chemical candidates*	**100%**							
Percent of chemical risk assessments (health and safety) completed	**100%**							
II. Process and Equipment Technology Requirements								
Energy Consumption								
Total fab tools (kWh/cm^2) [3]	**0.25–0.3**							
Tool energy usage per wafer pass (300 mm versus 200 mm); baseline 1999	**Functional Area Goals TBD**							
Water Consumption								*Sustainable growth and cost*
Wet bench UPW use (liters/300 mm-wafer pass)	**TBD**							
Chemical Consumption and Waste Reduction								*Environ-mental stewardship and cost*
Improvement in process chemical utilization (liters [liquid] or grams [gas]/cm^2/mask layer)	**3% per year**							
Worker and Workplace Protection								
Conformance of new tools to latest International ESH standards and guidelines such as SEMI S2 [1] and European CE mark requirements [2]	**100%**							
Conformance of AMHS/tool interface to latest SEMI S2 Guideline and CE mark directive.	**100%**							
III. Facilities Energy and Water Optimization Technology Requirements								
Energy Consumption								
Total fab support systems (kWh/cm^2) [3]	**0.35–0.5**							
Water Consumption								
Net feed water use (liters/cm^2) [3]	**3–5**							
Fab UPW use (liters/cm^2) [3]	**4–6**							
Chemical Consumption and Waste Reduction								
Hazardous liquid waste recycle/reuse	**80%**		**90%**					
Solid waste recycle/reuse	**90%**							
Reduce PFC emission	**Maintain 10% absolute reduction from 1995 baseline**							
IV. Sustainability and Product Stewardship Requirements								
Process environmental load/impact assessments for (%) of new materials	**100%**							

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

Notes for Table 104b:

[1] SEMI. S2-93A—Safety Guidelines for Semiconductor Manufacturing Equipment.

[2] European CE Mark Safety Requirements.

[3] cm^2 per wafer out.

** CPIF = Chemical Properties Information Form*

Manufacturable solutions exist, and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known

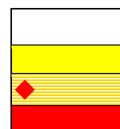


*Table 105a Chemicals and Materials Management Technology Requirements—Near-term Years*UPDATED*

** The Environment, Safety, and Health new chemical screening tool (Chemical Restrictions Table) is linked online*

Year of Production	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*Driver*
DRAM ½ Pitch (nm) (contacted)	*80*	*70*	*65*	*57*	*50*	*45*	*40*	*36*	*32*	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*90*	*78*	*68*	*59*	*52*	*45*	*40*	*36*	*32*	
Interconnect										
Low-κ materials—spin-on and CVD	**Minimum emission/waste processes**			**75% raw material (chemical) utilization*****			**90% raw material (chemicals) utilization*****			
Copper processes (ECD)	**75% copper reclaimed/recycled**			**85% copper reclaimed/recycled**			**100% copper reclaimed/recycled**			
Advanced metallization including Cu barrier and seed (PVD and ALD)	**Minimum emission/waste processes**					**Minimum emission/waste processes**				
Planarization (metal CMP)	**15% reduction in consumables from baseline**			**> 15% Reduction in consumables from baseline**			**5% reduction in consumables per year**			
Plasma etch processes	**Low ESH impact chemistries**					**Low ESH impact etch chemistries**				
CVD chamber clean (plasma)	**Low ESH impact CVD chamber clean chemistries**					**Low ESH impact CVD chamber clean chemistries**				
Front End Processes										
~~High-κ materials~~	~~**Lowest ESH impact high-κ materials**~~									~~*Transistor performance and device development*~~
High-κ materials	**Low-hazard deposition, etch, and cleans processes**			**ESH benign processes**						
High-κ materials	**High-κ materials without potentially toxic/ bioaccumulative metals**			**Low hazard compounds and processes**						
Doping (implantation and diffusion)	**Low hazard dopant materials and processes**									
Surface preparation (stripping, cleaning, rinsing)	**ESH-friendly wafer clean and rinse processes and tools evaluated**					**ESH-friendly wafer clean and rinse processes and tools incorporated into manufacturing**				
Novel wafer cleaning (supercritical CO_2, etc)	**Novel wafer cleaning technologies evaluated**					**Novel wafer cleaning technologies implemented**				
Front-end etch	**ESH-friendly etch processes evaluated**					**ESH-friendly etch processes implemented**				
Lithography										
New Equipment										
Optical	**Charac-tization of ESH impacts**	**Minimal ESH impact from radiation, ergonomics, chemical consumption, and disposal**				**Minimal ESH impact for ionizing radiation, ergonomics, chemical consumption, and disposal**				*Next generation lithography*
193 nm immersion lithography	**Low ESH impact resists**			**Low ESH impact immersion fluid additives, fluids and resists**						
EUV	**Characterization of ESH impacts**			**Minimal ESH impact from ionizing radiation, ergonomics, energy consumption and source gas**						
PFOS/PFAS**	**Non-critical uses eliminated**		**Non-PFOS/PFAS alternatives researched**						**Non-PFAS materials developed for critical uses in photo-lithography**	
Mask cleaning	**Cost-effective, ESH friendly technology (e.g., supercritical CO_2)**									

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

Notes for Table 105a:
** Everything that is not identified as a critical use.*
*** 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*

**** Utilization = [(Feed – Output) / Feed] x 100%*

*Table 105b Chemicals and Materials Management Technology Requirements—Long-term Years*UPDATED*

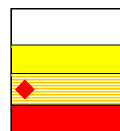
** The Environment, Safety, and Health new chemical screening tool (Chemical Restrictions Table) is linked online*

Year of Production	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Driver*
DRAM ½ Pitch (nm) (contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*	
Interconnect								
Low-κ materials—spin-on and CVD	**90% raw material (chemicals) utilization*****							
Copper processes (ECD)	**100% copper reclaimed/recycled**							
Advanced metallization including Cu barrier and seed (PVD and ALD)	**Minimum emission/waste processes**							
Planarization (metal CMP)	**5% reduction in consumables per year**							
Plasma etch processes	**Low ESH impact etch chemistries**							
CVD chamber clean (plasma)	**Low ESH impact CVD chamber clean chemistries**							
Front end Processes								*Reduced feature size*
~~High-κ materials~~								~~*Transistor perfor-mance and device development*~~
High-κ materials	**ESH benign processes**							
High-κ materials	**Low hazard compounds and processes**							
Doping (implantation and diffusion)	**Low hazard dopant materials and processes**							
Surface preparation (stripping, cleaning, rinsing)	**ESH-friendly wafer clean and rinse processes and tools incorporated into manufacturing**							
Novel wafer cleaning (supercritical CO_2, etc)	**Novel wafer cleaning technologies implemented**							
Front-end etch	**ESH-friendly etch processes implemented**							
Lithography								
New Equipment								
Optical	**Minimal ESH impact for ionizing radiation, ergonomics, chemical consumption, and disposal**							*Next genera-tion litho-graphy*
193 nm immersion lithography								
EUV	**Energy-efficient EUV lithography and/or other low ESH impact innovative patterning technology**							
PFOS/PFAS**	**Non-PFAS materials developed for critical uses in photolithography**							
Mask cleaning								

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

** The Environment, Safety, and Health new chemical screening tool (Chemical Restrictions Table) is linked online*

Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known



Notes for Table 105 b:

*** 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*

**** Utilization = [(Feed – Output) / Feed] x 100%*

Table 106a Facilities Energy and Water Optimization Technology Requirements—Near-term Years
UPDATED

Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013	Driver
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	90	78	68	59	52	45	40	36	32	
Interconnect										Increasing number of inter-layers
Copper processes (ECD)	Copper processes optimized to minimize waste to water and land									
Planarization	Reduced water use at idle									
Plasma processing	Reduced energy use at idle									
Front End Processes										
High-κ	Energy-efficient deposition processes					Energy efficient deposition processes				
Implantation	Energy use and heat removal optimized					Minimum implanting energy for future technologies				
Surface preparation	Energy efficient clean processes (reduced exhaust flow rates)					Energy efficient clean processes (optimized exhaust flow rates)				
	Novel wafer cleans based on surface/interface science					Wafer cleans with more dilute chemistries and lower water consumption				
Front end etch	Reduced tool idle energy									
Starting materials	Quantified energy/water reduction from SOI-based process flows									
Lithography										Reduced feature size
Equipment resource consumption: optical, e-beam, and EUV	Optimized energy consumption, equipment related chemicals/ gases/materials, and water consumption									
Assembly and Packaging										
Eliminate waste from molding process	Zero waste (after recycling) from molding technologies					Zero waste (after recycling) from molding technologies				
Reduce water use	0.8X (X = 1999 baseline)					0.5X (X = 1999 baseline)				
Reduce chemical use and consumption	0.8X (X = 1999 baseline)					0.5X (X = 1999 baseline)				

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known

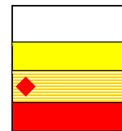


Table 106b *Facilities Energy and Water Optimization* Technology Requirements—Long-term Years UPDATED

Year of Production	2014	2015	2016	2017	2018	2019	2020	Driver
DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14	
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	28	25	22	20	18	16	14	
Interconnect								*Increasing number of interlayers*
Copper processes (ECD)	**Copper processes optimized to minimize waste to water and land**							
Planarization	**Water recycle/reclaim**							
Plasma processing	**Reduced tool idle energy use**							
Front End Processes								
High-κ	**Energy efficient deposition processes**							
Implantation	**Minimum implanting energy for future technologies**							
Surface preparation	**Energy efficient clean processes (optimized exhaust flow rates)**							
	Wafer cleans with more dilute chemistries and lower water consumption							
Front End etch	**Reduced tool idle energy**							
Starting materials	**Quantified energy/water reduction from SOI-based process flows**							
Lithography								*Reduced feature size*
Equipment resource consumption: optical, e-beam, and EUV	**Optimized energy consumption, equipment related chemicals/ gases/materials, and water consumption**							
Assembly and Packaging								
Eliminate waste from molding process	**Zero waste (after recycling) from molding technologies**							
Reduce water use	**0.5X (X = 1999 baseline)**							
Reduce chemical use and consumption	**0.5X (X = 1999 baseline)**							

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

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.

Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known

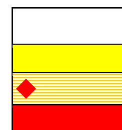


Table 107a Sustainability and Product Stewardship Technology Requirements—Near-term Years

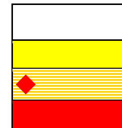
Year of Production	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
DRAM ½ Pitch (nm) (contacted)	*80*	*70*	*65*	*57*	*50*	*45*	*40*	*36*	*32*
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*90*	*78*	*68*	*59*	*52*	*45*	*40*	*36*	*32*
Factory Integration									
Improved integration of ESH into factory and equipment design	**Incorporate ESH design guidelines, methodology, and criteria into tool and factory design**								

Table 107b Sustainability and Product Stewardship Technology Requirements—Long-term Years

Year of Production	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
DRAM ½ Pitch (nm) (contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*
MPU/ASIC Metal 1 (M1) ½ Pitch (nm)(contacted)	*28*	*25*	*22*	*20*	*18*	*16*	*14*
Factory Integration							
Improved integration of ESH into factory and equipment design	**Incorporate ESH design guidelines, methodology, and criteria into tool and factory design**						

The status of some of the entries for 2005 is shown as "YELLOW", because the ESH TWG felt that there was still some work to be done. However, since the status was closer to the "WHITE" than the "RED", the TWG elected not to use the "INTERIM SOLUTIONS" color code for these line items.

Manufacturable solutions exist, and are being optimized
Manufacturable solutions are known
Interim solutions are known
Manufacturable solutions are NOT known



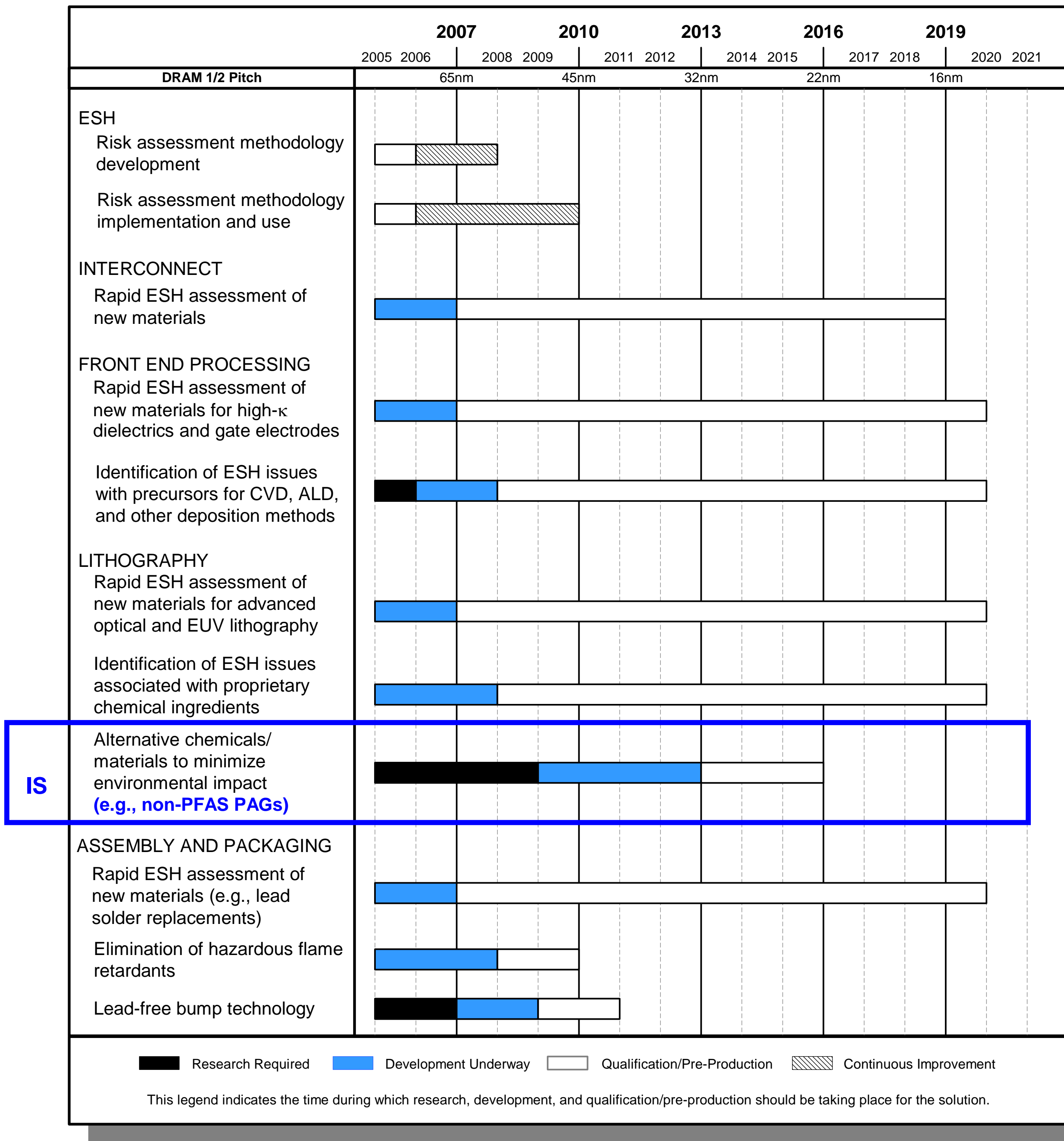


Figure 98 Potential Solutions for ESH: Chemicals and Materials Management UPDATED

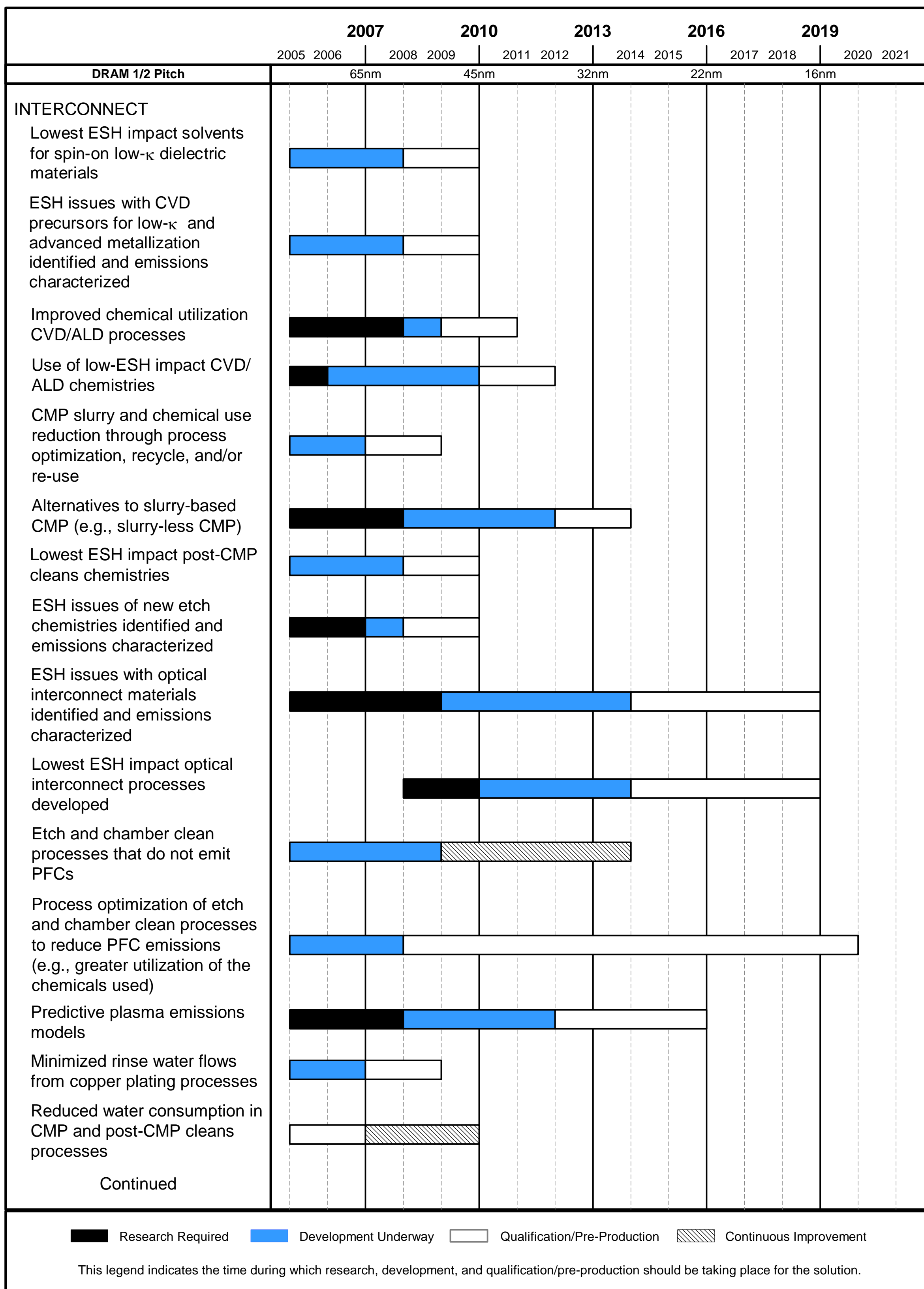


Figure 99 Potential Solutions for ESH: Process and Equipment Management UPDATED

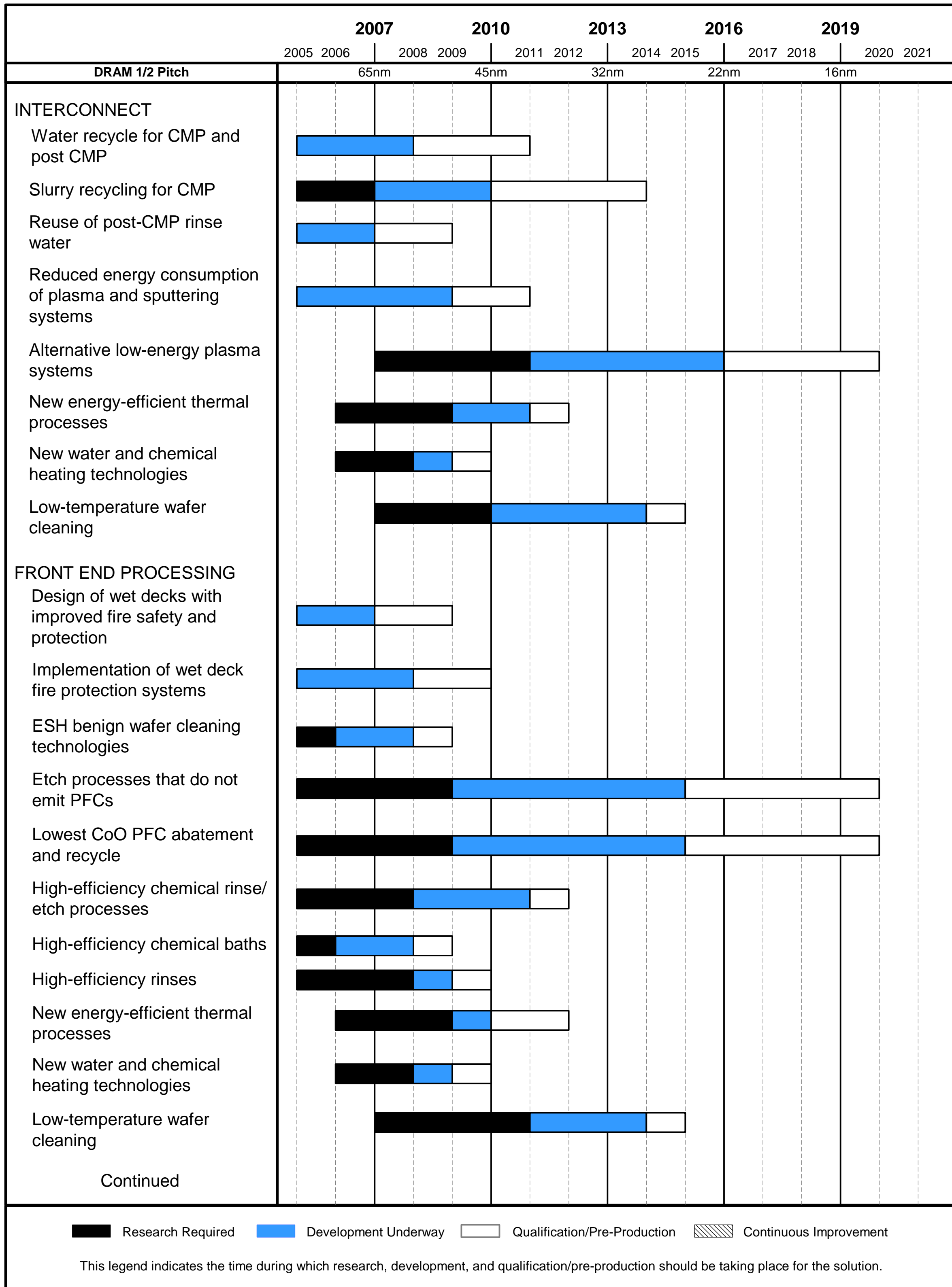


Figure 99 Potential Solutions for ESH: Process and Equipment Management (continued) UPDATED

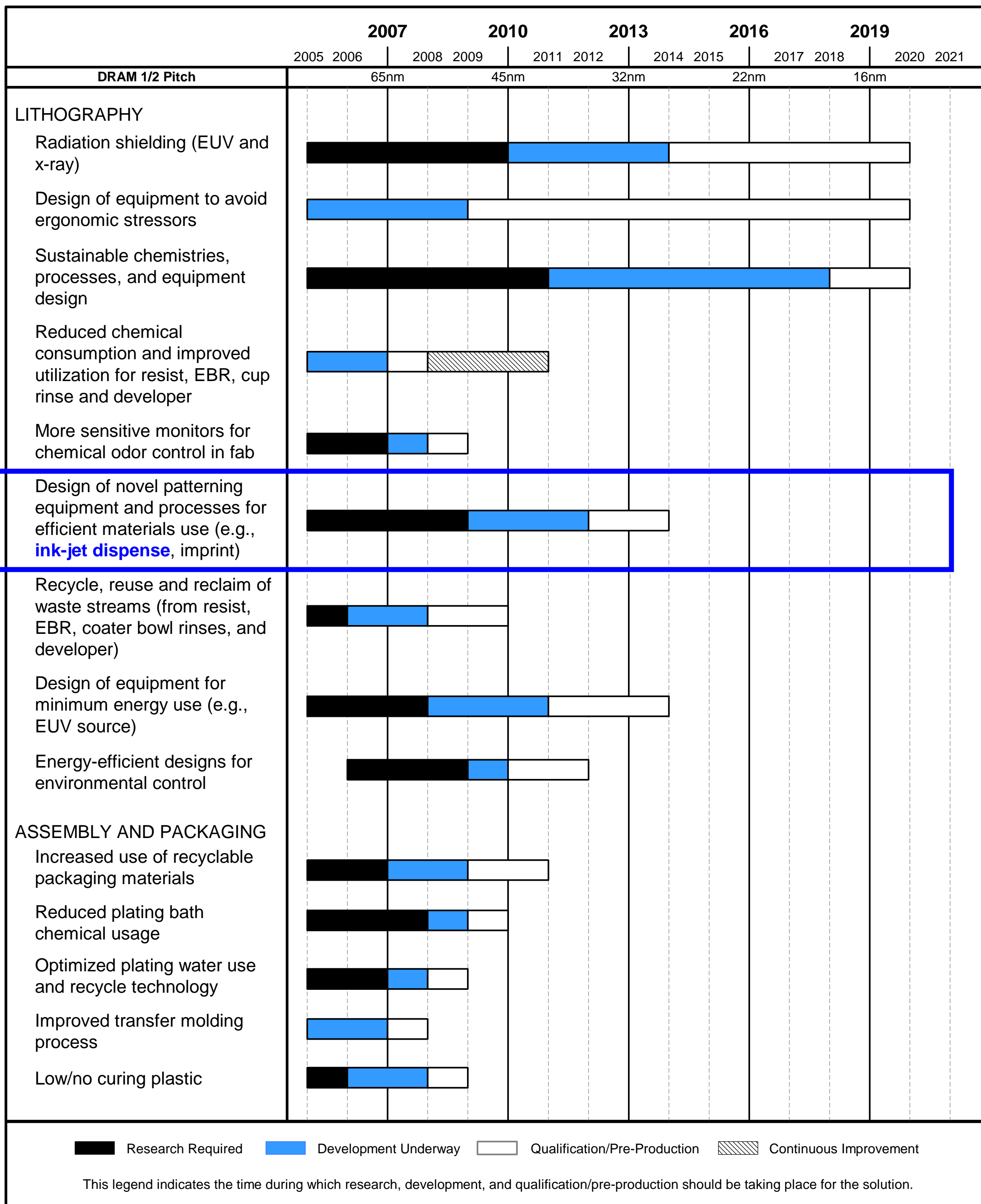


Figure 99 Potential Solutions for ESH: Process and Equipment Management (continued) UPDATED

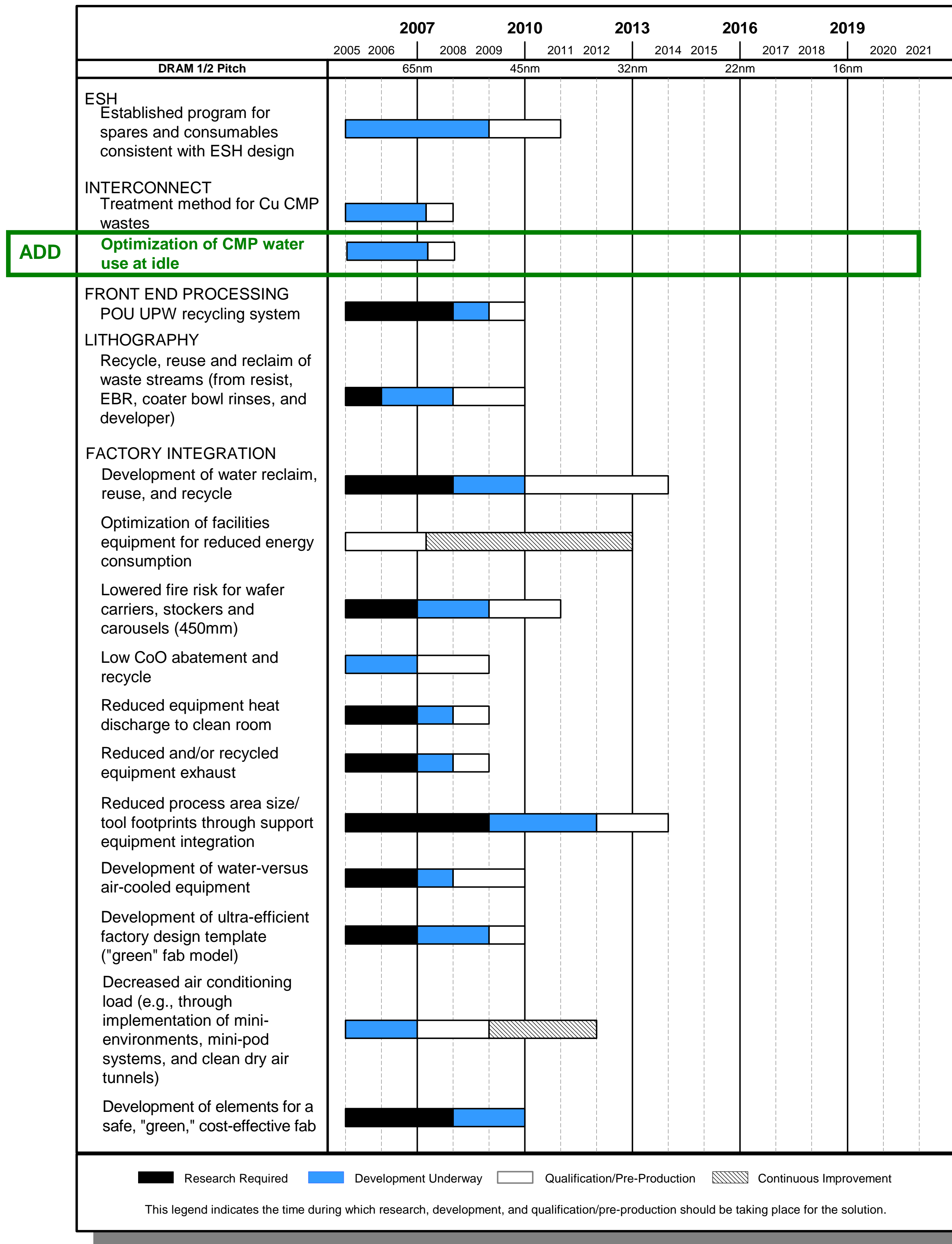


Figure 100 Potential Solutions for ESH: Facilities Energy and Water Optimization UPDATED