International Technology Roadmap for Semiconductors

2000 Update

Environment, Safety, and Health

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ENVIRONMENT, SAFETY, AND HEALTH

2000 UPDATE TABLES

*Table 68 ESH Difficult Challenges***

FIVE DIFFICULT CHALLENGES ≥ 100 nm / BEFORE 2005	SUMMARY OF ISSUES
Chemicals, Materials and Equipment Management	*Chemical Data Collection* Need to document and make available environment, safety, and health characteristics of chemicals. *New Chemical Assessment* Need for quality rapid assessment methodologies to ensure that new chemicals can be utilized in manufacturing, while protecting human health, safety, and the environment without delaying process implementation. *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.
Climate Change Mitigation	*Reduce Energy Use Of Process Equipment* Need to design energy efficient larger wafer size processing equipment. *Reduce Energy Use Of The Manufacturing Facility* Need to design energy efficient facilities to offset the increasing energy requirements of higher class clean rooms. *Reduce High Global Warming Potential (GWP) Chemicals Emission* Need ongoing improvement in methods that will result in emissions reduction from GWP chemicals.
Workplace Protection	*Equipment Safety* Need to design ergonomically correct and safe equipment. *Chemical Exposure Protection* Increase knowledge base on health and safety characteristics of chemicals and materials used in the manufacturing and maintenance processes, and of the process byproducts; and implement safeguards to protect the users of the equipment and facility.
Resource Conservation	*Reduce Water, Chemicals And Materials Use* Requirements for large amounts of water, chemicals, and materials limit sustainable growth. *Waste Recycle* Increase in resource use as the result of increasing process complexity will require that efficient waste recycling methods be developed.
ESH Design and Measurement Methods	*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 procedures for new equipment and processes.

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*Table 68 ESH Difficult Challenges (continued)***

Five Difficult Challenges *< 100 nm / Beyond 2005*	*Summary of Issues*
Chemicals, Materials and Equipment Management	*Chemical Use Information* Rapid introduction of chemicals and materials into new process requires the understanding of process fundamentals in order to reduce ESH impacts.
Climate Change Mitigation	*Reduce Energy Use* The importance of reducing energy use for climate change will grow. *Reduce High GWP Chemicals Emissions* No known alternatives and international regulatory pressure to reduce emissions of GWP chemicals.
Workplace Protection	*Equipment Safety* Need ergonomic principles integrated into the processing and wafer moving equipment for both operation and maintenance aspects, and into the overall manufacturing facility.
Resource Conservation	*Reduce Water, Energy, Chemicals And Materials Use* Need resource efficient processing and facility support equipment and improved water reclaim and recycling methods. Emphasis on resource sustainability will grow.
ESH Design and Measurement Methods	*Evaluate and Quantify ESH Impact* Need integrated ESH design in development of new equipment and processes.

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*Table 69a Chemicals, Materials and Equipment Management Technology Requirements—Near Term***

Year Technology Node	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	Driver
ESH								
Chemical risk assessment	Algorithm						Applica-tion	*New processes*
Data accumulation								
Existing chemicals	Design of data base			50%			100%	
New chemicals	Design of data base						After 2 years of market intro	*New processes*
Assessment of new chemicals: safety data and environmental load/impact	Evaluation terms and method			Evaluation system			Data accumula-tion	
Reduction of environmental load/impact materials								
Existing materials	Lead-free process and structure							
	Bromine-, Antimony-free fire-resistant plastics, Beryllium-free							
	Assessment of other materials			Substitution process and disposal treatments				
By-product materials				Process evaluation			Substitution process and disposal treatments	
Material LCA				Algorithm			Operation	
Environmental management								
Material balance	Algorithm			Pollutant release, and transfer disclosure (PRTR)			Automatic PRTR data acquisition system	
Disposal management	System design						Operation	
Equipment standards	Identify gaps in existing standards	Identify gaps in existing standards	Implement comprehensive foundation of international standards					
ESH impact of spares and consumables	Analysis of impact	Analysis of impact		Do testing and generate specifications				

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solutions* (red)

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*Table 69a Chemicals, Materials and Equipment Management Technology Requirements—Near Term (continued)***

Year *Technology Node*	*1999* *180 nm*	*2000*	*2001*	*2002* *130 nm*	*2003*	*2004*	*2005* *100 nm*	*Driver*
Interconnect								
Low κ materials – spin on and CVD		**Lowest ESH impact solvents/ CVD precursors**			**Emissions models/ESH benign processes**			*Speed, signal loss*
Copper processes	**Extend plating bath life**		**Lowest ESH impact plating chemistries**		**Plating bath recycle/ESH benign CVD processes**			*Speed, reliability*
Advanced metallization			**Lowest ESH impact processes/ emissions characterization**			**Improved chemical utilization**		*Perform, cost, SoC*
Planarization	**Reduce slurry required**			**Slurry recycling/ESH benign chemistries**				*Planarity*
Plasma processes			**Lowest ESH impact etch chemistries**					*Etch/clean*
Front end Processes								
High κ	**ESH evaluation for high κ**		**Lowest ESH impact high κ materials**		**ESH benign processes**			
	Low-hazard precursor materials		**Low-hazard deposition methods**		**ESH benign processes**			
			High κ materials without potentially toxic/bioaccumulative metals (Pb, Ni)		**Lowest hazard metal compounds**			
Doping processes	**Subatmos-pheric hydride and halo-genated gas delivery systems**	**Subatmospheric delivery for additional dopants**			**Lowest hazard dopant materials**			
Surface preparation	**Fundamental research on surface/interface science**		**Ongoing research and integration of solutions**		**Optimized surface preparation processes**			
	Alternate wafer rinse methods		**Incorporation into new rinse/clean tools**					
	Alternate clean methods (O_3, super-critical etc., research)		***In situ* chemical generation**		**Chemical optimization of high κ cleans**			
	Elimination of sulfuric acid							
Front end etch	**Characterize plasma by-products**		**Plasma process simulation-optimize processes for by-product destruction**					

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*Table 69a Chemicals, Materials and Equipment Management Technology Requirements—Near Term (continued)***

Year Technology Node	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	Driver
Lithography								
Introduction and integration of new equipment into manufacturing								*Reduced feature size*
Optical		**Hazardous chemicals, material compatibility**						
e-Beam		**Ionizing radiation, ergonomics, chemical consumption, disposal**						
EUV		**Non-ionizing radiation, ergonomics, chemical consumption, disposal**						
Specification and integration of new chemicals and materials introduced into manufacturing: Optical, e-Beam, and EUV		**New chemicals, purification requirements, wastes, emissions**						*Reduced feature size*

Solutions Exist *Solutions Being Pursued* *No Known Solutions*

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*Table 69b Chemicals, Materials, and Equipment Management Technology Requirements—Long Term***

Year *Technology Node*	*2008* *70 nm*	*2011* *50 nm*	*2014* *35 nm*	*Driver*
ESH				
Data accumulation				
New chemicals	**After 1 year of market intro**			*New processes*
Material LCA	**Revision**			
Interconnect				
Low κ materials	**Zero waste deposition/soluble precursors**			*Speed, signal loss*
Copper/advanced metallization	**Zero waste deposition**			*Speed*
Planarization	**Non-chemical consuming processes**			*Planarity*
Optical interconnect	**Lowest ESH impact materials & processes**			*Speed*
Front End Processes				
High κ dielectrics	**ESH benign materials and deposition processes**			
Doping	**Self-cleaning dopant tools (*in situ* clean)**			
	ESH benign materials and processes			
Surface preparation	**Ambient temperature cleans**			
		"No-clean" processes		
Front end etch	**ESH – benign process, including high κ etch methodologies**			
Lithography				
Introduction and integration of new equipment into manufacturing				*Reduced feature size*
Optical	**Hazardous chemical, material compatibility**			
e-Beam and EUV	**Ionizing radiation, ergonomics, chemical consumption, disposal**			
Innovative options	**Ionizing/non-ionizing radiation, ergonomics, chemical consumption, disposal**			
Specification and integration of new chemicals and materials introduced into manufacturing				*Reduced feature size*
Optical	**New chemicals, purification requirements, wastes, emissions**			
e-Beam, EUV, and innovative options	**New chemicals, purification requirements, wastes, emissions**			

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solutions* (red)

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Table 70a Climate Change Mitigation Technology Requirements—Near Term **

YEAR TECHNOLOGY NODE	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	DRIVER
ESH								
Energy consumption: overall fab equipment kWh/cm^2(kWh/in^2)	**0.5 (3.2)–0.7 (4.5)**						**0.4 (2.6)–0.5 (3.2)**	
Energy consumption: fab facility kWh/cm^2(kWh/in^2)	**0.5 (3.2)–0.7 (4.5)**						**0.4 (2.6)–0.5 (3.2)**	
300 mm production fab equipment energy consumption	**X***				**0.5X**			*Productivity*
Reduce PFC emissions	**[Note 1]**							
Front End Processes								
Reduce PFC emissions (etch)	**Develop optimized etch processes, alternate chemistries, and cost effective abatement**							
				Continued research in alternate etch chemistries				
Lithography								
Equipment energy and material consumption								*Reduced feature size*
e-Beam		**Emission of climate change gases, energy consumption**						
Specification and integration of new chemicals and materials introduced into manufacturing								*Reduced feature size*
e-Beam		**Use of climate change gases, air emissions, wastes**						
Assembly & Packaging								
Reduce energy use	**X**	**0.8X**						

** X is based on 200 mm tool energy per wafer requirement.*

[Note 1] 10% or greater absolute reduction from 1995 baseline by 2010 is agreed to by the World Semiconductor Council.

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*Table 70b Climate Change Mitigation Technology Requirements—Long Term***

Year Technology Node	2008 70 nm	2011 50 nm	2014 35 nm	Driver
ESH				
Energy consumption: overall fab equipment kWh/cm^2(kWh/in^2)	**0.4 (2.6)–0.5 (3.2)**	**0.3 (1.9)–0.4 (2.6)**		
Energy consumption: fab facility kWh/cm^2(kWh/in^2)	**0.4 (2.6)–0.5 (3.2)**	**0.3 (1.9)–0.4 (2.6)**		
300 mm production fab equipment energy consumption	**0.4X**			*Productivity*
Reduce PFC emissions	**Note 1**			
Lithography				
Equipment energy and material consumption				*Reduced feature size*
e-Beam	**Emission of climate change gases, energy consumption**			
Innovative options	**Emission of climate change gases, energy consumption**			
Specification and integration of new chemicals and materials introduced into manufacturing				*Reduced feature size*
e-Beam	**Use of climate change gases, air emissions, wastes**			
Innovative options	**Use of climate change gases, air emissions, wastes**			
Assembly & Packaging				
Reduce energy use	**0.5X**			

** X is based on 200 mm tool energy per wafer requirement.*

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*Table 71a Workplace Protection Technology Requirements—Near Term***

Year *Technology Node*	*1999* *180 nm*	*2000*	*2001*	*2002* *130 nm*	*2003*	*2004*	*2005* *100 nm*	*Driver*
ESH								
Equipment safety, gases and chemicals leak, and equipment stability during an earthquake	**Implement S2 Safety Guidelines and S8 Ergonomic/ Human Factor Guidelines [6, 7]**							
Safe interface of Automated Material Handling Systems (AMHS) and manufacturing equipment	**Standardized control features and procedures**							
Comprehensive exposure data	**Comprehensive industrial hygiene (IH) exposure data For operations and maintenance**							
MSDS data sheets	**Industry standardized format**		**Use format**					
Personal protection equipment (PPE)				**Test and rate PPE against chemicals used**				
PPE trade-off versus hazard elimination or engineering control			**Cost of PPE per employee per shift**					
Protocol for selecting risk management solutions	**Industry acceptance**		**Full imple-mentation**					
Reduced chemical exposure	**Isolate workers from chemicals and by-products during operation and maintenance**							
Ergonomic improvement	**Understand physiological stresses**		**Minimize/eliminate physiological stresses**					
New chemical qualification	**Collaboration of government/academia/industry/company resources**							
X-ray exposure	**Fundamental research required**							
Endocrine disrupters in mold resin	**Develop new materials**							
N-methyl-2-pyrrolidone (NMP) exposure					**Phase out**			

[6] SEMI. S2-93A – *Safety Guidelines for Semiconductor Manufacturing Equipment.*
[7] SEMI. S8-95 – *Safety Guidelines for Ergonomics / Human Factors Engineering of Semiconductor Equipment.*

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*Table 71a Workplace Protection Technology Requirements—Near Term (continued)***

Year *Technology Node*	*1999* *180 nm*	*2000*	*2001*	*2002* *130 nm*	*2003*	*2004*	*2005* *100 nm*	*Driver*
Interconnect								
Copper plating processes		**Tools w/reduced employee exposure**						
Front End Processes								
Less flammable wet deck materials	**Develop new materials**							
Work environment	**Continued reduction of physical stressors in clean room environment – noise, non-ionizing radiation, thermal stress**							
High κ		**Lowest hazard materials and precursors**						
Doping	**Low pressure dopants**	**Reduced potential for exposure during maintenance**				**Low hazard dopants**		
Surface preparation	**Robotics safety**		**Reduced chemical use in clean processes**		**Inert material cleans (supercritical, cryogenic)**			
Front end etch	**Minimize potential exposure to plasma etch by-products**		**Optimize processes to minimize production of potentially hazardous by-products**					
Lithography								
Health and safety								*Reduced feature size*
Optical		**Ergonomics issues, potential exposure to hazardous chemicals**						
e-Beam		**Ergonomics issues, hazardous chemicals, potential exposure to ionizing radiation**						
EUV		**Ergonomics issues, potential exposure to hazardous chemicals, potential exposure to non-ionizing radiation**						
Specification and integration of new chemicals and materials introduced into manufacturing								*Reduced feature size*
Optical		**Potential exposure to toxic chemicals**						
e-Beam and EUV		**Hazardous chemical use**						

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*Table 71b Workplace Protection Technology Requirements—Long Term***

YEAR TECHNOLOGY NODE	2008 70 nm	2011 50 nm	2014 35 nm	DRIVER
ESH				
Comprehensive exposure data	Industry database of IH exposure data			
New chemical qualification	Apply new methods			
X-ray exposure	Collaboration of government/ academia/ company resources	Apply new methods		
Endocrine disrupters in mold resin	Use new materials			
NMP exposure	Complete elimination			
Interconnect				
Optical interconnect	Tools with no employee exposure			
Front End Processes				
Less flammable wet deck materials	Use new materials			
High κ	ESH-benign dielectrics, electrode materials and deposition processes			
Doping	Low hazard dopants			
Surface preparation	Novel rinse/clean methods that reduce water and chemical usage			
Starting materials	Ergonomic design of tools and wafer handling for >300 mm wafers			
Front end etch	*In situ* equipment clean processes			
Lithography				
Health and safety				*Reduced feature size*
Optical and e-beam	Potential exposure to hazardous chemicals			
EUV	Potential exposure to non-ionizing radiation			
Innovative options	Potential exposure to ionizing/non-ionizing radiation			
Specification and integration of new chemicals and materials introduced into manufacturing				*Reduced feature size*
Optical, e-beam, and EUV	Potential exposure to toxic chemicals			
Innovative options	Potential exposure to toxic chemicals			

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*Table 72a Resource Conservation Technology Requirements—Near Term***

Year Technology Node	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	Driver
ESH								
Zero emissions	**Thorough recycle/reuse system**						**Develop recycling technology**	
Recycle rate: %		**60%**			**65%**		**70%**	
Interconnect								
Copper processes			**Minimize rinsewater**					
Planarization		**Reduce water consumption**			**Water recycle**			
Plasma processing		**Measure/ optimize energy use**			**Reduce tool/system energy requirements**			
Front End Processes								
High κ				**Energy-efficient deposition processes**		**Precise uniform thermal processes with minimal energy consumption**		
Doping			**Energy-use evaluation for future doping technologies such as PGILD**		**Energy efficient processes**			
Surface preparation	**Energy use quantification for surface preparation methodologies**			**Energy efficient clean process with heated chemistries and UPW**				
	Water conservation through rinse optimization; idle flow reduction			**Incorporation of novel rinse methodologies in wet tools**		**Novel water reduction techniques derived from surface/interface science**		
Front end etch	**Measure/ optimize energy use**			**More energy efficient plasma processes**				
Starting Materials		**Quantitation of energy/water reduction from simplified SOI-based process flows**						
Lithography								
Optimization of resource consumption by equipment: optical, e-beam, and EUV		**Equipment energy consumption, equipment related chemicals/ gases/materials**						*Reduced feature size*
Optimization of resource usage: optical, e-beam, and EUV		**Water/waste recycle/reuse/reduction**						*Reduced feature size*
Factory Integration								
Decrease net feed water use Liters/cm^2 (gal/ in^2)	**7.6 (13)**	**7.6 (13)**	**5.9 (10)**	**5.9 (10)**	**3.5 (6)**	**3.5 (6)**	**2.9 (5)**	
Decrease UPW use Liters/cm^2 (gal/ in^2)		**6 (10.2)–8 (13.6)**			**5 (8.5)–7 (11.9)**		**4 (6.8)–6 (10.2)**	
Assembly & Packaging								
Eliminate waste from molding process	**Develop/use new molding technologies**							
Reduce water use	**X**	**0.8X**						
Reduce chemical use and consumption	**X**	**0.8X**						

*** In response to the observed acceleration of the Technology Nodes (TN) represented by DRAM half-pitch, the IRC proposes a new TN called Scenario 2 (SC. 2.0) for the year 2001 Renewal. However, due to the lack of time the subsequent contents of this Table are not updated to reflect the new TN.*

All modifications of the items and/or numericals modified from the 1999 ITRS are based on the TN of ITRS 1999 and are highlighted in bold blue text.

2000 UPDATE										
YEAR OF PRODUCTION TECHNOLOGY NODE (1999 ITRS)	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	2008 70 nm	2011 50 nm	2014 35 nm
YEAR OF PRODUCTION TECHNOLOGY NODE **(PROPOSED NODE YEARS ARE NOW 2007/65NM; 2010/45NM; 2013/33NM; 2016/23NM) (SC. 2.0)**	1999 180 nm	2000	2001 **130 nm**	2002	2003	2004 **90nm**	2005	2008 **[60 NM]**	2011 **[40 NM]**	2014 **[30 NM]**

*Table 72b Resource Conservation Technology Requirements—Long Term***

YEAR TECHNOLOGY NODE	2008 70 nm	2011 50 nm	2014 35 nm	DRIVER
ESH				
Zero emissions (recycle rate: %)	80%	90%		
Front End Processes				
Surface preparation	Ambient temp. processes	Virtual closed loop water systems		
Lithography				
Optimization of resource consumption by equipment: optical, e-beam, and EUV	Equipment energy consumption, equipment related chemicals/gases/materials			*Reduced feature size*
Innovative options	Equipment energy consumption, equipment related chemicals/gases/materials			
Optimization of resource usage: optical, e-beam, and EUV	Water/waste recycle/reuse/ reduction			*Reduced feature size*
Innovative options	Water/waste recycle/reuse/reduction			
Factory Integration				
Decrease net feed water use Liters/cm^2 (gal/in^2)	1.2 (2)			
Decrease UPW use Liters/ cm^2 (gal/ in^2)	3 (5.1)–5 (8.5)			
Assembly & Packaging				
Reduce/eliminate waste from molding process	Develop/use alternative molding materials			
Reduce water usage	0.5X			
Reduce chemical use and consumption	0.5X			

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solutions* (red)

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All modifications of the items and/or numericals modified from the 1999 ITRS are based on the TN of ITRS 1999 and are highlighted in bold blue text.

2000 Update										
Year of Production Technology Node (1999 ITRS)	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	2008 70 nm	2011 50 nm	2014 35 nm
Year of Production Technology Node **(Proposed node years are now 2007/65nm; 2010/45nm; 2013/33nm; 2016/23nm) (Sc. 2.0)**	1999 180 nm	2000	2001 **130 nm**	2002	2003	2004 **90nm**	2005	2008 **[60 nm]**	2011 **[40 nm]**	2014 **[30 nm]**

*Table 73a ESH Design & Measurement Methods Technology Requirements—Near Term***

Year Technology Node	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	Driver
ESH								
Methodology for determining lowest ESH impact of materials and processes	Develop basic approach			Beta test the approach			Integrate approach into industry	
Material balance	Basic study			System performance check by existing data			Implement	
Risk assessment	Standardized methodology to identify, access, and accept risk							
Case study for cost and relative risk model	Case study							
Relative risk model with cost performance				Modeling			Check and improve	
Default values for risk and cost model				Interim version			Improve accuracy	
Design tool integration				Basic study of integration for different values			Study for integration	
Resource cycle system model	Basic approach			Modeling			Check and improve	
Process simulation model				Establish basic methodology			Develop advanced process methods	
Evaluation of major process				Use of simulation model on a major process			Use on advanced processes	
Data base for chemicals and materials				Software development				
Data base for regulatory requirements				Survey on requirements, guidelines, NGO trends, and others				
Lithography								
Equipment design tools—optical, e-beam, and EUV		Risk assessment/performance/ cost of ownership						*Reduced feature size*
Chemical usage design tools—optical, e-beam, and EUV		Risk assessment/performance/ cost of ownership						*Reduced feature size*
Factory Integration								
Improved factory design and equipment integration for ESH	Training for factory designers				Implement			
	Industry strategy to develop and write codes				Implement			
	Consensus designs for chemical delivery and by-product management			Implement				
	Consensus design for equipment factory interface			Implement				

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solutions* (red)

*** In response to the observed acceleration of the Technology Nodes (TN) represented by DRAM half-pitch, the IRC proposes a new TN called Scenario 2 (SC. 2.0) for the year 2001 Renewal. However, due to the lack of time the subsequent contents of this Table are not updated to reflect the new TN.*

All modifications of the items and/or numericals modified from the 1999 ITRS are based on the TN of ITRS 1999 and are highlighted in bold blue text.

2000 UPDATE										
YEAR OF PRODUCTION TECHNOLOGY NODE (1999 ITRS)	1999 180 nm	2000	2001	2002 130 nm	2003	2004	2005 100 nm	2008 70 nm	2011 50 nm	2014 35 nm
YEAR OF PRODUCTION TECHNOLOGY NODE **(PROPOSED NODE YEARS ARE NOW 2007/65NM; 2010/45NM; 2013/33NM; 2016/23NM) (SC. 2.0)**	1999 180 nm	2000	2001 **130 nm**	2002	2003	2004 **90nm**	2005	2008 **[60 NM]**	2011 **[40 NM]**	2014 **[30 NM]**

*Table 73b ESH Design & Measurement Methods Technology Requirements—Long Term***

YEAR TECHNOLOGY NODE	2008 70 nm	2011 50 nm	2014 35 nm	DRIVER
ESH				
Design tool integration	**Integration**			
Evaluation methodology for resource cycle system model	**Performance and predictability check**			
Process simulation model	**Develop advanced process methods**			
Evaluation of major process	**Use on advanced processes**			
Lithography				
Equipment design tools				*Reduced feature size*
Innovative options	**Risk assessment/performance/cost of ownership**			
Chemical usage design tools				*Reduced feature size*
Innovative options	**Risk assessment/performance/cost of ownership**			

Solutions Exist (white) *Solutions Being Pursued* (yellow) *No Known Solution* (red)

*** In response to the observed acceleration of the Technology Nodes (TN) represented by DRAM half-pitch, the IRC proposes a new TN called Scenario 2 (SC. 2.0) for the year 2001 Renewal. However, due to the lack of time the subsequent contents of this Table are not updated to reflect the new TN.*

All modifications of the items and/or numericals modified from the 1999 ITRS are based on the TN of ITRS 1999 and are highlighted in bold blue text.