OUTLOOK FOR CMP CONSUMABLES

CMPUG April 12, 2018

Mike Corbett

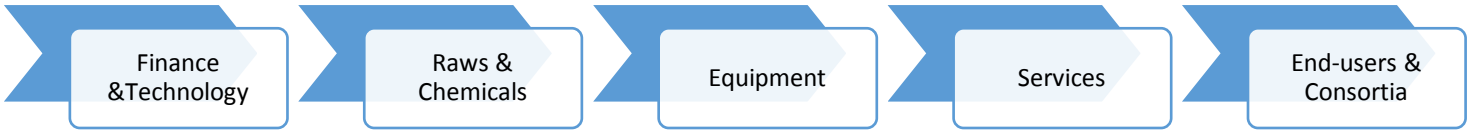
Linx Consulting Inc.

Outline

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

Introduction to Linx Consulting

Linx Consulting

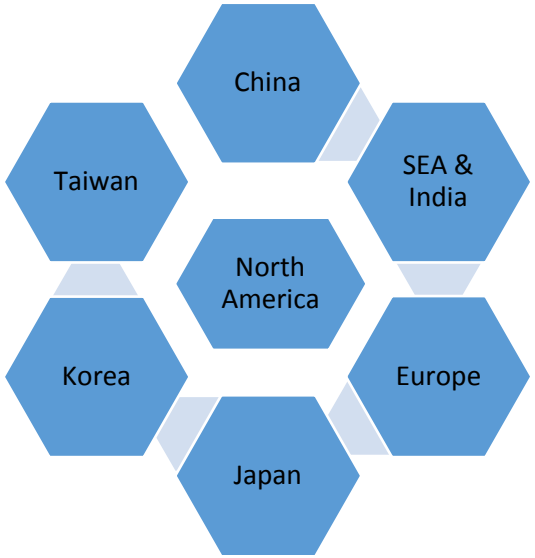


1. *We help our clients to succeed by creating knowledge and developing unique insights at the intersection of electronic thin film processes and the chemicals industry on a global basis*

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*

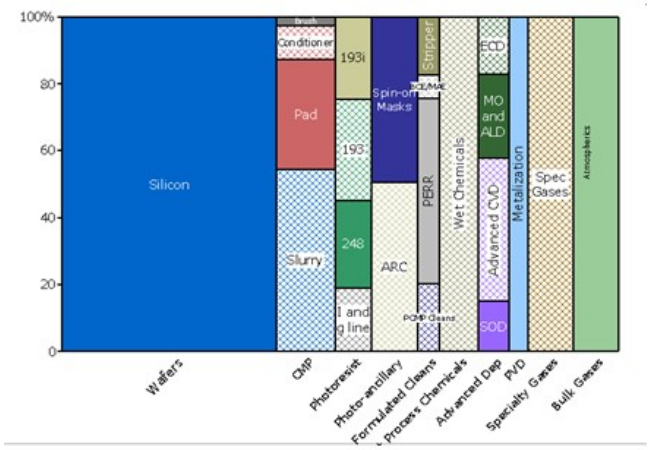
4. *Our perspectives are by direct research and leveraging our extensive experience throughout the global industry value chain*



www.linx-consulting.com

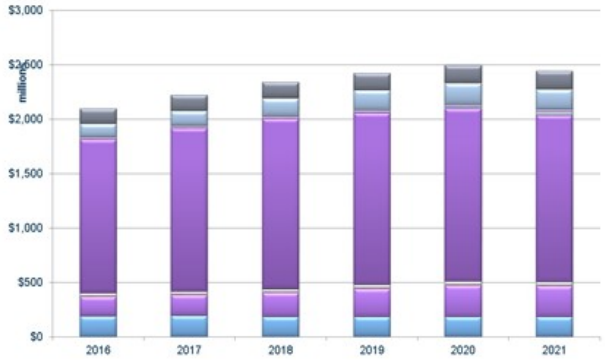
MSI Breakdown & Forecasts

Market Knowledge

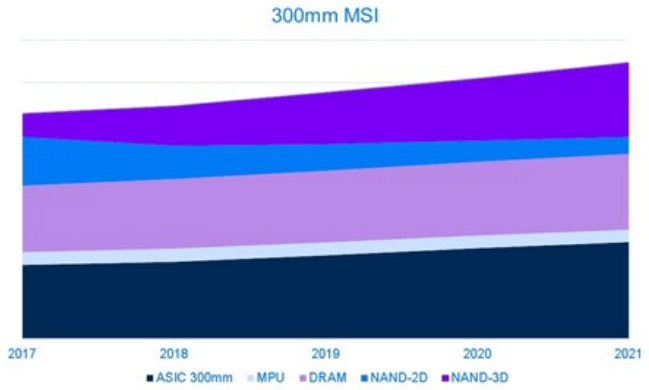


and Understanding

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

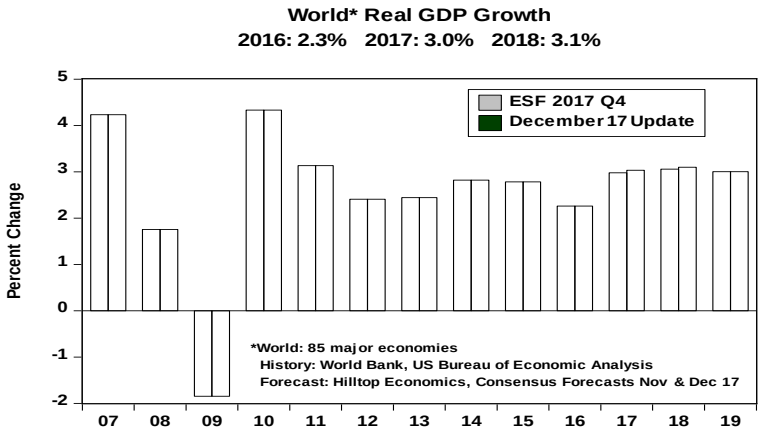
  With IC Knowledge, LLC

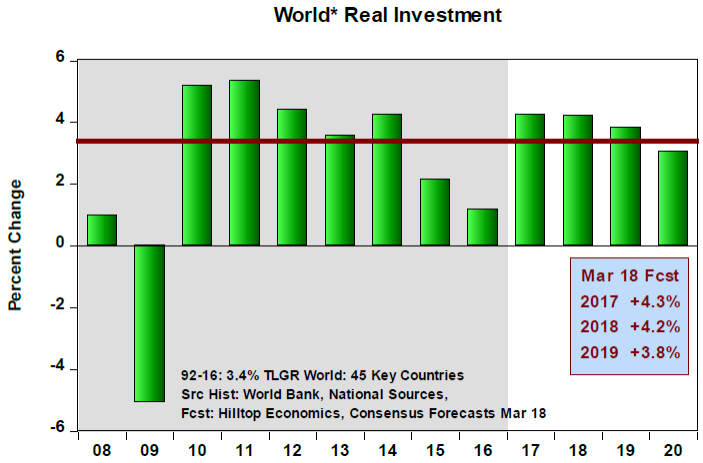
- **Conference Production**
  - The Business of Cleans & SPCC

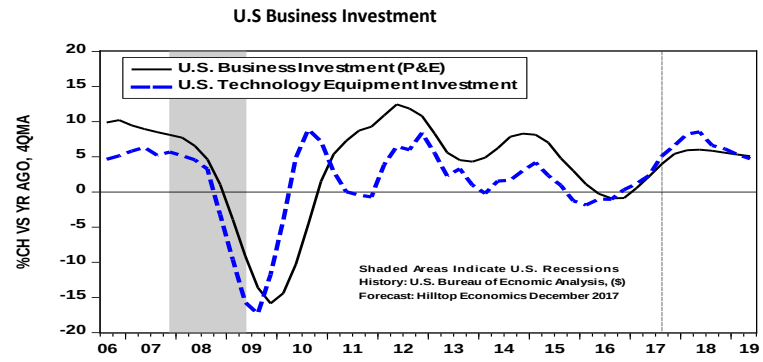
- **Wafer Start Demand Forecasting**
  - Device type and technology node

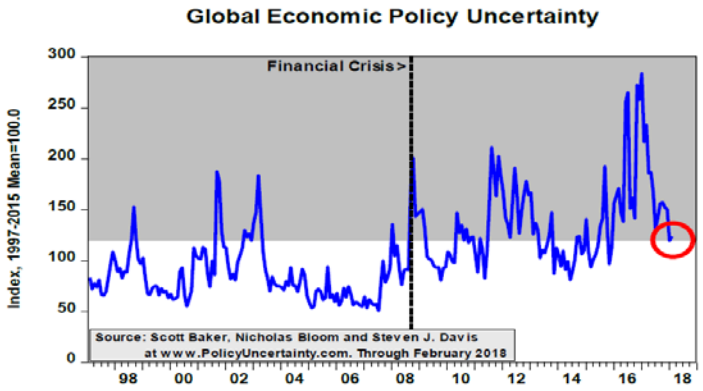
Semi Industry Outlook

Economic Drivers

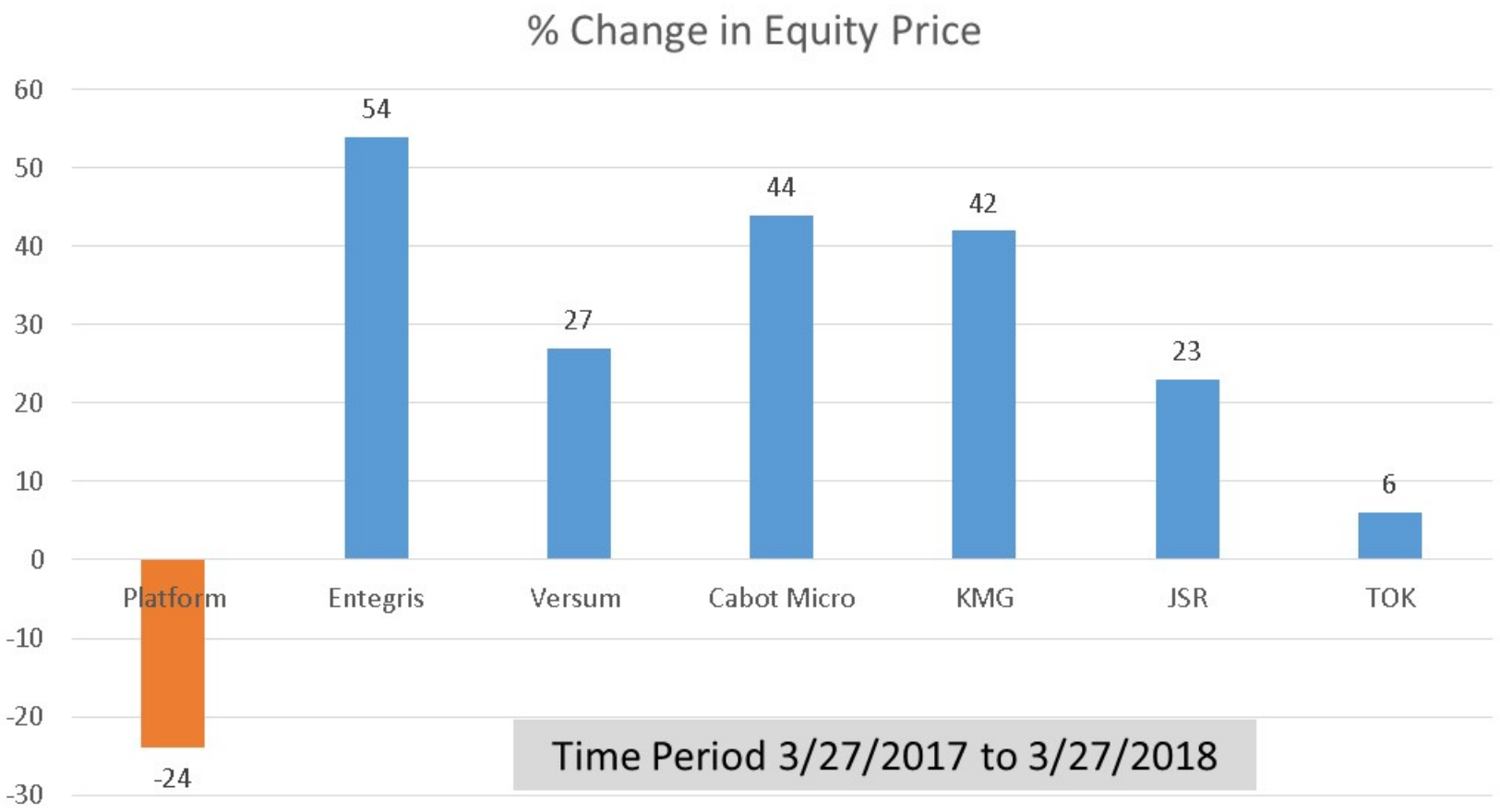






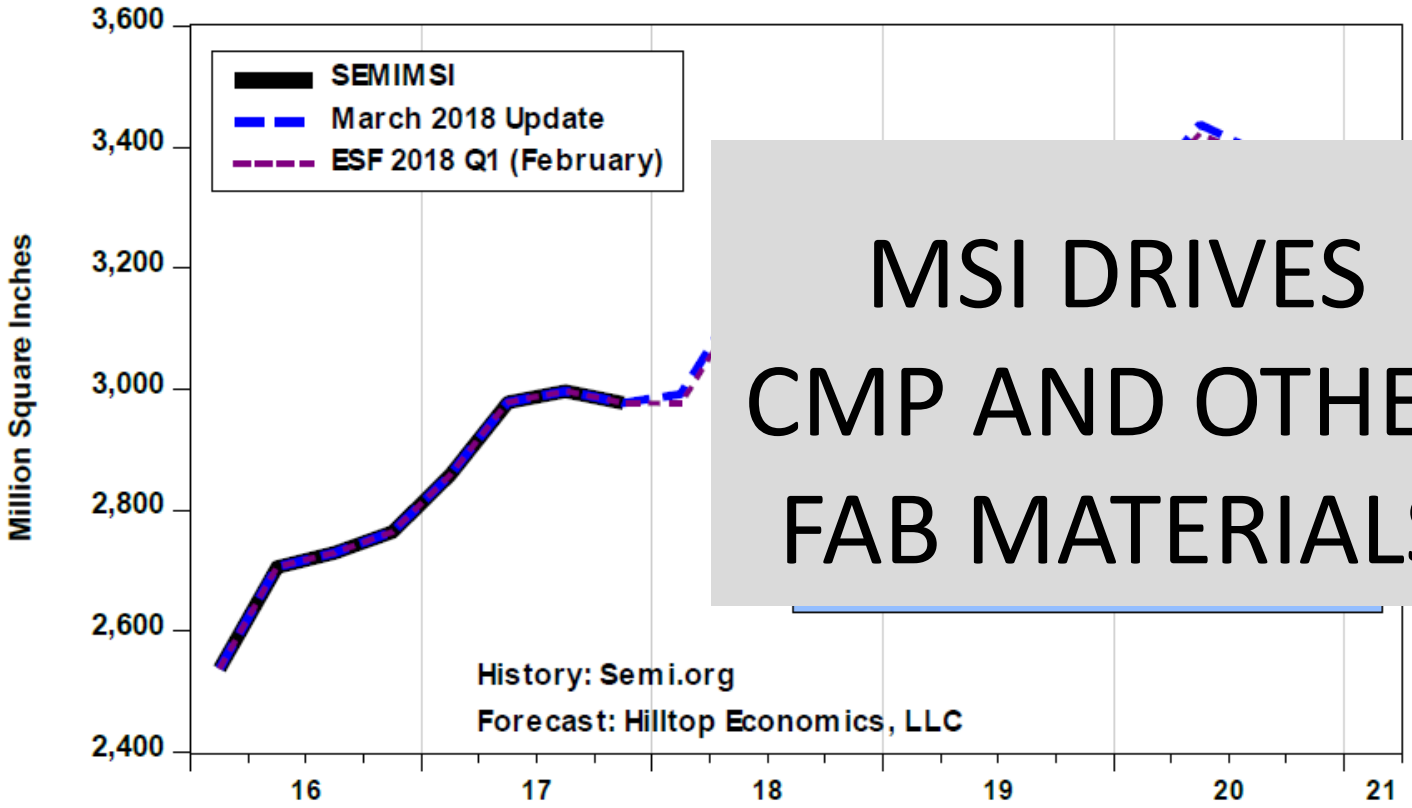


Linx WFM Equity Index



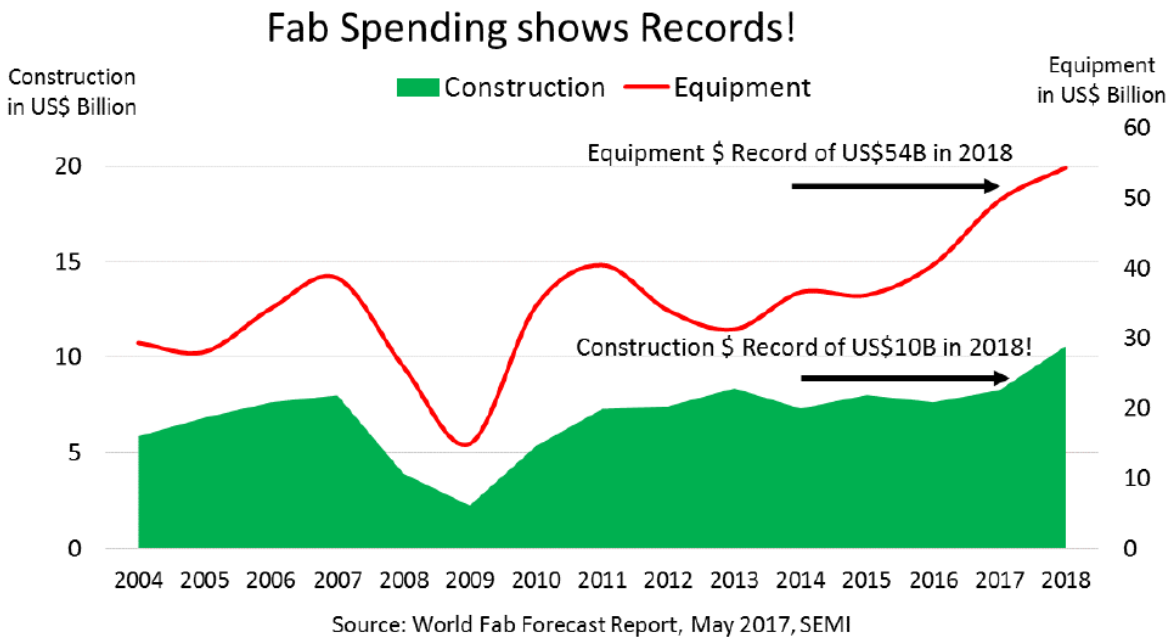
Latest MSI Forecast by ESF Model

Semiconductor Forecast: ESF 2018 Q1



MSI DRIVES CMP AND OTHER FAB MATERIALS

Record Levels of Capex



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

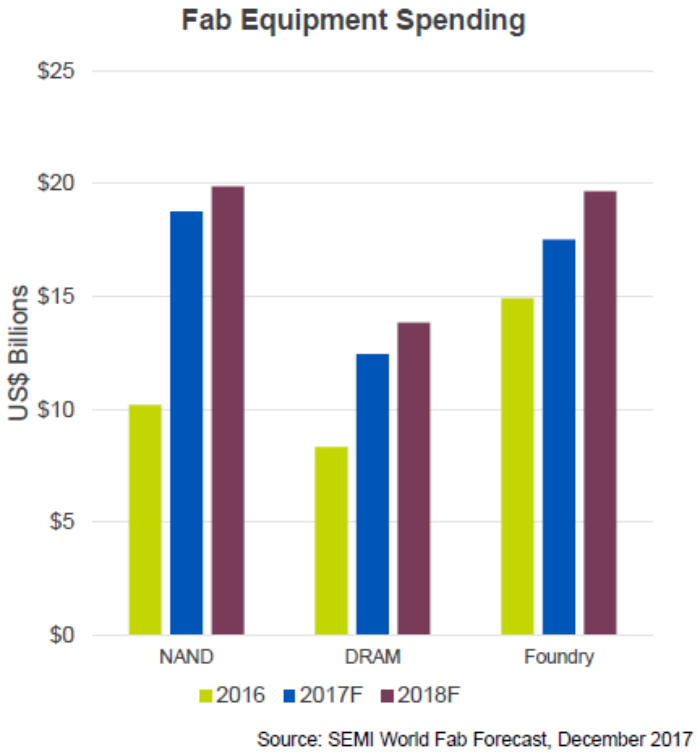
Key Growth Drivers: NAND, DRAM and Foundry

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

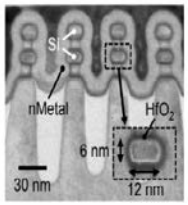
3DN and Logic driving growth. Vertical scaling helps drive Materials Growth

Materials Challenges

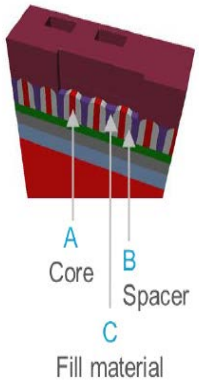
Materials Challenges

Demand Drivers

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



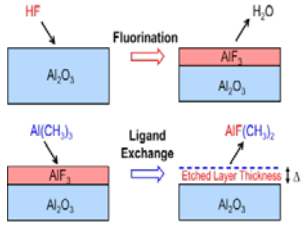
- Memory technology extension
  - 3D-NAND growth
  - DRAM capacitor dielectric
  - Novel architectures



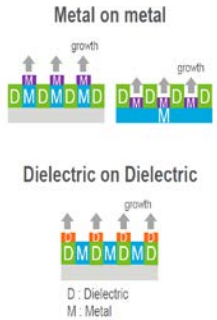
- Pitch doubling and quadrupling
  - Low temperature spacers
- Lithography aids

Opportunities

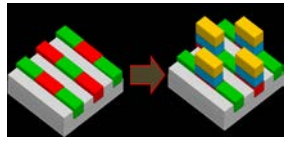
- Possible changes in conductor metal
  - Cu ⇨ Co Barrier ⇨ Co plating
- 3D-NAND aspect ratio
  - Hard mask technology
  - 2D stair-step



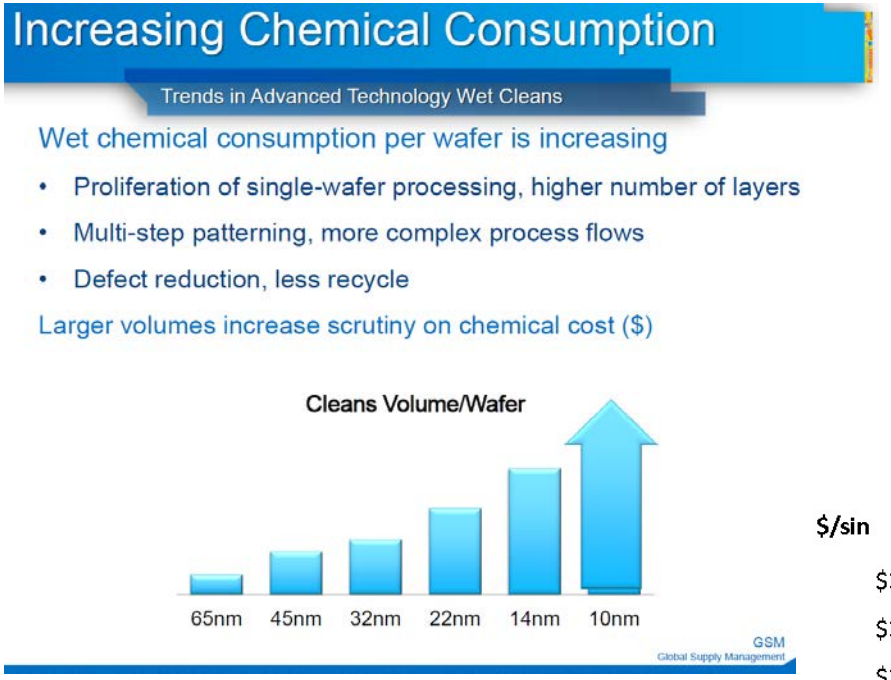
- Novel process development
  - Multi color, self aligning etch
  - CVD ⇔ Continuous etch
  - ALD ⇔ ALE



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

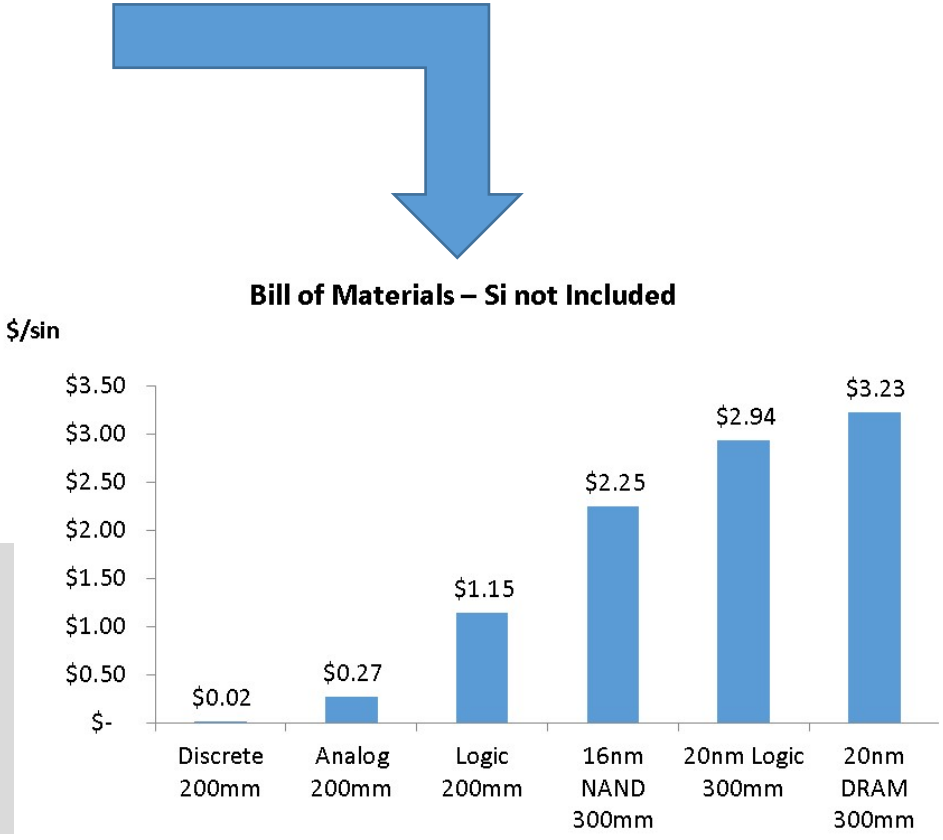


Trends - WFM Spend at Advanced Nodes



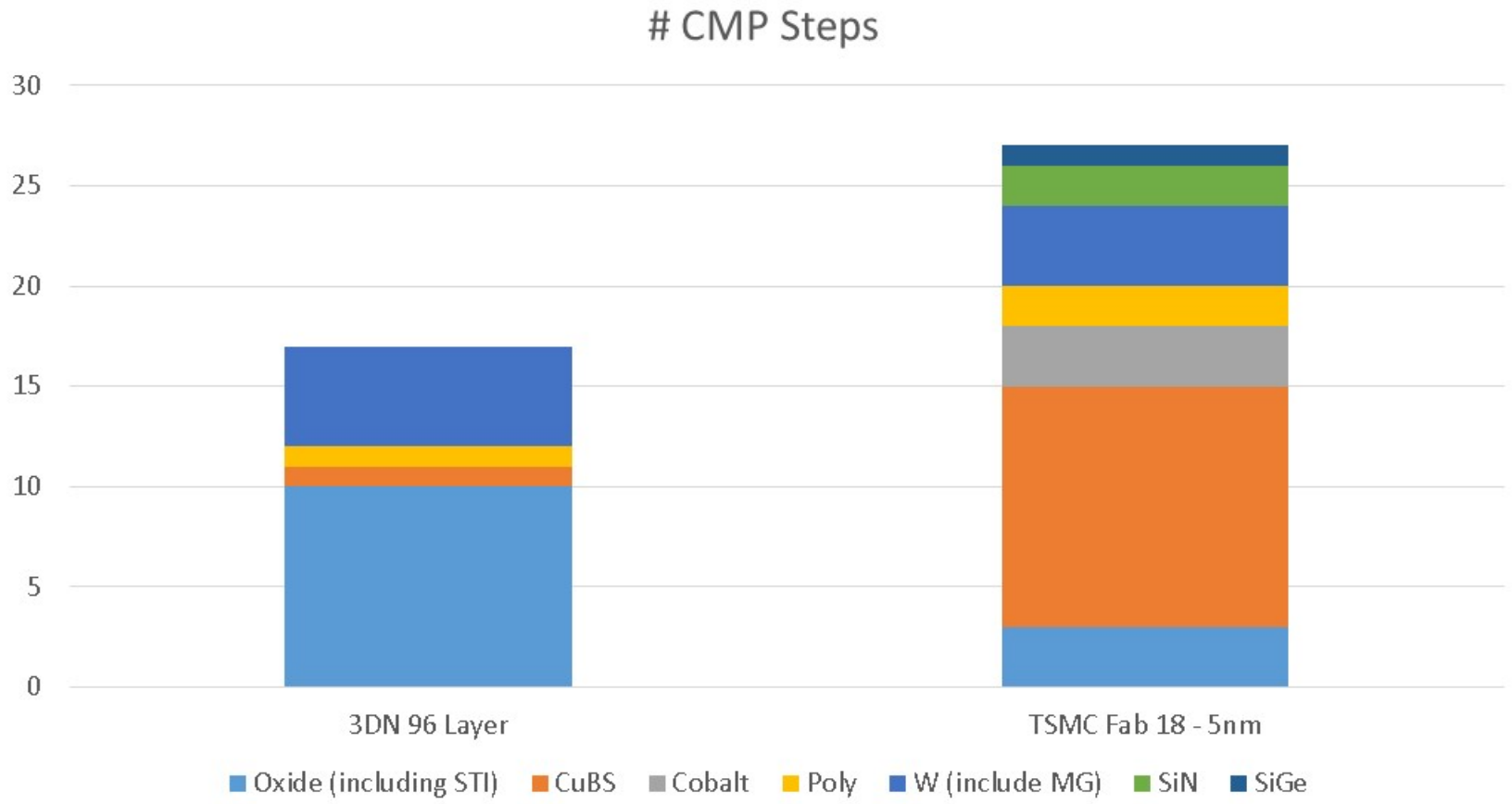
Trend driven by:

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

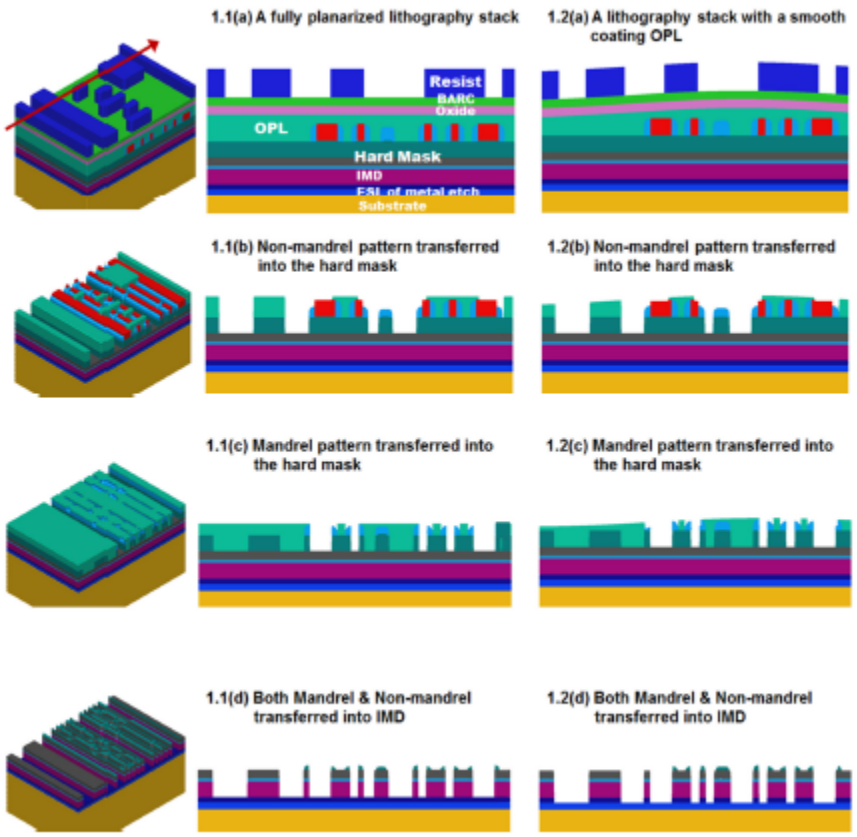


Source: Linx, IC Knowledge, Intel

CMP Benefits from New Devices



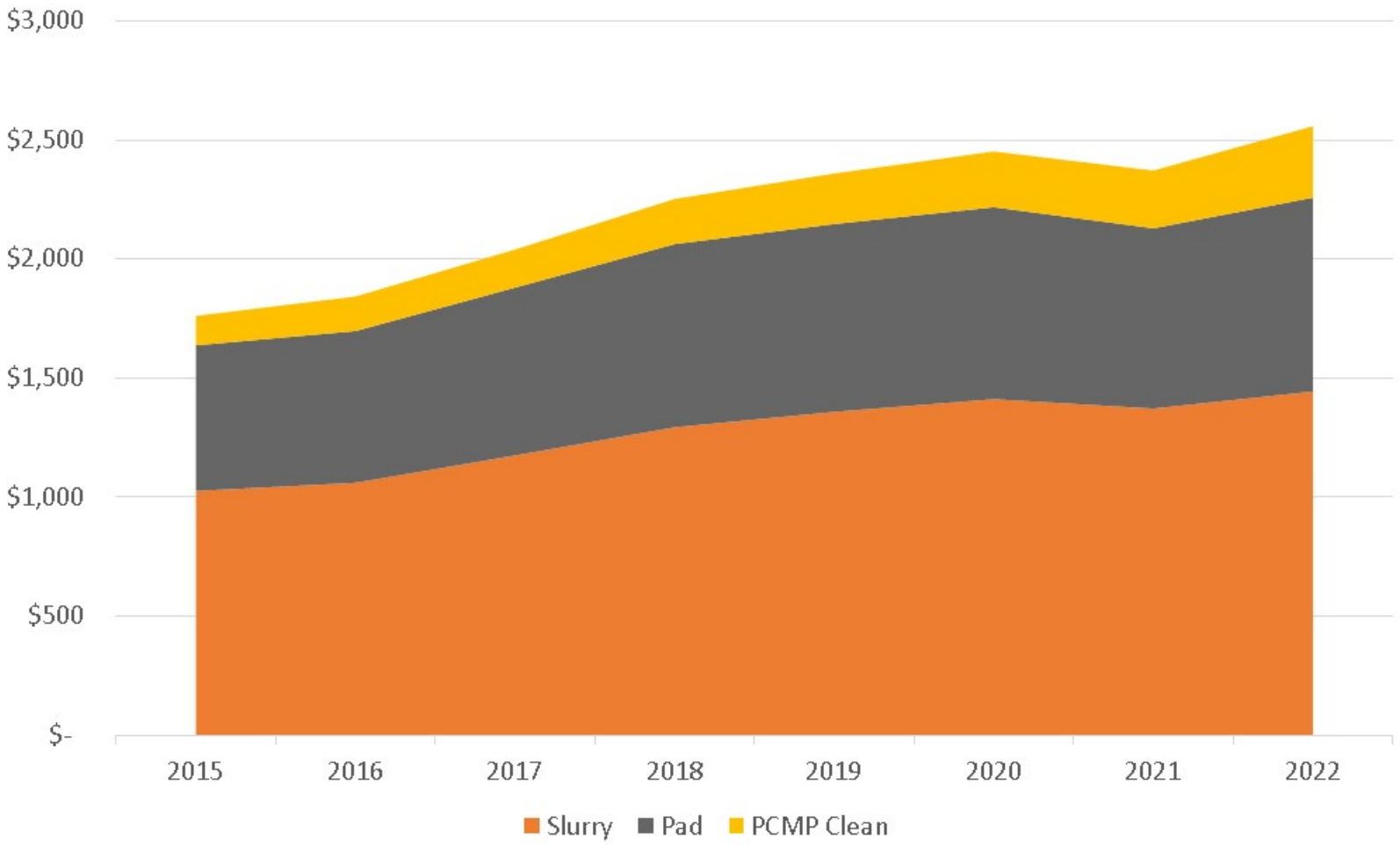
Planarity Considerations in SADP for Advanced BEOL Patterning



- CNSE have shown the impact of gap-fill planarity on SADP process for advanced 7nm/5 nm technology
- Multiple patterning has been the main stream integration scheme in the sub 14 nm before the maturity of EUV lithography
- Among all the practical schemes, SADP not only simplified the overlay control, but also provides a better RC performance over the LELE scheme
- Therefore, minimizing the number of cuts in the SADP integration became important to HVM
- CNSE demonstrated that a robust SADP process through insertion of etch stop layer (ESL) between two coatings of organic polymer layers

Source: Albany Nanotech/IBM

Slurry, Pad & PCMPC Forecast ($M)



Impact on Suppliers

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

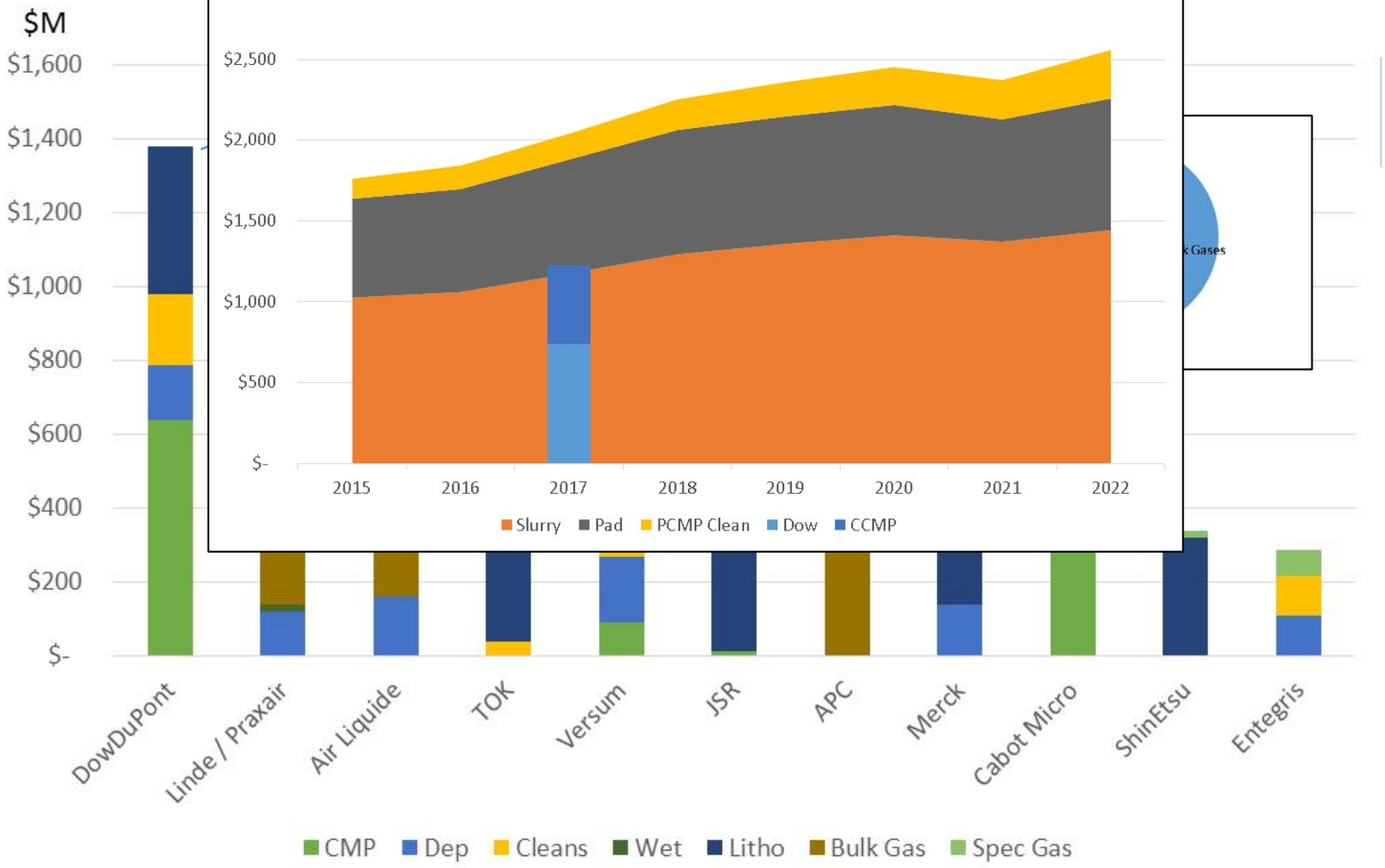
China

- 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