2001 International Technology Roadmap for Semiconductors (ITRS)
Factory Integration Attributes and Drivers for E-Manufacturing

Michio Honma, NEC
Jeff Pettinato, Intel
Agenda

1. Important Elements of the ITRS
2. Scope and Factory Drivers
3. Difficult Challenges
4. Need for Integrated Solutions
5. Key Technology Requirements
6. Solutions Being Driven by Technology Requirements
   - Direct Transportation
   - Agile Manufacturing
   - Advanced Process Control (APC)
   - Equipment Engineering Systems (EES)
7. Summary
What is the ITRS?

- ITRS = International Technology Roadmap for Semiconductors

- It identifies industry challenges, technology requirements (metrics), and potential solutions over a 15 year timeline

- It’s a global effort with experts participating from 5 regions: Japan, Europe, Korea, Taiwan, and the United States

- Experts come from IC makers, Suppliers, Universities, Research Consortia, and Standards bodies (e.g. SEMI)

- Expected output from the roadmap is ACTION to analyze options and develop solutions that meet technology requirements
# The Roadmap

## Major node years

<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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<tbody>
<tr>
<td>Technology Node (nm)</td>
<td>130</td>
<td>115</td>
<td>100</td>
<td>90</td>
<td>80</td>
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<td>65</td>
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<tr>
<td>Wafer size (mm)</td>
<td>300</td>
<td>300</td>
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## Shrink years

<table>
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<th>Year</th>
<th>2010</th>
<th>2013</th>
<th>2016</th>
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<tbody>
<tr>
<td>Technology Node (nm)</td>
<td>45</td>
<td>32</td>
<td>22</td>
</tr>
<tr>
<td>Wafer size (mm)</td>
<td>300</td>
<td>450</td>
<td>450</td>
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**Next wafer size change date**
ITRS Roadmap Elements

A VISION OF THE FUTURE

Difficult Challenges that must be overcome

Potential Solutions that must be developed

Technology and Business Requirements

Cross-cut domains: its relationships must be understood & its potential solutions made available

Deployment date to which solutions and products must be synchronized to
## Factory Integration Contributing Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Company/Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jim Ammenheuser (ISMT)</td>
<td>Damon Genetti (Novellus)</td>
</tr>
<tr>
<td>Bob Bachrach (AMAT)</td>
<td>Randy Goodall (ISMT)</td>
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<td>Eddy Bass (Intel)</td>
<td>Dave Gross (AMD)</td>
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<td>Dave Bloss (Intel)</td>
<td>Larry Hannessy (IDC)</td>
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<td>Ray Bunkofske (IBM)</td>
<td>Duane Howard (IBM)</td>
</tr>
<tr>
<td>Chris Burkhart (Novellus)</td>
<td>Michio Honma (NEC)</td>
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<tr>
<td>Al Chasey (ASU)</td>
<td>Jim Irwin (Irwin Consulting)</td>
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<tr>
<td>Hugo Chang (Winbond)</td>
<td>Mani Janakiram (Intel)</td>
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<td>Ivan Chou (Compaq)</td>
<td>Carl Johnson (PRI)</td>
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<td>Eric Christianson (AMD)</td>
<td>Melvin Jung (Intel)</td>
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<td>Blaine Crandell (TI)</td>
<td>Giichi Inoue (Toshiba)</td>
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<tr>
<td>Klaus Eberhardt (M+W Zandar)</td>
<td>Junji Iwasaki (Mitsubishi)</td>
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<td>Anne Eldar (Intel)</td>
<td>Shoichi Kodama, (Toshiba)</td>
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<td>John Ellis (SEMI-NA)</td>
<td>Dave Miller (IBM)</td>
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<td>Rick Filippuzzi (Asyst)</td>
<td>Mitsui-san (Matsushita)</td>
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<tr>
<td>Len Foster (TI)</td>
<td>Mori-san (Daifuku)</td>
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<tr>
<td>John Fowler (ASU)</td>
<td>Rohan Nageswaran (Intel)</td>
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<tr>
<td>Karl Gartland (IBM)</td>
<td>Seiichi Nakazawa (F-RIC)</td>
</tr>
<tr>
<td>Bruce Gehman (SEMI)</td>
<td>John O’Reilly (ION Systems)</td>
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</tbody>
</table>

Many International members have contributed to FI
2001 Factory Integration Scope Includes Wafer, Chip and Product Manufacturing

The Factory is driven by Cost and Productivity:
- Reduce factory capital and operating costs per function
- Enable efficient high-volume production with operational models for varying product mixes (high to low) and other business strategies
- Increase factory and equipment reuse, reliability, and overall efficiency
- Quickly enable process technology shrinks and wafer size changes
E-Manufacturing Capabilities are Needed to Improve Capital and Operational Productivity

**Production Equipment = 80% of Total Capital**
- $2,160M for $2.7B factory
- Process and Metrology equipment
- Mainframe and process chambers
- Wafer Handling Robots
- Load Ports
- Installation, but not qualification
- Software & computers within the equipment

**Facilities = 15% of Total Capital**
- $405M for $2.7B factory
- Cleanroom, Labs, Central Utility Building
- Facilities Control and Monitoring Systems
- Support buildings (Café, office, parking)
- Power, Plumbing, HVAC, Utilities, Pipes, UPS
- Life safety systems, waste treatment
- Includes site prep, but not land and off-site dev costs

**Material Handling Systems = 3% of Total Capital**
- $81M for $2.7B factory
- Wafer and Reticle Carriers
- Carrier ID readers
- Automated storage systems
- Interbay & intrabay transport systems
- Personnel guided vehicles
- Software & computers within the equipment

**Factory Information & Control = 2% of Total Capital**
- $54M for $2.7B factory
- Manufacturing execution systems
- Decision support systems
- Process Control systems
- Planning systems, Schedulers, Dispatching
- Material Control, document management systems
- Computers, databases, software outside equipment

Assumptions
Total Capital Cost = $2.7B
Total Capacity = 40k wspm
300mm wafer size
130nm technology
**Current trends in a leading-edge factory**

<table>
<thead>
<tr>
<th>Difficult Challenge</th>
<th>Current trend</th>
<th>What’s Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity, time, &amp; cost to integrate new factories and respond to business changes</td>
<td></td>
<td>▪ Equipment + process control systems with standard interfaces that are simple to integrate.</td>
</tr>
<tr>
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<td>▪ Flexible factory information &amp; control systems that can forecast and change with business conditions</td>
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<td>▪ Conversion agility for all factory elements</td>
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<td>▪ Improved forecasting models</td>
</tr>
<tr>
<td>Production equipment OEE performance &amp; extendibility</td>
<td></td>
<td>▪ Equipment meets stated run rates and reliability specs out of the box</td>
</tr>
<tr>
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<td>▪ Ability to reuse equipment through multiple technology nodes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Factory scheduling, dispatching, and monitoring systems to effectively utilize equipment and quickly fix factory floor issues</td>
</tr>
<tr>
<td>Realize 300mm conversion goals and efficiencies</td>
<td>TBD</td>
<td>▪ Get &gt;30% die cost reduction while hitting ramp and yield targets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Realize cycle time improvements, operational cost reductions, and 100% fully automated factory paradigm change</td>
</tr>
</tbody>
</table>
Factories Must be Better integrated to solve Difficult Challenges

Technology Requirements and Potential Solutions are expressed through these factory areas.

**Factory Areas or Thrusts**

- **Factory Operations**
  - Example: Manufacturing rules, production size, mix

- **Production Equipment**
  - Example: Equipment unit, real-time process control, interface standards, Embedded Control

- **Material Handling**
  - Examples: AMHS Transport, storage, ID Systems, interface standards

- **Factory Information and Control Systems**
  - Example: MES, Computers, Networks, Apps MCS, APC, etc

- **Facilities**
  - Examples: Building, cleanroom, utility systems, process fluid delivery

**Complexity Management**
- Rapid changes to business needs & demands; Increasing process & product complexity; Larger wafers and carriers, Increased reliance on factory information & control systems

**Factory Optimization**
- Increased customer expectation to meet on time delivery; Increased urgency for improved factory effectiveness, High factory yield at startup; Reduce wafer and product cost; Satisfy all local regulations

**Extendibility, Flexibility, Scalability**
- Reuse of building, production equipment, and factory information and control systems; Factory designs that support rapid process and technology changes/retrofits; Comprehend tighter ESH/Code requirements

International Technology Roadmap for Semiconductors

04 December 2001
Integrated Solutions are Essential to Meet Needs

Technology Requirements
1. New disruptive process technologies
   - 157nm litho
   - High K gate stack
   - Low k dielectrics
   - Copper processing

2. Improved Productivity
   - Decreased Factory Cycle Time (QTAT)
   - Improved Equipment Efficiency
   - Reduction in non-product (i.e. test) wafer usage
   - More efficient direct labor
   - Faster factory conversion at technology nodes

Integrated Solutions

- Agile Manufacturing
  - Equipment Engineering Systems - EES
  - Single wafer control
  - e-Diagnostics

- Process Control
  - Fault Detection & Classification
  - Run to Run & Wafer to Wafer control
  - Integrated Metrology
  - Machine to machine matching

- Material Handling
  - Direct Transport AMHS
  - AMHS to support Send-Ahead, gating monitors, and very hot lots
  - Integrated Sorters, Stockers, Metrology

Goal = Meet Factory Challenges and Technology Requirements

International Technology Roadmap for Semiconductors
<table>
<thead>
<tr>
<th>YEAR</th>
<th>TECHNOLOGY NODE</th>
<th>WAFER DIAMETER</th>
<th>Factory cycle time per mask layer (non-hot lot for High Volume High Mix) (days)</th>
<th>Wafer layers/day/head count</th>
<th>Lots per carrier (lot)</th>
<th>Groundbreaking to first tool move-in (months)</th>
<th>First tool move-in to first full loop wafer out (months)</th>
<th>Bottleneck production equipment OEE</th>
<th>Average production equipment OEE</th>
<th>% capital equipment reused from previous node</th>
<th>Production Equipment Install as a % of capital cost</th>
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<tbody>
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<td>2001</td>
<td>130 NM</td>
<td>300 MM</td>
<td>1.2</td>
<td>55</td>
<td>Multiple</td>
<td>9</td>
<td>4</td>
<td>75%</td>
<td>55%</td>
<td>Limited reuse</td>
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<td>3.5</td>
<td>78%</td>
<td>58%</td>
<td>&gt;90%</td>
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<td>63%</td>
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<td>Limited reuse</td>
<td>8%</td>
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12
## Key Material Handling, Factory Info and Control Systems, and Test Mfg Technology Requirements

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</table>

### Material Handling

- **# of AMHS transport system types in a factory**
  - 2001: 2
  - 2002: 2
  - 2003: Some 1 and some 2
  - 2004: 1
  - 2005: 1
  - 2006: 1
  - 2007: 1
  - 2010: 1
  - 2013: 1
  - 2016: 1

- **System throughput (moves/hour)**
  - Interbay transport
    - 2001: 1200
    - 2002: 1300
    - 2003: 1400
    - 2004: 1500
    - 2005: 1625
    - 2006: 1750
    - 2007: 1875
    - 2010: 2000
    - 2013: 2000
    - 2016: 2000
  - Intrabay transport
    - 2001: 170
    - 2002: 180
    - 2003: 190
    - 2004: 200

### Factory Info and Control

- **MTBF for mission critical applications (months)**
  - >6
  - >7
  - >8
  - >8
  - >9
  - >9
  - >10
  - >12
  - >12
  - >24

- **Time to create FICS interface Standard (months)**
  - <12
  - <12
  - <6
  - <6
  - <6
  - <6
  - <6
  - <6
  - 4

- **Lead time for software to conform to standards**
  - >18
  - <9
  - <9
  - <6
  - <6
  - <6
  - <4
  - <4
  - <4

### Test Mfg

- **1st Article Test Equipment integration time improvement from previous year**
  - 0%
  - 0%
  - 30%
  - 20%
  - 20%
  - 10%
  - 10%
  - 10%
  - 10%
## Translating Factory Operations, Production Equipment, and Facilities Metrics to Reality

<table>
<thead>
<tr>
<th>Metric</th>
<th>Potential Solution it is driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-Lot and regular lot cycle time per mask layer</td>
<td>a) Direct transport systems, b) <strong>Agile manufacturing leveraging internet technologies</strong>, c) <strong>Integrated Planning, Scheduling, and Dispatch Software</strong></td>
</tr>
<tr>
<td>Wafer Layers / Day / Headcount</td>
<td>a) Fully automated material handling &amp; data sys</td>
</tr>
<tr>
<td>Multiple lots per carrier</td>
<td>a) Embedded controller standards</td>
</tr>
<tr>
<td>Groundbreaking to first tool move in</td>
<td>a) Standardized design concepts, b) Design tools including e-tools, d) More off-site fabrication</td>
</tr>
<tr>
<td>First tool move-in to first full loop out</td>
<td>a) <strong>Standard equipment interfaces to reduce integration time</strong></td>
</tr>
<tr>
<td>Overall Equipment Efficiency (OEE)</td>
<td>a) Minimize MTTR by e-Diagnostics, b) <strong>Advanced Process Control</strong>, c) <strong>Equipment Engineering Systems</strong>, d) <strong>Equipment events integrated with factory scheduler</strong></td>
</tr>
<tr>
<td>Capital Reuse from one node to the next</td>
<td>a) Common main-frame and chamber interfaces, b) High exchangeability of chamber modules / parts</td>
</tr>
<tr>
<td>Production Equipment Install &amp; Qualification cost as a % of capital cost</td>
<td>a) Earlier involvement with new technology tool designers, b) Design for tool install emphasis, c) Standard / consistent equipment connections</td>
</tr>
</tbody>
</table>
## Translating Material Handling, FICS, and Test Manufacturing Metrics to Reality

<table>
<thead>
<tr>
<th>Metric</th>
<th>Potential Solution it is driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMHS system throughput for interbay and intrabay</td>
<td>a) Fundamental capability that permits AMHS system to transport hot lots, gating send-aheads and hand carry</td>
</tr>
<tr>
<td>MTBF/MTTR for mission critical applications</td>
<td>a) Equipment Engineering Systems, b) E-Diagnostic and c) E-manufacturing capabilities</td>
</tr>
<tr>
<td>Time to create industry standards</td>
<td>a) Improved business processes to speed up standard cycle time, b) Use Internet for balloting/approval</td>
</tr>
<tr>
<td>Lead time for solutions to conform with standards</td>
<td>a) Supplier/IC Maker collaboration to develop standards and solutions in parallel, b) Automated test tools for systematic interface testing</td>
</tr>
<tr>
<td>1st Article Test Equipment integration time change from previous year</td>
<td>a) Standard interfaces for equipment control, b) Standards for test programs, c) Standard data formats for test results</td>
</tr>
</tbody>
</table>
Summary of Key Potential Solutions

✿ Material Handling using Direct Transport
   - Impact on factory layout and overall design

✿ Agile Manufacturing Leverage Internet capabilities
   - Full Factory Automation (Data and Material Handling)

✿ Advance Process Control (APC)

✿ Equipment Engineering System (EES)
   - e-Diagnostics, proactive monitoring of output, quality, variance reduction
   - Trend is to also have facilities support equipment “connected” through e-Diagnostics and internal factory networks

✿ Continued Need for Standards to reduce integration time, cost, and complexity
   - For Factory Information & Control Systems, Production Equipment, Test manufacturing systems, Material Handling, and Facilities
Summary

1. Rapid changes in process technologies, business requirements, market conditions, and accelerated ramp and yield targets make factories more complex and difficult to integrate.

2. Factory of the future must be extremely agile and quick to meet these rapid technology and business changes with cost effective solutions

3. Equipment suppliers must deliver stable equipment running new process technologies with very high Overall Equipment Efficiency

4. The industry must realize 300mm Wafer conversion efficiencies to get 2.25X die per wafer with a 30% die cost reduction

5. Innovative solutions in Agile manufacturing, Process Control, Equipment Engineering systems, and Material Handling are needed to meet future factory output goals and realize 300mm conversion efficiencies

6. We invite and encourage you to participate in FITWG activities for 2002 to convert these plans to reality
Agile Manufacturing Means…

- Quick turn around [*faster cycle] time for production
  - Quick turn around time without productivity deterioration
  - No productivity reduction even if many lots production formed with few wafers

- Quick capability to product, scale and technology change
  - Quick ramp-up of equipment installation and product
  - Assure high productivity even if low production volume

Which can be Realized by…

- Internet technologies for B2B, Factory to Factory, Internal factory connectivity and communications
- Supply Chain Management (SCM)
- Integrated Planning, Scheduling, and Real Time Dispatching Flexible Material Handling and Data Automation Systems
- Single Wafer Control and Tracking
  - Multiple lots/single wafer control in equipment module (group)
Type 1: Carrier Level integrated Flow and Control

Potential Solutions Require:
- Standardized Intrabay Operation
- Integrated Software
- High reliability equipment

When Solutions Are Needed:
• Research Required in 2001
• Development Underway by 2002
• Qualification/Production by 2003

Sorter & Metrology with Stockers
Type 2-1 : Wafer Level Integrated Flow and Control (Connected EFEM)

Potential Solutions Require:
- I/F Standard (H/W, S/W)
  - Standardized EFEM
- Software
  - Integrated
  - Wafer level APC
- Standardized Intrabay Operation

When Solutions Are Needed:
- Research Required by 2002
- Development Underway by 2004
- Qualification/Production by 2005

Conceptual Only
Potential Solutions Require:
- System controller of Equipment Group
  - Wafer Dispatcher
- Module structure of equipment
  - Standardized I/F
  - Standardized Width
- Modular Process Steps
- High Speed Wafer Transfer
- Standardized Intrabay Operation

When Solutions Are Needed:
- Research Required by 2003
- Development Underway by 2005
- Qualification/Production by 2006

Conceptual Only
Type 2-3: Wafer Level Integrated Flow and Control
Continuous EFEM (Revolving Sushi Bar)

Potential Solutions Require:
- Ultra High Speed Wafer Transfer
  Target M/C to M/C 7sec.
- Wafer Level Dispatching

When Solutions Are Needed:
- Research Required by 2007
- Development Underway by 2010
- Qualification/Production by 2013

Target 450mm
Semiconductor industry business model changing

IDM age

Foundry/Fabless Age

Collaboration Age

IT technology is a must. Speed is most important

Transactions and Interlinkage will be flexible and open.

Marketing

Design

Fab

IP

Fabless

Foundry

International Technology Roadmap for Semiconductors

04 December 2001
e-Manufacturing Hierarchy

Company to Company (E-Commerce)

Factory to Factory (E-Factory)

Within a Factory (E-Factory)

Equipment/AMHS

Suppliers

e-diagnostics capability

firewall

Equipment Engineering System

International Technology Roadmap for Semiconductors
The e-Business structure for manufacturing

- **e-Business**

  - **e-Manufacturing**
    - Product and pre-product’s e-Commerce
    - Chip buyers support
    - Spare parts logistics, etc.

  - **Equipment Engineering (EE)**
    - Real time control (APC/AEC)
    - Machine-to-Machine difference management
    - Maintenance scheduling, etc.

  - **e-Diagnostics**
    - Diagnostics data collection
    - Remote access and analysis of diagnostic data
E-manufacturing Direction

e-Supply Chain Management
   e-Business/Commerce

   e-Engineering
      design, reticle data, analysis

   Second handed equipment

   Spare parts management

   e-Manufacturing control the fab

   APC/FDC

   e-Preventative Maintenance prevent problems

   e-Maintenance solve problems

   e-Diagnostics project

   e-Diagnostics extract information

   e-Engineering System

   EES (Equipment Engineering System)
What will Equipment Engineering Systems (EES) replace?

Manufacturing Execution System (MES)

- MCS
- AMHS
- Operators still watch the tool to confirm its health status and do miscellaneous things

Equipment Engineering System

- FAX and telephone be replaced by Internet
- e-Diag Capability
- Suppliers

New!

What will Equipment Engineering Systems (EES) replace?
The Next Generation Factory Concept

Planning System

User’s SCM - Supply Chain Management

Direct Transport

Wafer Level Control

E-Diagnostic

Supplier’s SCM

Supporting System

Agile Mfg. System

E-Mfg.

EES

International Technology Roadmap for Semiconductors
ITRS and Adv. Process Control

ITRS Process Control discussion is divided into 3 basic high level Capabilities:

1. Fault Detection and Classification
   - ITRS Problem: Prevent scrap or equipment damage
   - ITRS Problem: Optimize performance to processing spec

2. Run to Run Control (lot to lot, and wafer to wafer)
   - ITRS Problem: Optimize performance to processing spec

3. Integrated Metrology
   - ITRS Problem: Reduce module level TPT + AMHS moves

Fault Detection and Classification

- Inside the Tool
  - FDC Models defined / configured
  - FDC host signals configured
  - FDC actions may be configured

- Outside of Tool
  - Host determines actions based on type of fault
  - Host issues control command

Run to Run Control

- Host System
  - EE Interface
  - Detailed Historical Data

Integrate Metrology

- EES
  - Integrated GEM Interface for Process and Metrology
  - Integrated EE Interface for Process and Metrology

- Metrology data and detailed wafer and chamber data collected via EE interface

- Parameterized recipes required

Parameterized recipes required

- Process Equipment
  - Integrated Process and Metro Equip.
  - Recipe and Model Selection and Download via GEM Interface

- Host System
  - Equip Controller
  - Integrated Metrology Module (not Bolt on)
Continued Standardization is needed to Reduce Integration Time, Cost, and Complexity

Production Equipment
- Enhanced parallel I/O standard for ground based transporters
- Enhanced parallel I/O standard for ceiling based transporters
- Buffering standards for continuous operation
- Wafer & carrier standards
- Carrier environment standards
- Carrier ID standards
- Loadport standards
- PGV docking standards
- Equipment footprint & height management standards
- Isolation standards for equipment maintenance

Factory Information and Control Systems
- Manufacturing Execution Systems
- Process Job, Control Job standards
- Reticle carrier & loadport standards
- Carrier mgt standard
- Equipment footprint & height management standards
- Standards for safety counter-measures

Legend:
- -> Standards Exist
- => Standards Are Under Development
- => Standards Are Needed