OUTLOOK FOR ADVANCED CLEANS

Business of Cleans

April 9, 2018

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Linx Consulting Inc.

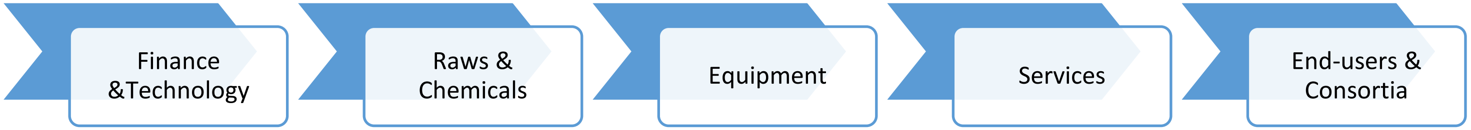
www.linx-consulting.com

Outline

- Introduction to Linx Consulting
- Semi Industry Outlook
- Materials Challenges
- Impact on Suppliers
- Conclusions

Introduction to Linx Consulting

Linx Consulting



Finance &Technology

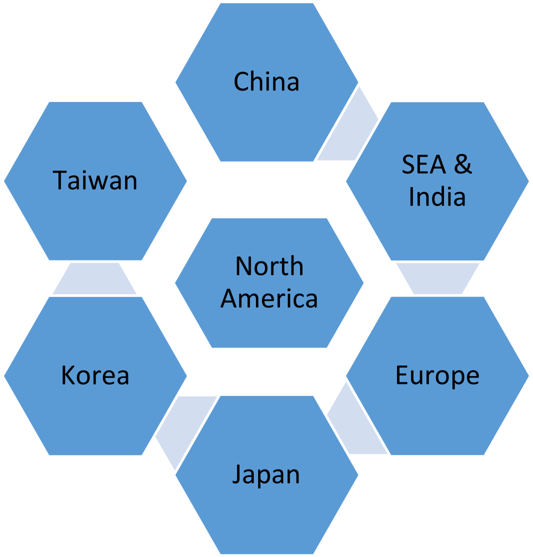
Raws & Chemicals

Equipment

Services

End-users & Consortia

1. ***We help our clients to succeed by creating knowledge and developing unique insights at the intersection of electronic thin film processes and the chemicals industry on a global basis***
2. ***The knowledge is based on a core understanding of the semiconductor device technology; manufacturing processes and roadmaps; and the global structural industry dynamics***
3. ***This knowledge is leveraged to create advanced models, simulations and real-world forecasts***
4. ***Our perspectives are by direct research and leveraging our extensive experience throughout the global industry value chain***



China

SEA & India

Taiwan

North America

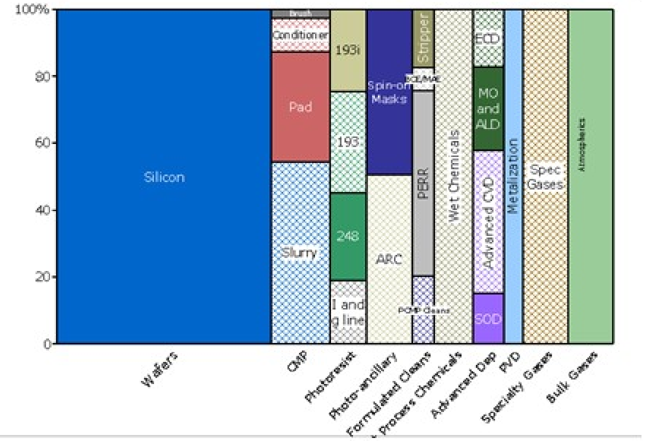
Korea

Europe

Japan

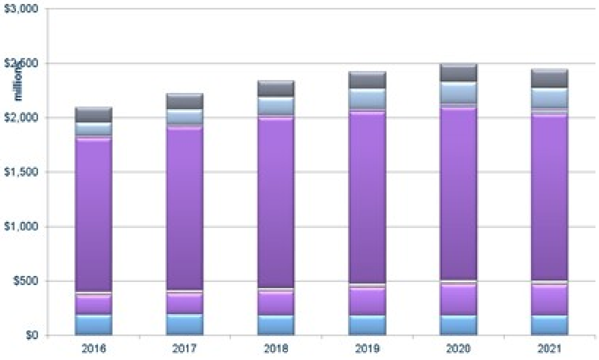
MSI Breakdown & Forecasts

Market Knowledge

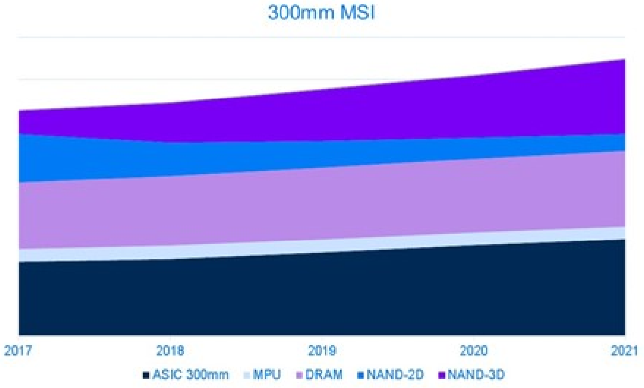


and Understanding

Accurate Forecasts



Insights on Evolution



Linx Consulting Service Portfolio

- **Full Service**
  - Forecast Service
  - Technology Trends

- **Multi-Client Reports**
  - IC Materials
    - CMP
    - Deposition
    - Patterning
    - Cleaning
    - Gases
    - Bulk Chemicals
    - Packaging

- **Proprietary Projects**
  - Market Planning
  - M & A
  - Growth and Diversification
  - Supply Chain Optimization
  - Technology Commercialization
  - Strategic Planning
  - Voice of the Customer
  - Market Diligence

- **Econometric Semiconductor Forecast**
  - Financial planning
  - Sales and Operational planning
  - Forecasting

With Hilltop Economics LLC

- **Cost Modeling**
  - Client demand modeling
  - Product development
  - Bill of Materials quantification

With IC Knowledge, LLC

- **Conference Production**
  - The Business of Cleans & SPCC

- **Wafer Start Demand Forecasting**
  - Device type and technology node

Semi Industry Outlook

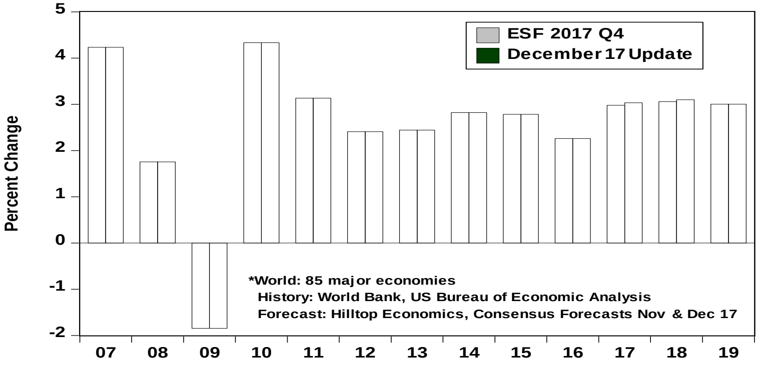
Industry Trends Summary

- Healthy GDP growth rates expected in all major regions
- Record levels of CapEx reflect very high utilization (>95%) across both 200 mm and 300 mm fabs, driven by record demand for Logic and 3D NAND chips
- Fifteen IDMs exceed $1B spend in 2017, spanning US-based (Intel, Micron, Global Foundries), European (ST Micro, Infineon) and Asian companies
- Samsung remains the industry top spender, with $20B CapEx forecasted for both 2017 and 2018
- Geographically, new fab construction is highly concentrated in Asia, with China investment dominating the list
- Several trends support such rapid industry expansion
  - Some are already driving significant volume of chips, e.g. next-generation communication networks, automotive electronics/ADAS, and Internet of Things/IoT
  - Others are nascent and will fuel this growth for years to come, e.g. Artificial Intelligence/AI, VR/AR technologies, and autonomous vehicles

Economic Drivers

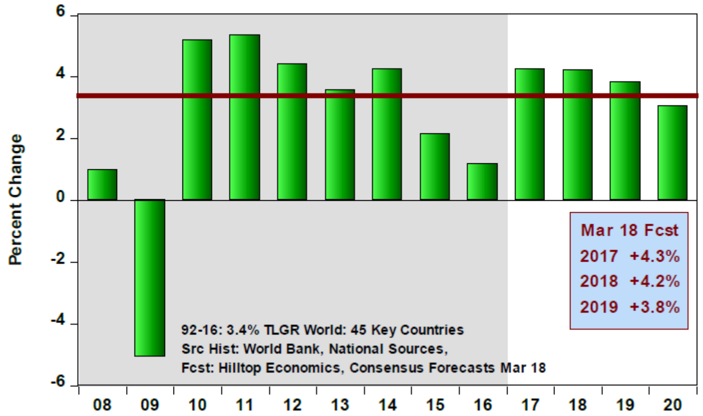
World* Real GDP Growth

2016: 2.3% 2017: 3.0% 2018: 3.1%



*World: 85 major economies
History: World Bank, US Bureau of Economic Analysis
Forecast: Hilltop Economics, Consensus Forecasts Nov & Dec 17

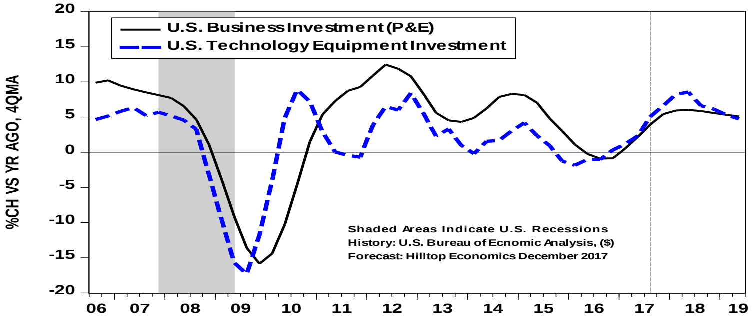
World* Real Investment



Mar 18 Fcst
2017 +4.3%
2018 +4.2%
2019 +3.8%

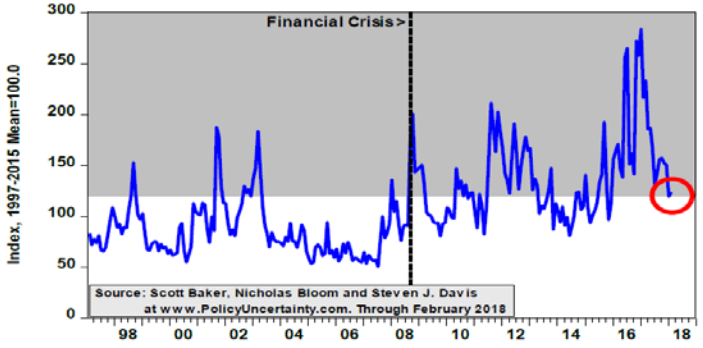
92-16: 3.4% TLGR World: 45 Key Countries
Src Hist: World Bank, National Sources,
Fcst: Hilltop Economics, Consensus Forecasts Mar 18

U.S Business Investment



Shaded Areas Indicate U.S. Recessions
History: U.S. Bureau of Ecnomic Analysis, ($)
Forecast: Hilltop Economics December 2017

Global Economic Policy Uncertainty



Source: Scott Baker, Nicholas Bloom and Steven J. Davis
at www.PolicyUncertainty.com. Through February 2018

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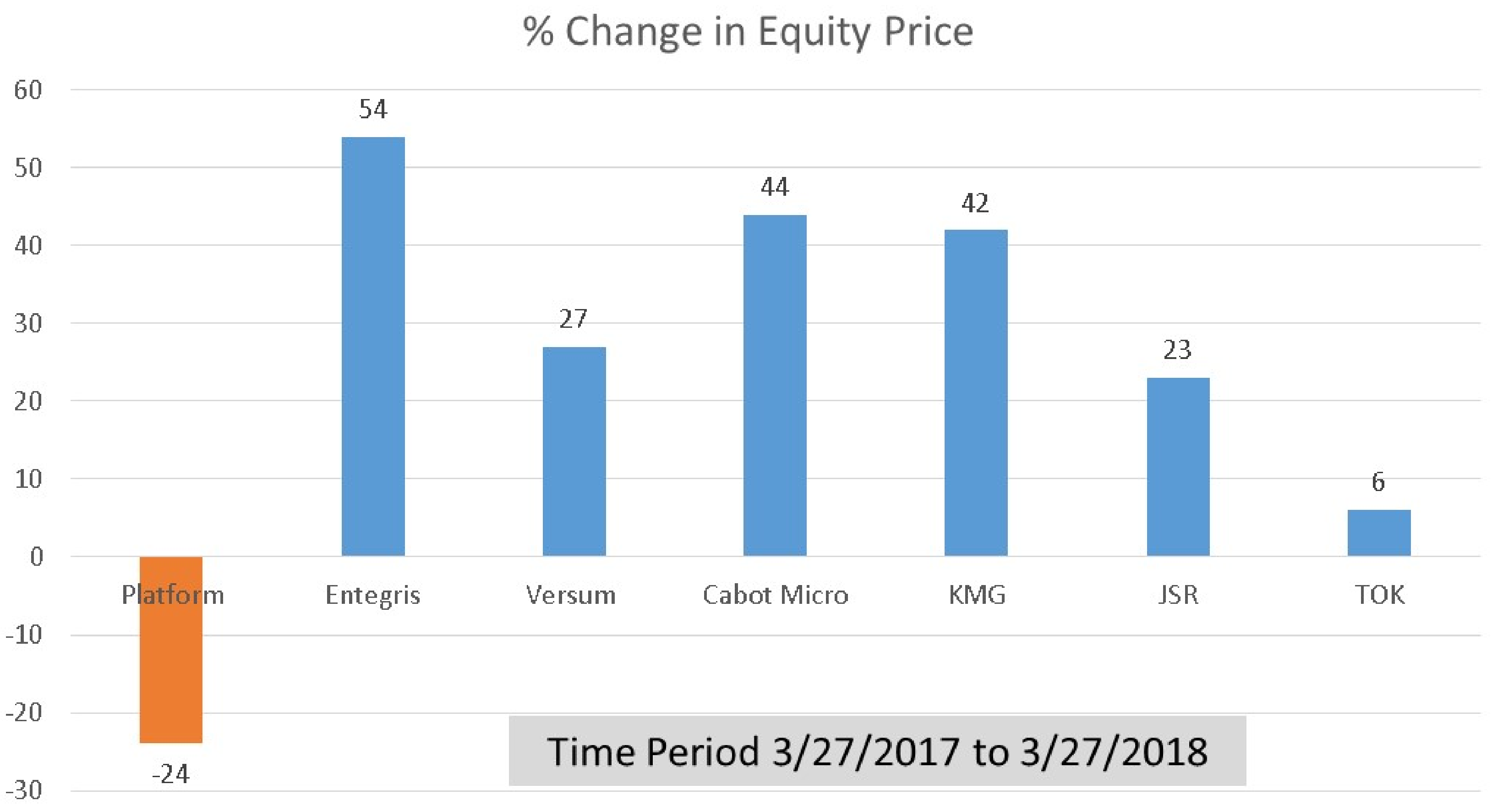
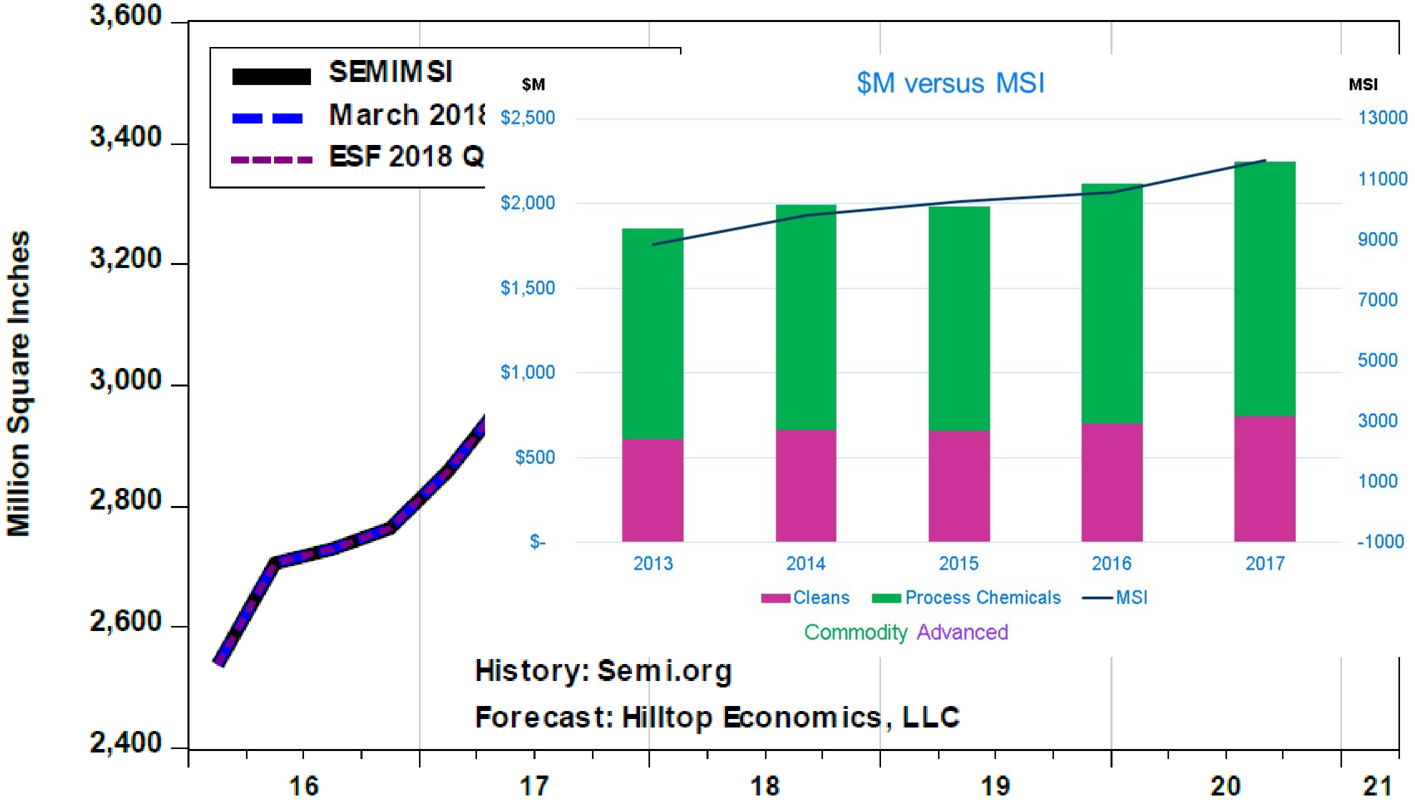
Linx WFM Equity Index



Latest MSI Forecast by ESF Model

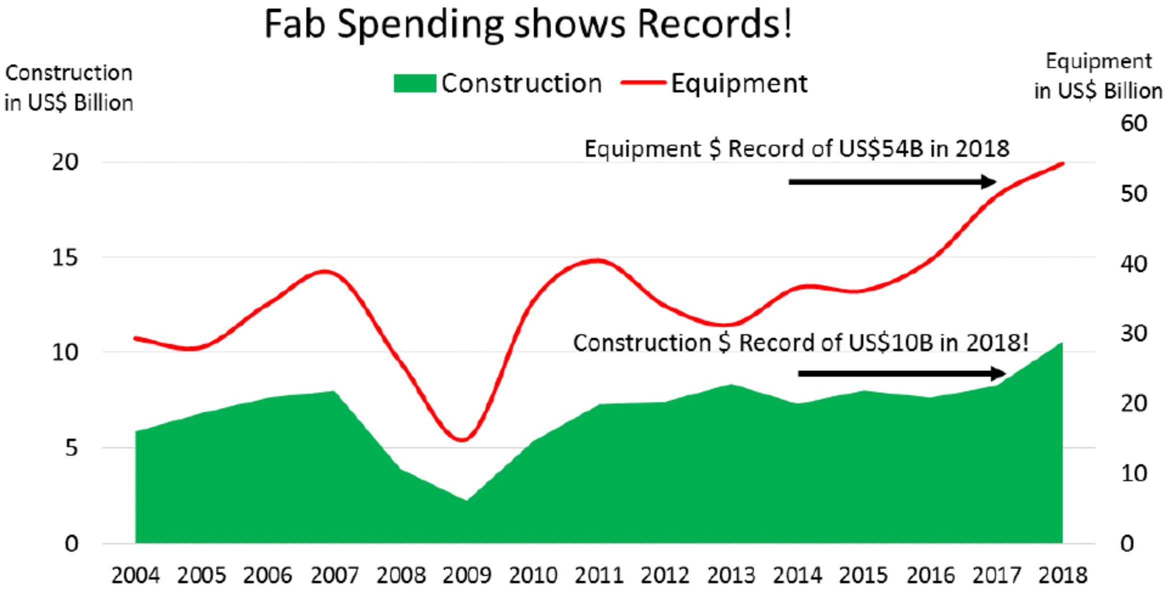
Semiconductor Forecast: ESF 2018 Q1



History: Semi.org

Forecast: Hilltop Economics, LLC

Record Levels of Capex



Source: World Fab Forecast Report, May 2017, SEMI

Fab equipment spending includes new and secondary equipment; and facilities for such

Billion Dollar Spenders in 2017

- Samsung
- Intel
- TSMC
- SK Hynix
- Micron
- Toshiba
- GLOBALFOUNDRIES
- SMIC
- Western Digital (SanDisk)
- UMC
- Nanya
- Sony
- Infineon
- ST Microelectronics
- Renesas

Capacity Utilization for 200mm and 300mm fabs > 95% in 2017

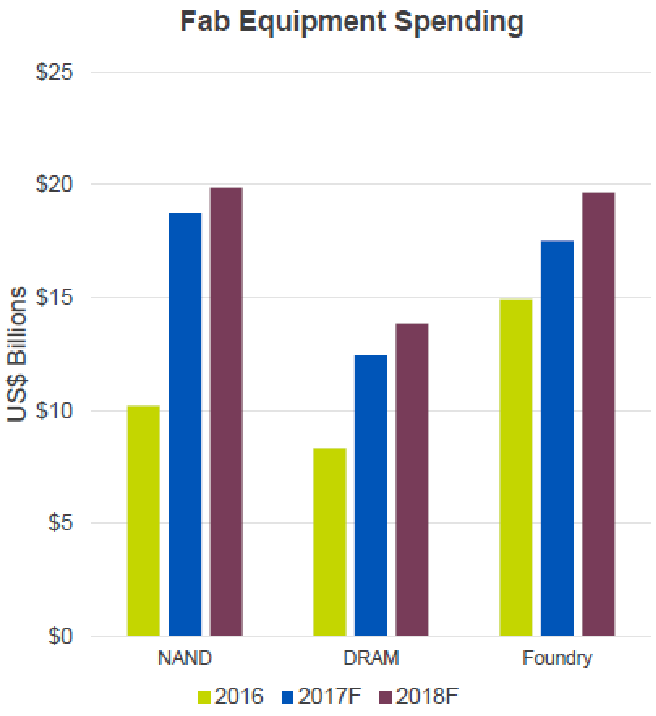
Key Growth Drivers: NAND, DRAM and Foundry

Driven by NAND, DRAM and Foundry

NAND
- Samsung Pyeongtaek P1
- SK Hynix M14 3D NAND line
- Micron Building 60 (Lehi) and Fab 10X in Singapore
- Toshiba/Flash Alliance Fab 2, Fab 6 and new R&D Center
- Intel Fab 68 in China

DRAM
- Samsung Pyeongtaek P1 and Line 15
- Micron Fab 15 (Hiroshima) and Fab 16
- SK Hynix M14

Foundry
- TSMC Fab 12, Fab 14 and Fab 15
- Samsung S2 and S3
- GLOBALFOUNDRIES Fab 1, Fab 8 and Fab 11
- SMIC Beijing B2 and B3, new Shanghai 300mm fab and Shenzhen 300mm fab
- UMC Fab 12A P5 and Xiamen fab



Source: SEMI World Fab Forecast, December 2017

3DN and Logic driving growth. Vertical scaling helps drive Materials Growth

Materials Challenges

Trends Impacting WFM Suppliers

Enhanced Operating Requirements

Tech. Dev & Apps Support

WFM SUPPLIERS

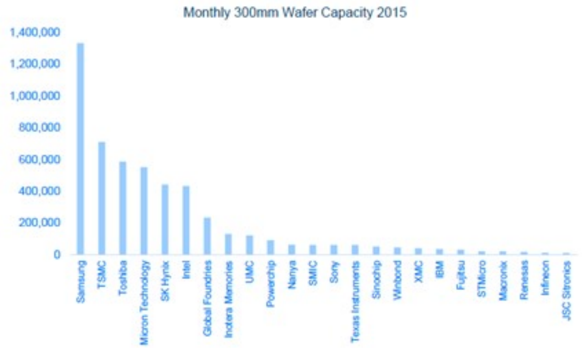
New Entrants from China

成员单位

用户单位：9家
材料企业：44家
研究机构：5家
大　　学：5家
融资机构：1家

Collaborative Innovation, Cooperative Developing

Consolidating Customer Base

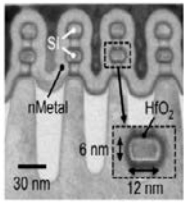


Sources: Intel, ICMTIA, AMAT, ICKnowledge

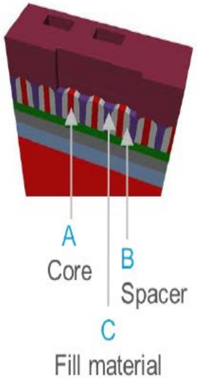
Materials Opportunities

Demand Drivers

- CuBS demand increasing in Logic Interconnect
  - Limitations of current architectures
- FinFET gate deposition
  - GAA Nanowire develop
  - High mobility materials



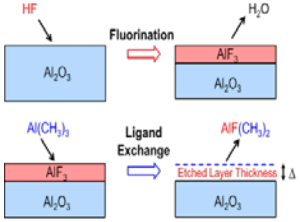
- Memory technology extension
  - 3D-NAND growth
  - DRAM capacitor dielectric
  - Novel architectures
- Pitch doubling and quadrupling
  - Low temperature spacers



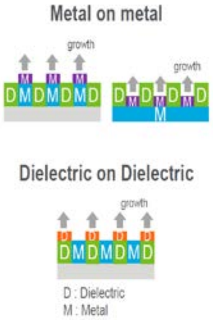
- Lithography aids

Opportunities

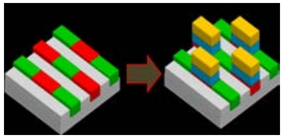
- Possible changes in conductor metal
  - Cu ⇨ Co Barrier ⇨ Co plating
- 3D-NAND aspect ratio
  - Hard mask technology
  - 2D stair-step
- Novel process development
  - Multi color, self aligning etch
  - CVD ⬄ Continuous etch
  - ALD ⬄ ALE



- Self Assembling Materials for selective processes
- Few new PVD applications
  - 3DXpoint / MRAM?



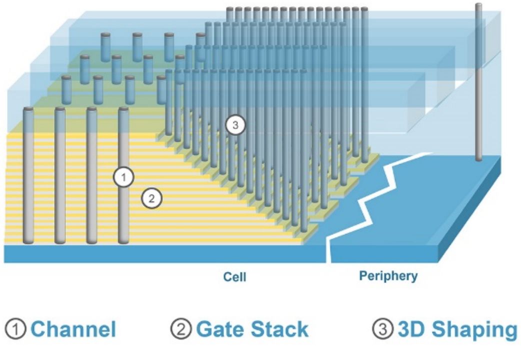
- Selective Deposition
  - Self Assembling Materials
  - Selective Deposition



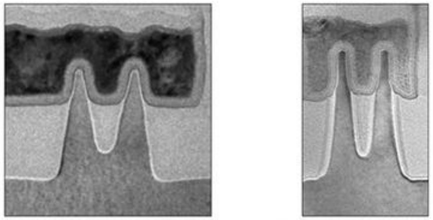
The Cleaning Market Environment

- Technology – The cleaning challenge continues to increase, and new, smaller device structures and materials will increase the difficulty of preparing the wafer for the next process step. Enabling technologies are valued significantly more by end-users than “like” or “me too” products.
- Proliferation of novel materials in gate architecture, memory cell technology, interconnect and packaging is adding complexity in material choice and formulation.
- Increased Customization – Customers are increasingly specifying custom products for layer specific problems.

New Materials and Architectures Enable Moore’s Law

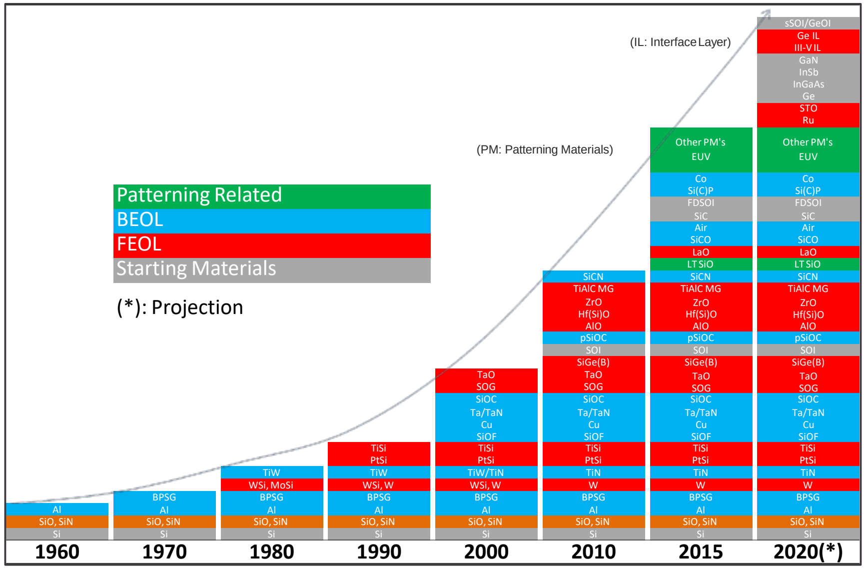


Transistor Fin Improvement



22 nm 1st Generation Tri-gate Transistor

14 nm 2nd Generation Tri-gate Transistor



(*): Projection

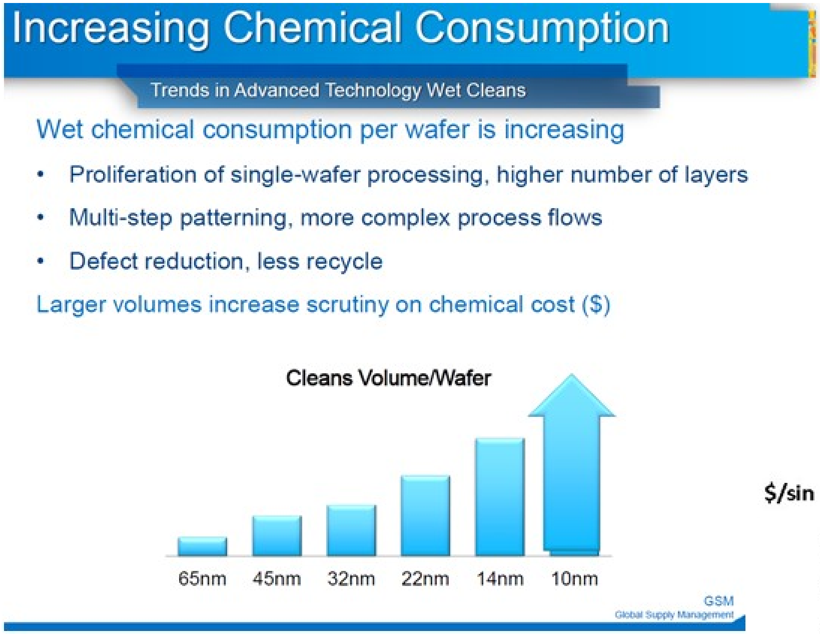
Defectivity Paradigm Shift & Cleans

- Pursuit of Moore’s Law is driving ever increasing design innovation, process sensitivity & complexity
- Paradigm shift in thoughts about what we did not care about earlier in >20nm era & what we care to control now!
  - Complex Chemistry: Compatibility Issues
  - New Defect Sources, increase Defect Sensitivity
- Metrology techniques of all types are challenged to provide sufficient sensitivity for early detection & prevention
  - Supplier Infrastructure Development needed for better defect detection & characterization
  - Metrology and Quality Control
- Proactive engagement and collaboration across the supply chain are essential to HVM readiness

- Shrinking device features will challenge cleaning technologies to deliver new capabilities and higher levels of particle removal with every generation.
- These shrinking geometries will challenge clean technologies to move beyond purely undercutting particulates to removal without loss of the underlying substrate.
- Three-dimensional structures (3D Gate structures and stacked storage devices) will constrain chemical and physical approaches to cleaning, and require novel technologies to achieve defect free results.
- Such three-dimensional structures will have extreme aspect ratios, and very challenging mass transport requirements for the removal of contaminants from deep structures.

Source: Archita Sengupta, Intel

Trends - WFM Spend at Advanced Nodes



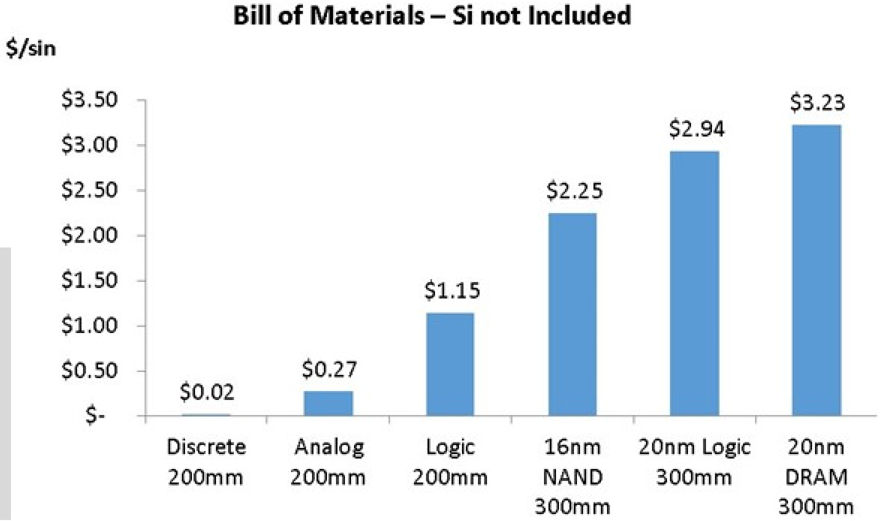
Increasing Chemical Consumption

Trends in Advanced Technology Wet Cleans

Wet chemical consumption per wafer is increasing

- Proliferation of single-wafer processing, higher number of layers
- Multi-step patterning, more complex process flows
- Defect reduction, less recycle

Larger volumes increase scrutiny on chemical cost ($)



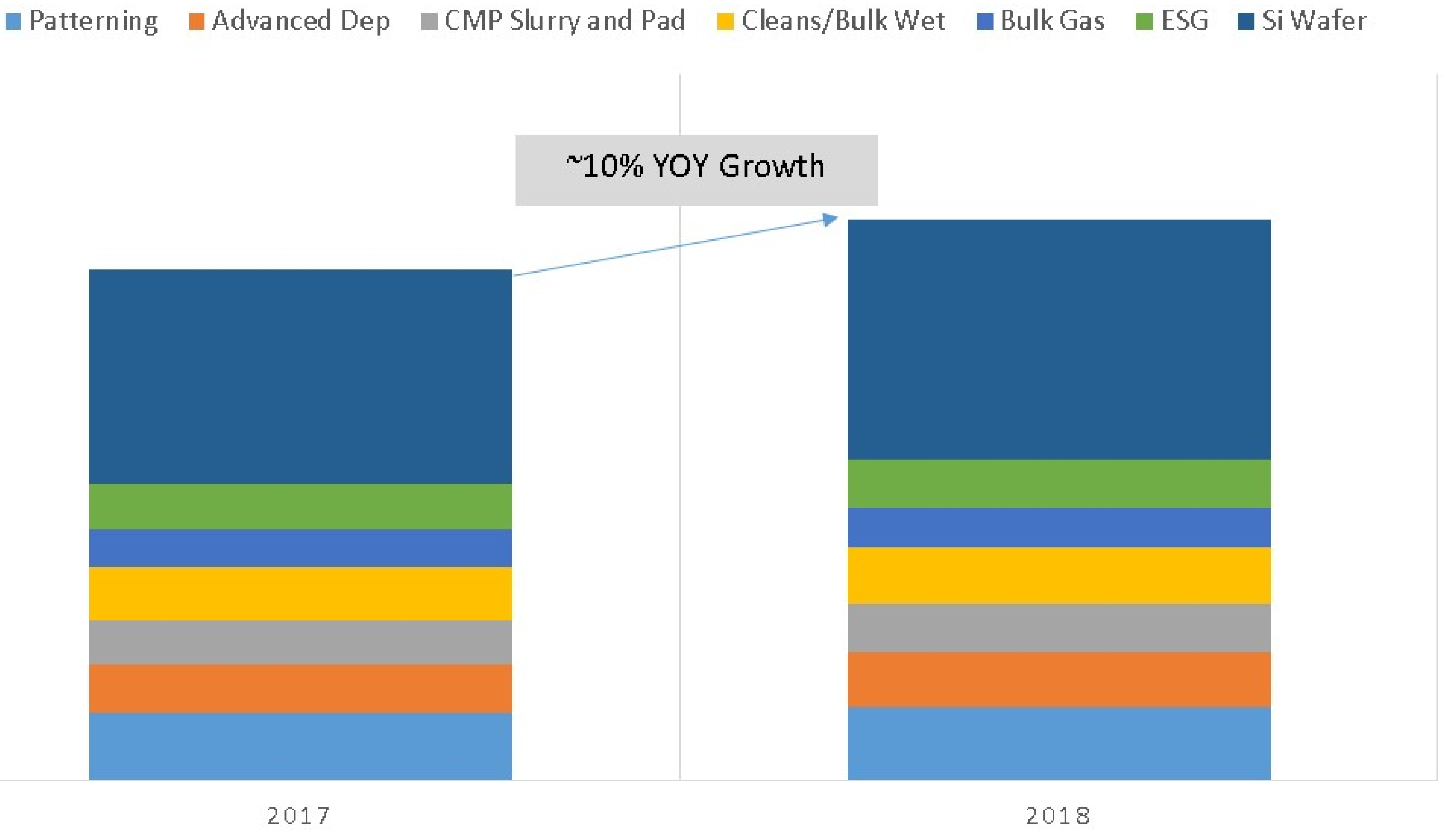
Bill of Materials – Si not Included

Trend driven by:

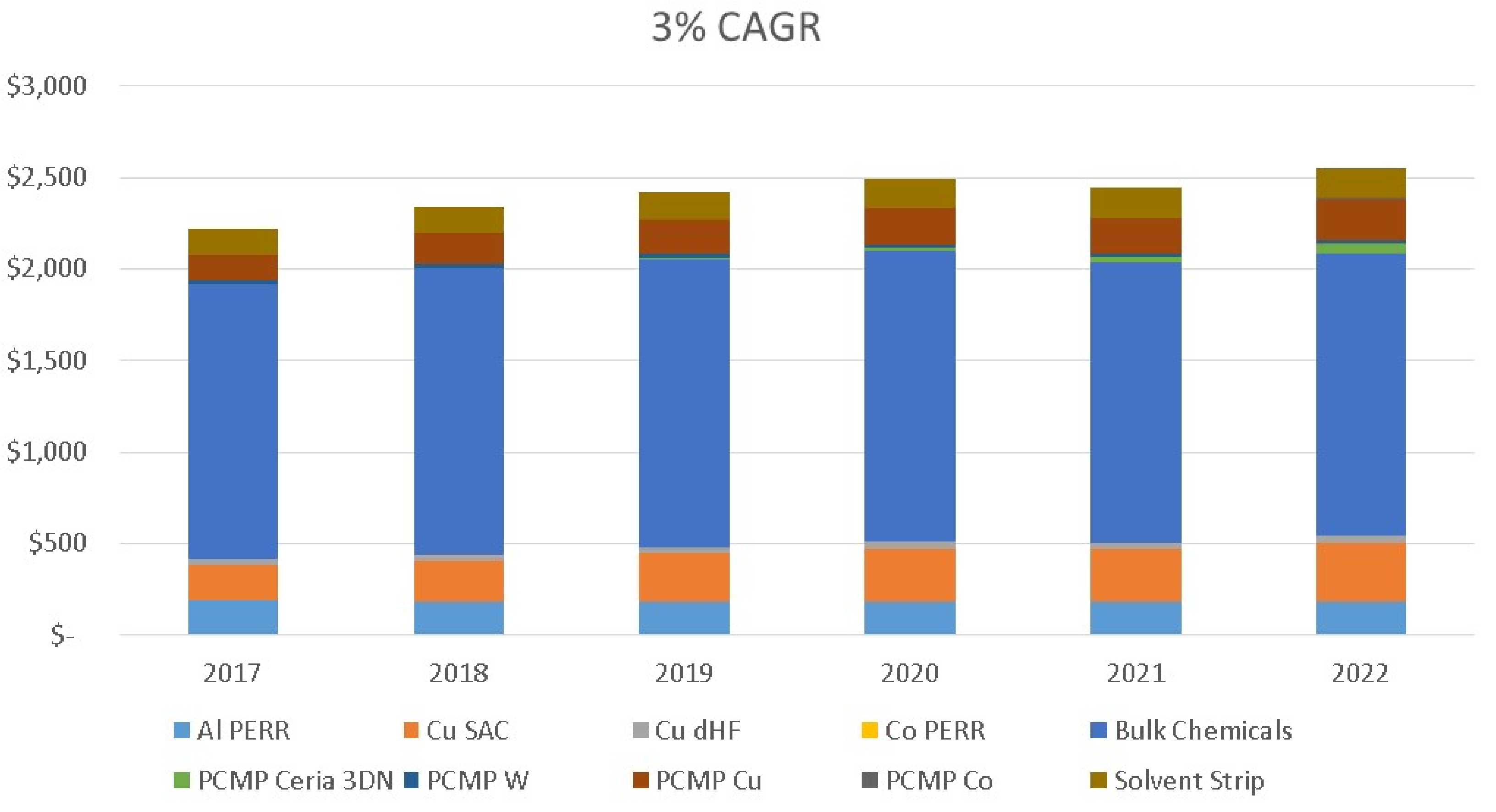
- Increased # of interconnect and FEOL layers
- RMG process
- Multi-Patterning
- New materials integration

Source: Linx, IC Knowledge, Intel

WFM Materials Outlook



Advanced Cleans Outlook



Paths Forward for Consumables

ADVANCED / SPECIALTY

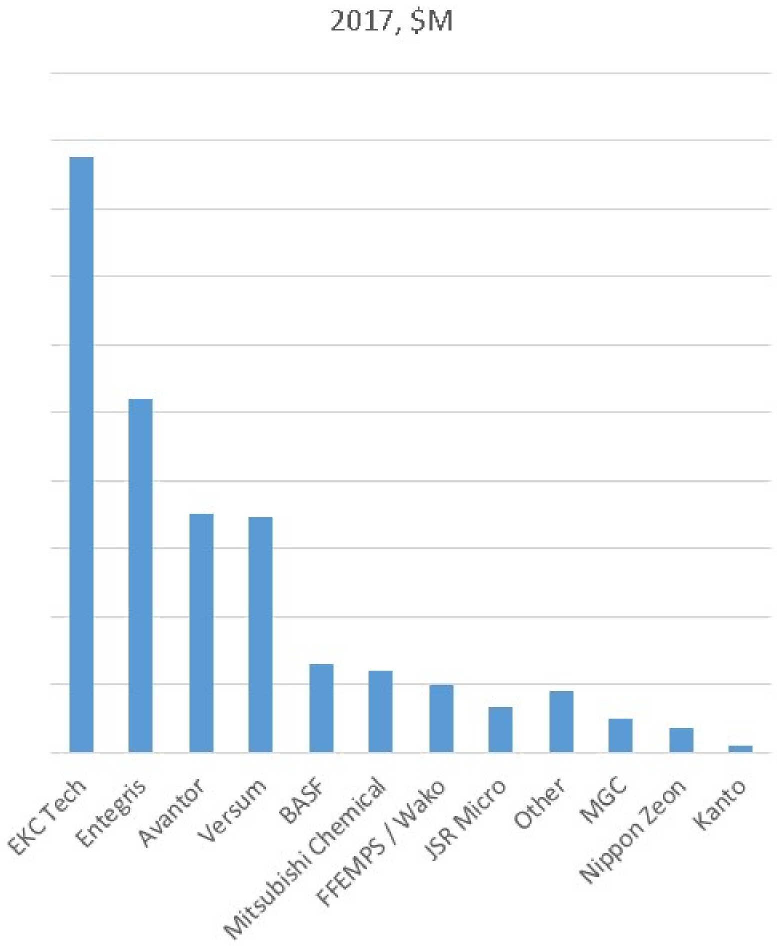
- Enable novel architectures and litho schemes:
    - 3DN
    - FinFET
    - Horizontal Nano wire
- Enable new memory technologies
    - PCM
    - STT MRAM
- Enable new BEOL materials
    - Cobalt, Ru
    - Alternative/self forming barrier
- Solve productivity and defectivity problems

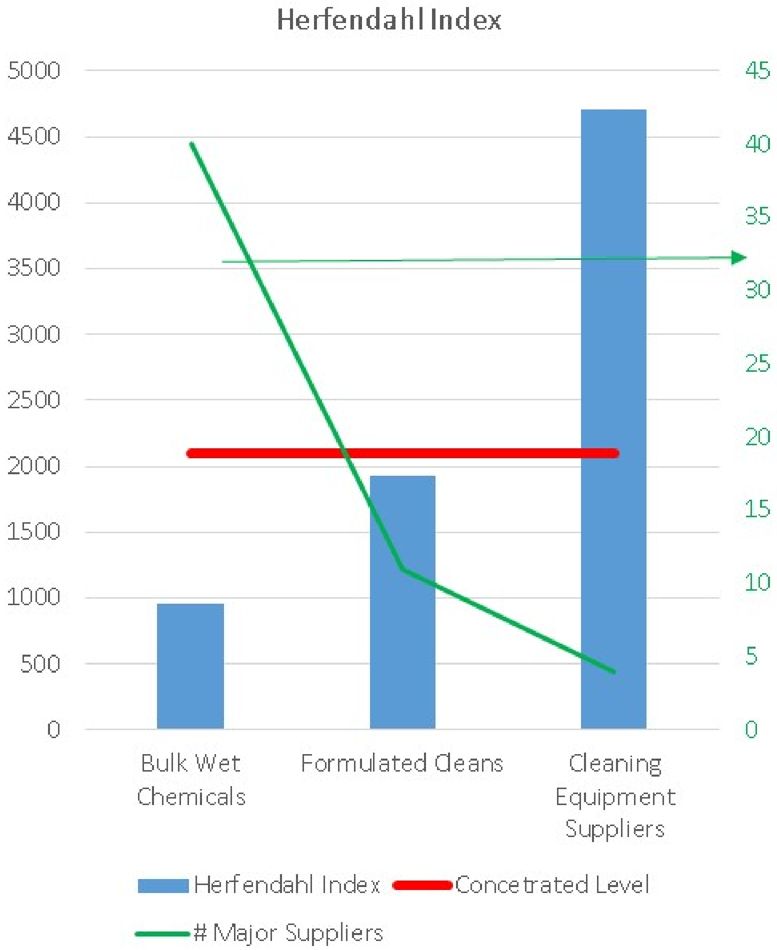
COMMODITY

- Have evolved from current materials base
- Need to be drop-in ready
- Are readily copied
- Will compete based on cost
- Most impacted by changes to business model

Impact on Suppliers

Leading Suppliers Formulated Cleans





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Regional & Structural Trends

Recent Transactions

- Cabot Microelectronics – NexPlanar
  - Fujimi Collaboration
- FujiFilm EM – Ultra Pure + Wako
- Wonik – Nova-Kem
- NATA - Kempur
- Air Liquide – AirGas + Voltaix
- Air Products – Versum Materials spinout
- SK - OCIM + Tri-Chem
- Dow Chemical – DuPont + Dow Corning
- Global Wafer - SunEdison
- Yoke – UPChem
- Versum - Dynaloy
- SK Holding – LG Siltron + OCIM
- Linde + Praxair
- Avantor - Gelest

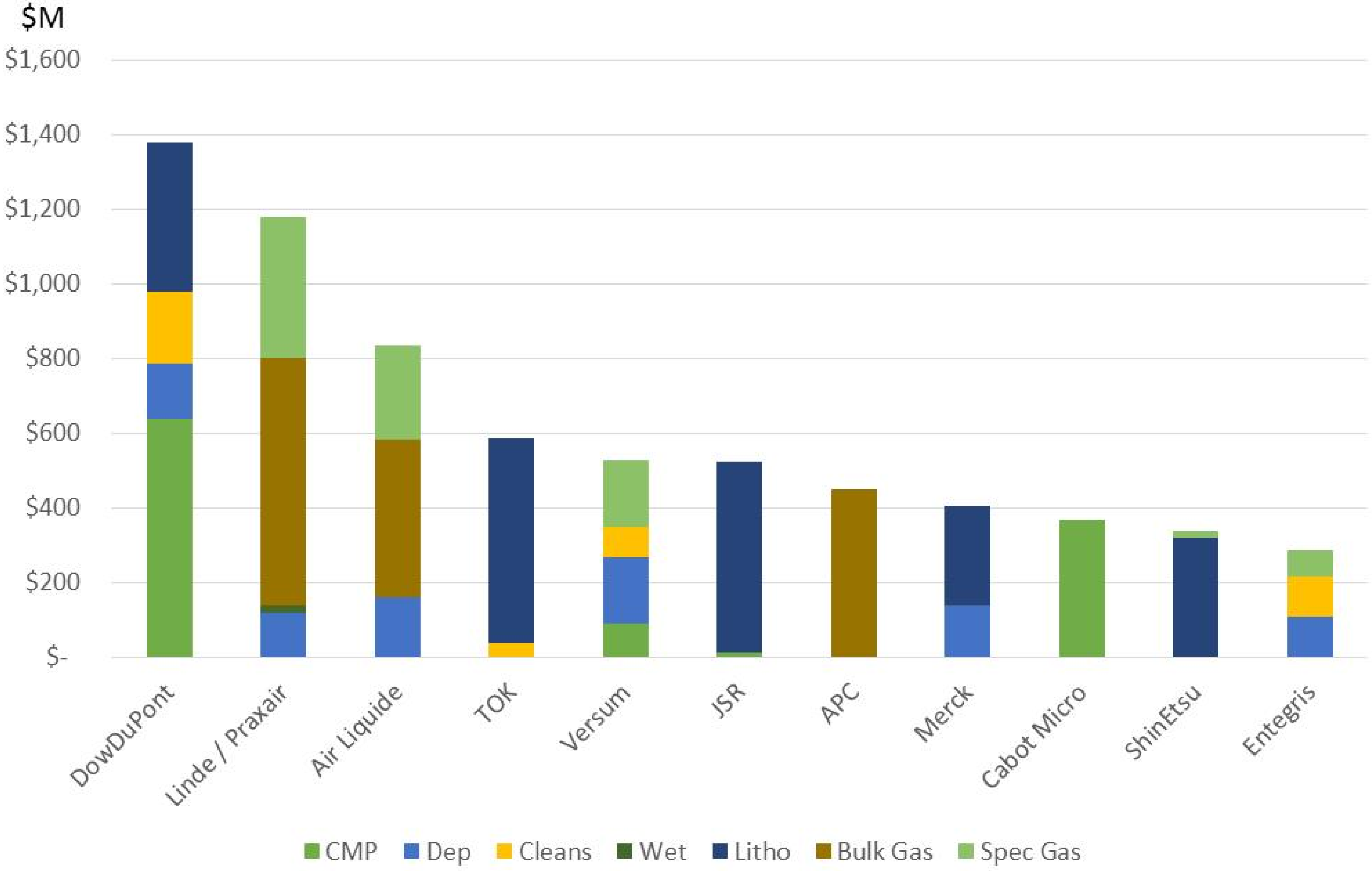
China

- Leveraged government equity positions to enable significant sized acquisitions
- Continued acquisition activity from multiple companies.
- Acquisitions along the line of key product areas:
  - Silicon
  - Gases
  - Lithography materials
  - Advanced deposition materials

Korea

- Korean companies also looking to change business model
- Gain international market access

Top Tier WFM Suppliers



Conclusions

Conclusions

- Sustainable strong growth outlook anticipated for several years
- 3D structures and new materials will continue to drive semiconductor technology advancement at 1Xnm and beyond.
- 200mm and older wafer fab is expected to remain at high levels of capacity utilization over the next several years. Productivity will be a major driver
- Concentrated customer base and tool supplier base, along with increasing barriers to serve end-users will drive WFM consolidation
- New capacity in China will enable new suppliers who will initially compete with special commodities
- Expect Korea to focus more effort on specialty chemicals