

Outlook for Cleans in the Semiconductor Industry

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Business of Cleans, 2019



Linx Consulting Service Portfolio

- **Comprehensive 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 Demand Forecasting**



Background & Market Trends



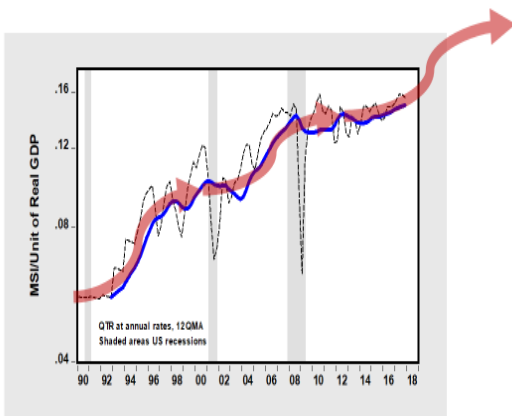
Industry Has a Strong Growth Outlook

Semiconductor may be set to capture a larger share of global GDP.

Hilltop Economics

Positive Risk: Semiconductors

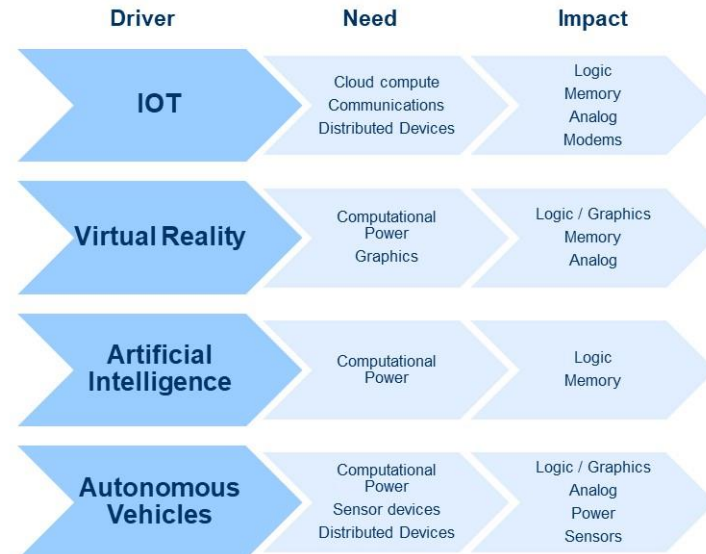
Semiconductor Penetration of the Global Economy



Duncan Meldrum
SPCC April 11, 2018

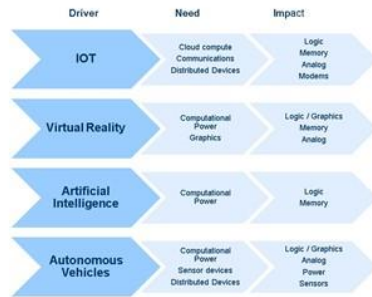
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Connected World Growth Drivers

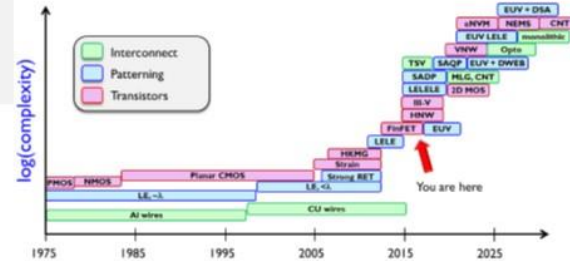




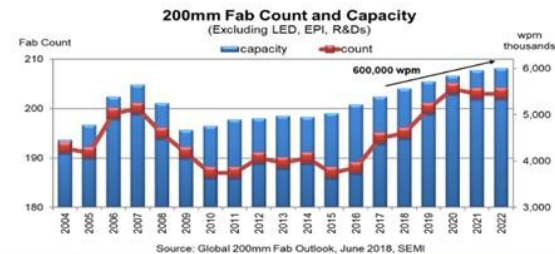
Connected World Drives Many Opportunities



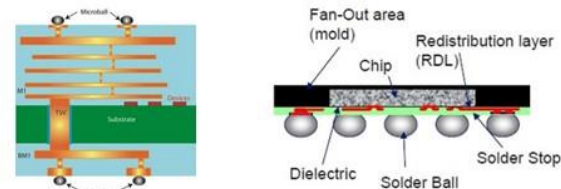
Scaling and New Materials



200mm Fabs



FOWLP, TSV, etc.



Opportunities for Cleans

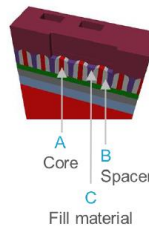
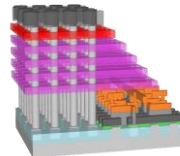
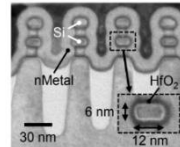
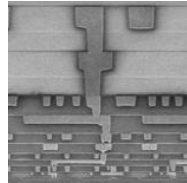
- Novel Materials
- Cobalt, Mo, Ru, etc.
- Novel Integrations
- AI PERR for 200mm wafers
- Replacement chemistries
- Novel strippers
- Copper compatible products
- Advanced Packaging

There are Still Many Technical Challenges



Scaling and New Materials

- RC considerations impacting Logic Interconnect
 - Limitations of current architectures/materials
- FinFET gate deposition
 - GAA Nanowire development
 - High mobility materials
- Memory technology extension
 - 3D-NAND growth
 - DRAM capacitor dielectric
 - Novel architectures
- Patterning
 - Low temperature spacers
 - Lithography aids
 - EUV insertion



Challenges

- BEOL
 - Novel barriers, Liners
 - Novel cleans and CMP
- FEOL/MOL
 - WF metals
 - Novel MHM
 - Cobalt Contacts
 - Novel cleans and CMP
 - Gap fill
- Memory
 - Novel cleans and CMP
 - Gap fill
 - Horizontal fill



Cleaning Trends

PERR - FEOL, MOL and BEOL Materials

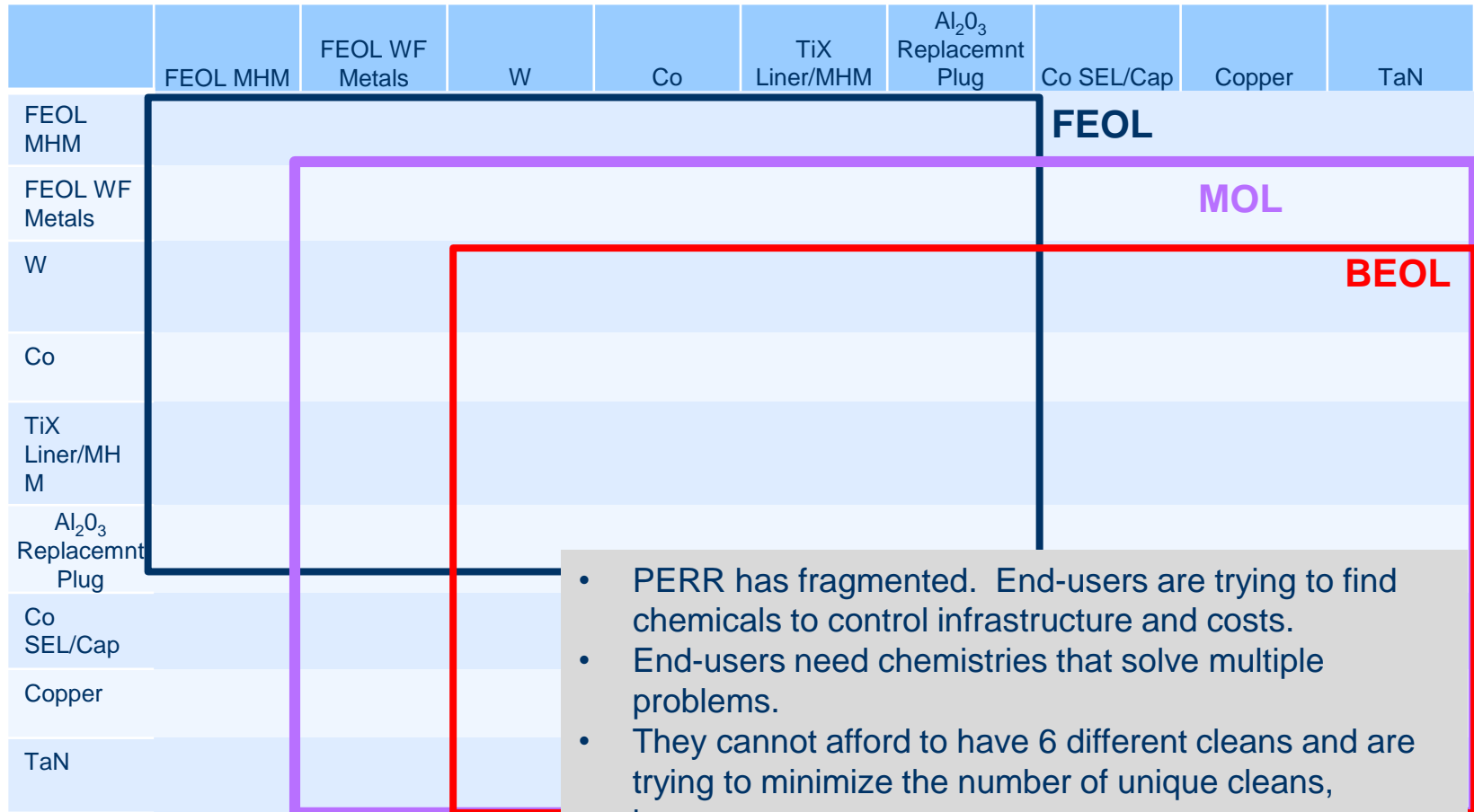


Location/ Step	FEOL, MOL and BEOL Metals & Combinations (Illustrative)								
	Layers								
	FEOL MHM	FEOL WF Metals	W	Co	TiX Liner/MHM	Al ₂ O ₃ Replacemnt Plug	Co SEL/Cap	Copper	TaN
FEOL/ Cleans	X	X	X	X	X	X			
MOL/ Cleans	X	X	X	X	X	X	X	X	X
BEOL/ Cleans			X	X	X	X	X	X	X

- The introduction of new metals for FEOL, MOL and BEOL and novel integration schemes has led to an increase in the number of unique PERR cleaning steps in advanced logic
- Some new formulations can be utilized/tuned across multiple metals so the number of cleaning steps is difficult to know exactly
- Above are some of the different potential combinations of metals that may be present on advanced logic device



PERR Has Fragmented



- PERR has fragmented. End-users are trying to find chemicals to control infrastructure and costs.
- End-users need chemistries that solve multiple problems.
- They cannot afford to have 6 different cleans and are trying to minimize the number of unique cleans, however.
- There are some key selectivity including: Copper, Cobalt, TiN, MHM, W



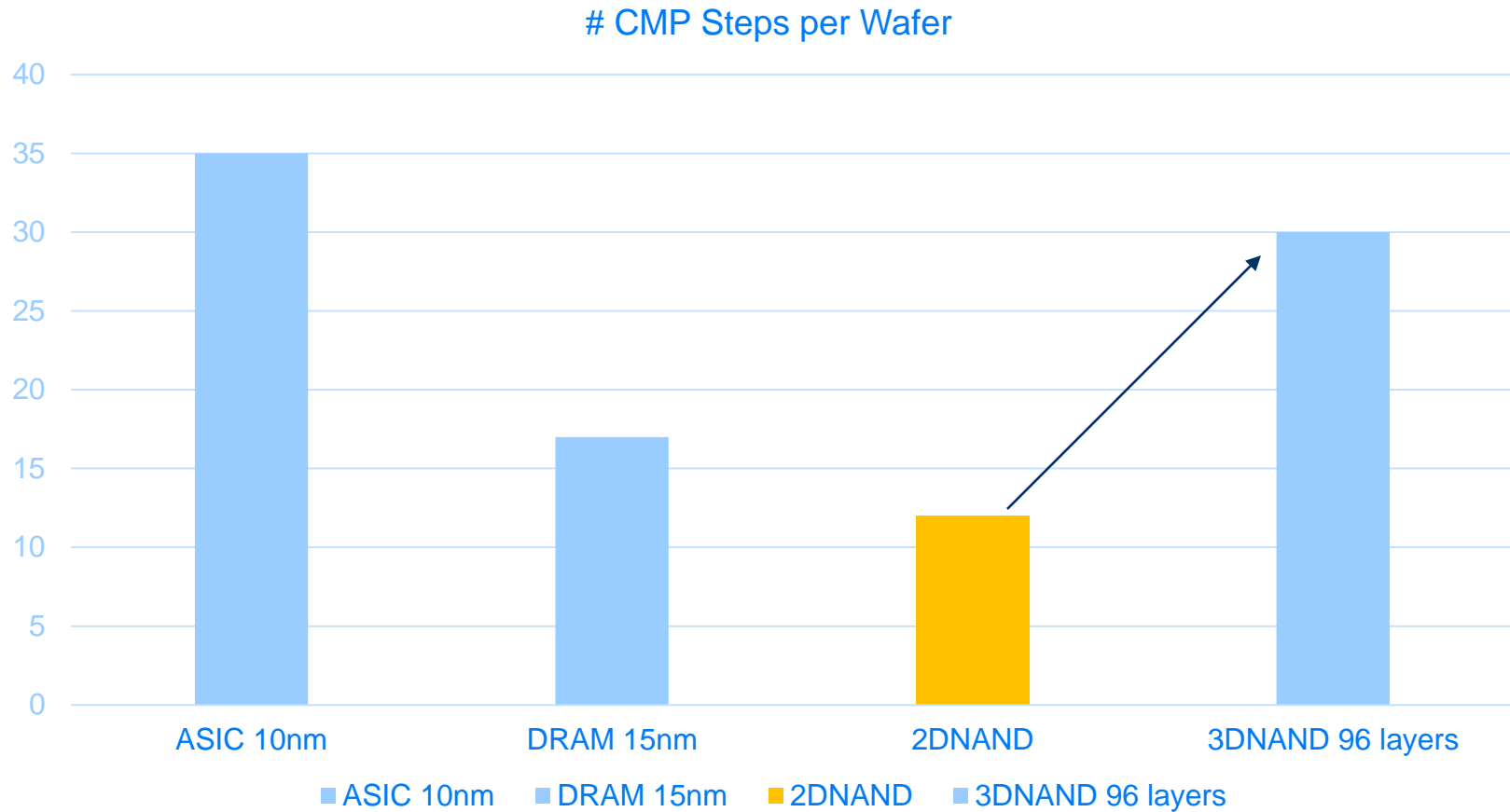
PCMP Evolution

- Whereas historically the major home for formulated PCMP cleans was in copper CMP, the industry is now using advanced formulated products for Cobalt, W and ceria-based polishes, as shown below
- As the requirements to develop products for these applications becomes increasingly difficult, the industry is relying more heavily on the larger multi-national chemical companies to develop technology based solutions

Formulated Post CMP Cleans

Copper	Copper/Cobalt	Cobalt	Tungsten	Ceria
<ul style="list-style-type: none">• Memory• Logic	<ul style="list-style-type: none">• Advanced Logic• SEL and Cap	<ul style="list-style-type: none">• Advanced Logic• Bulk Metal	<ul style="list-style-type: none">• Advanced Logic• Contacts• MG	<ul style="list-style-type: none">• Advanced Logic• 3DNAND• STI• Oxide

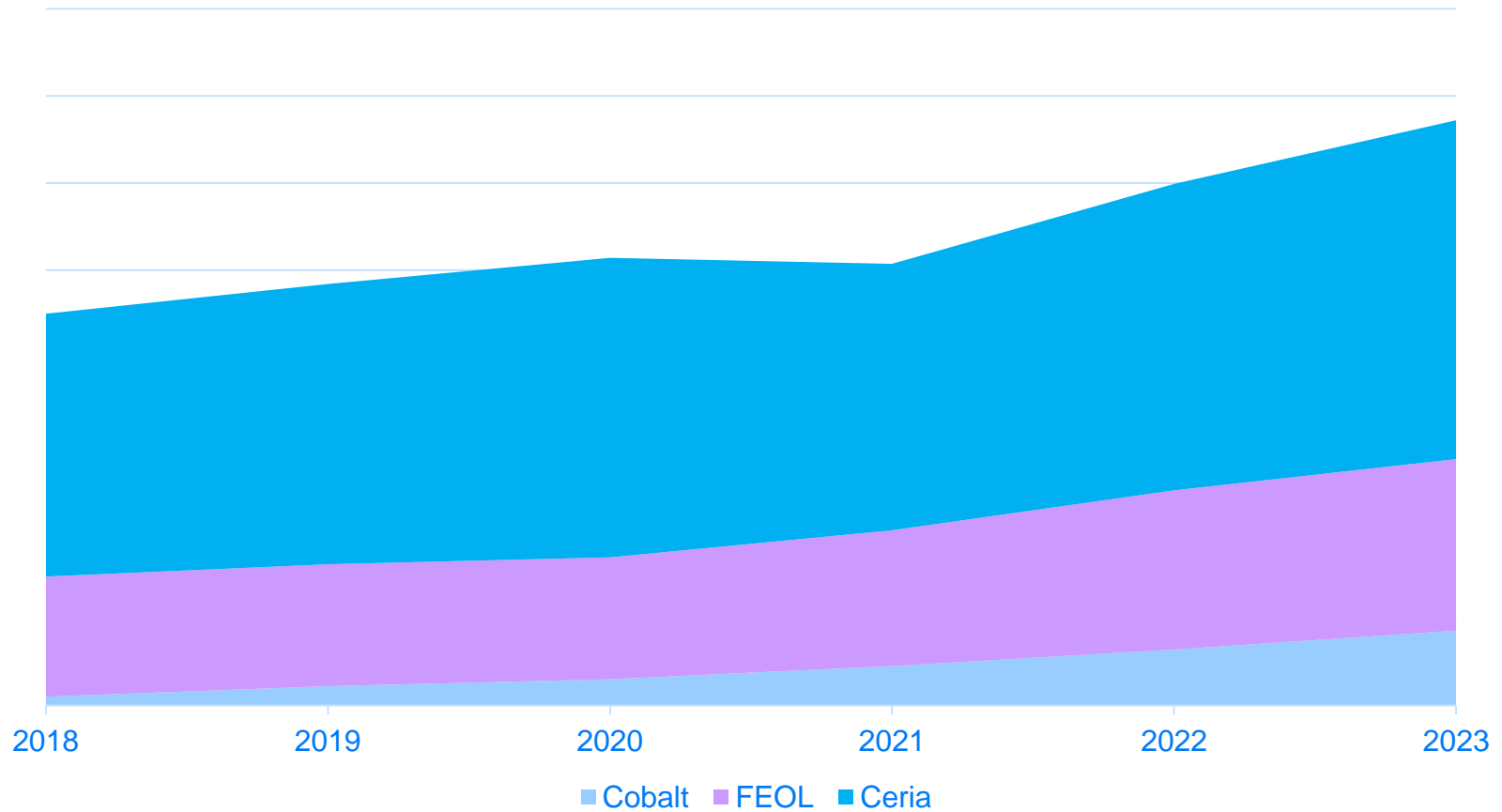
CMP Intensity Continues to Increase



Highest Growth CMP Segments All Have Cleaning Challenges



Slurry Growth



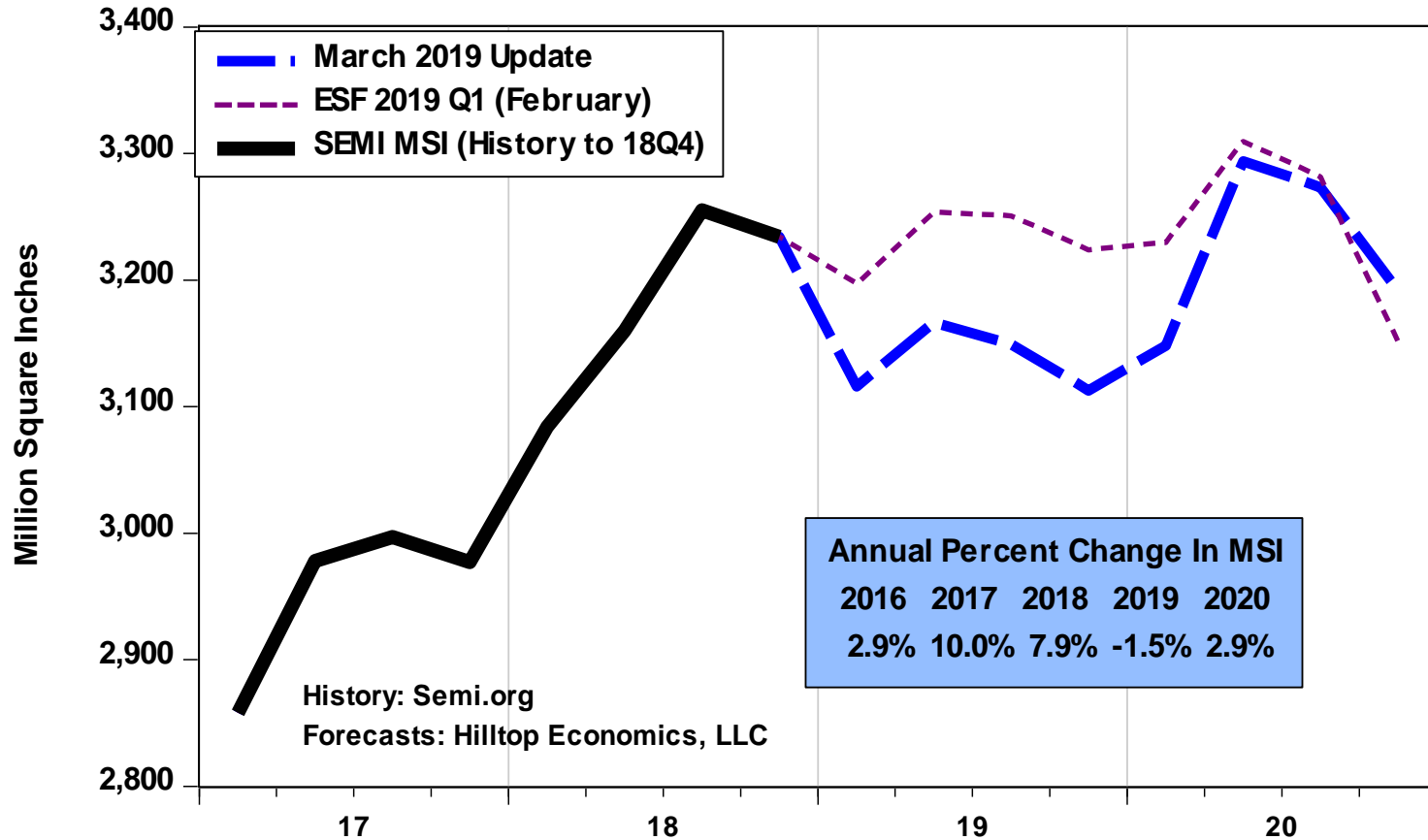


Outlook & Suppliers



Latest MSI Forecast by ESF Model

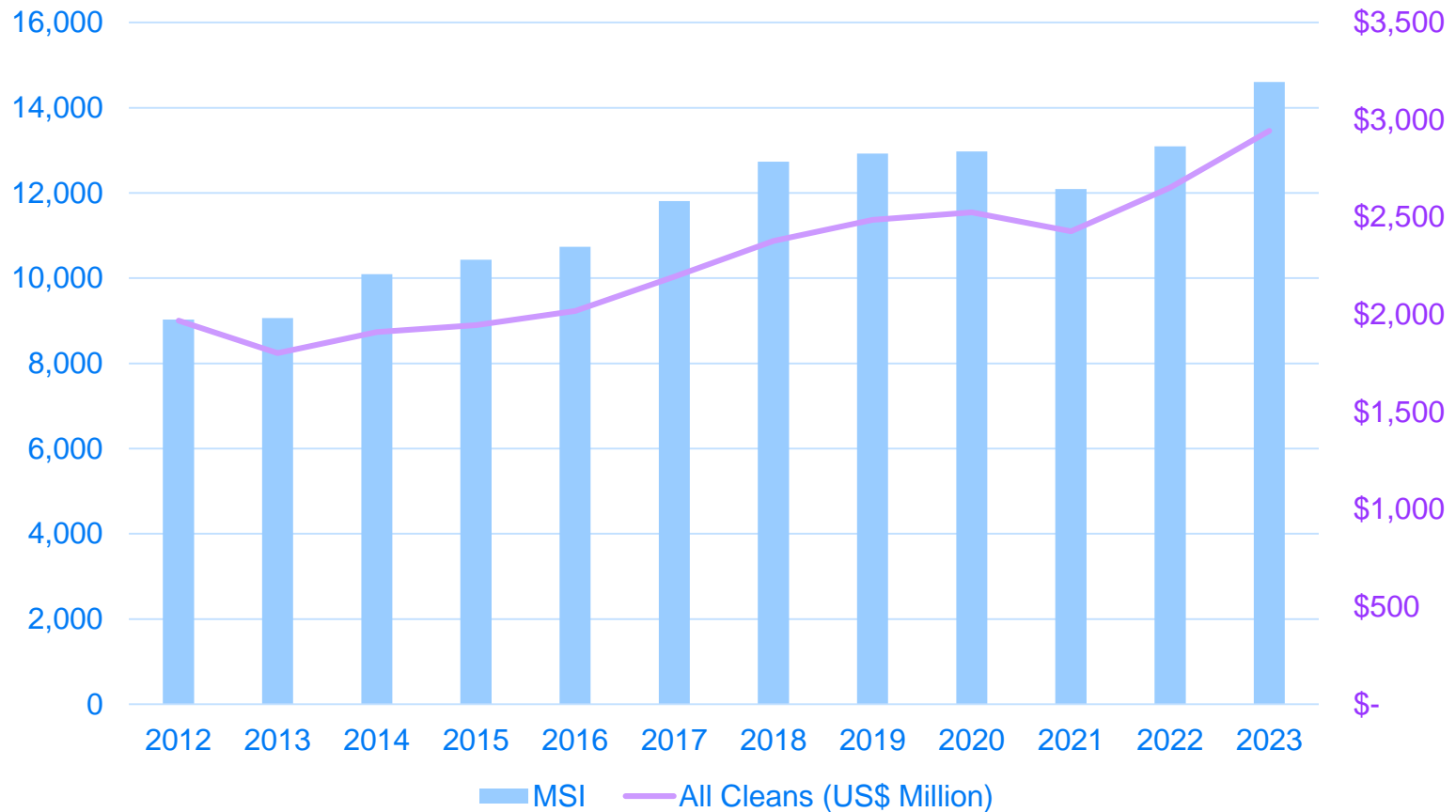
Semiconductor MSI Outlook





MSI Vs. All Cleans

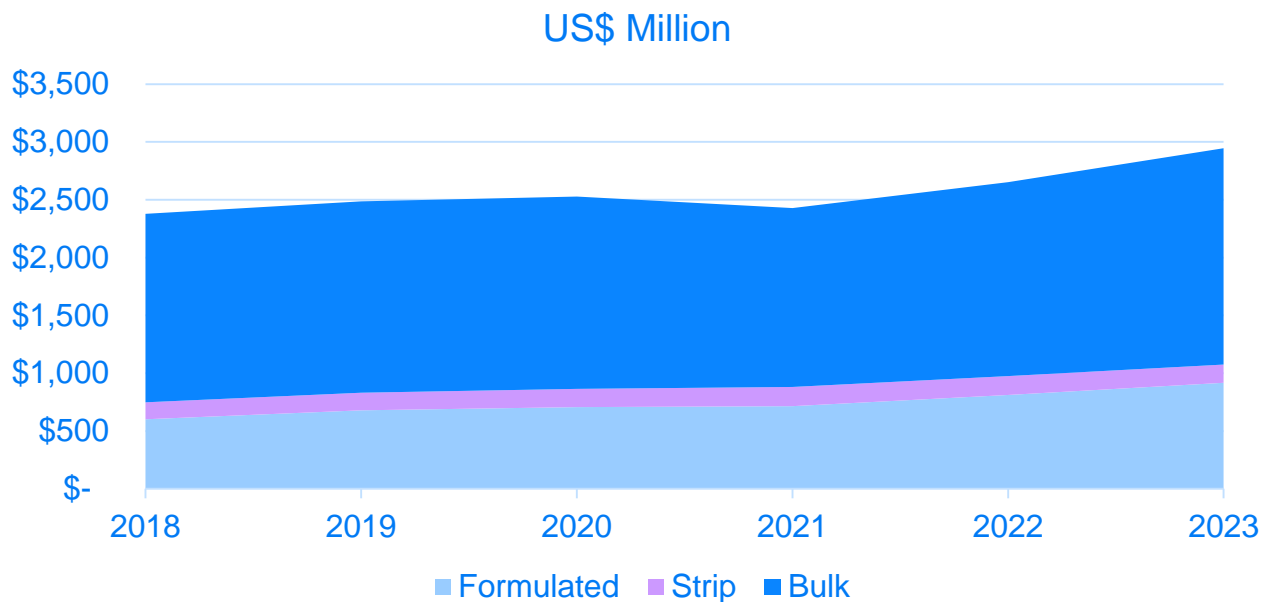
All Cleans includes Bulk Wet + Strippers + Formulated Cleans





Overall Outlook

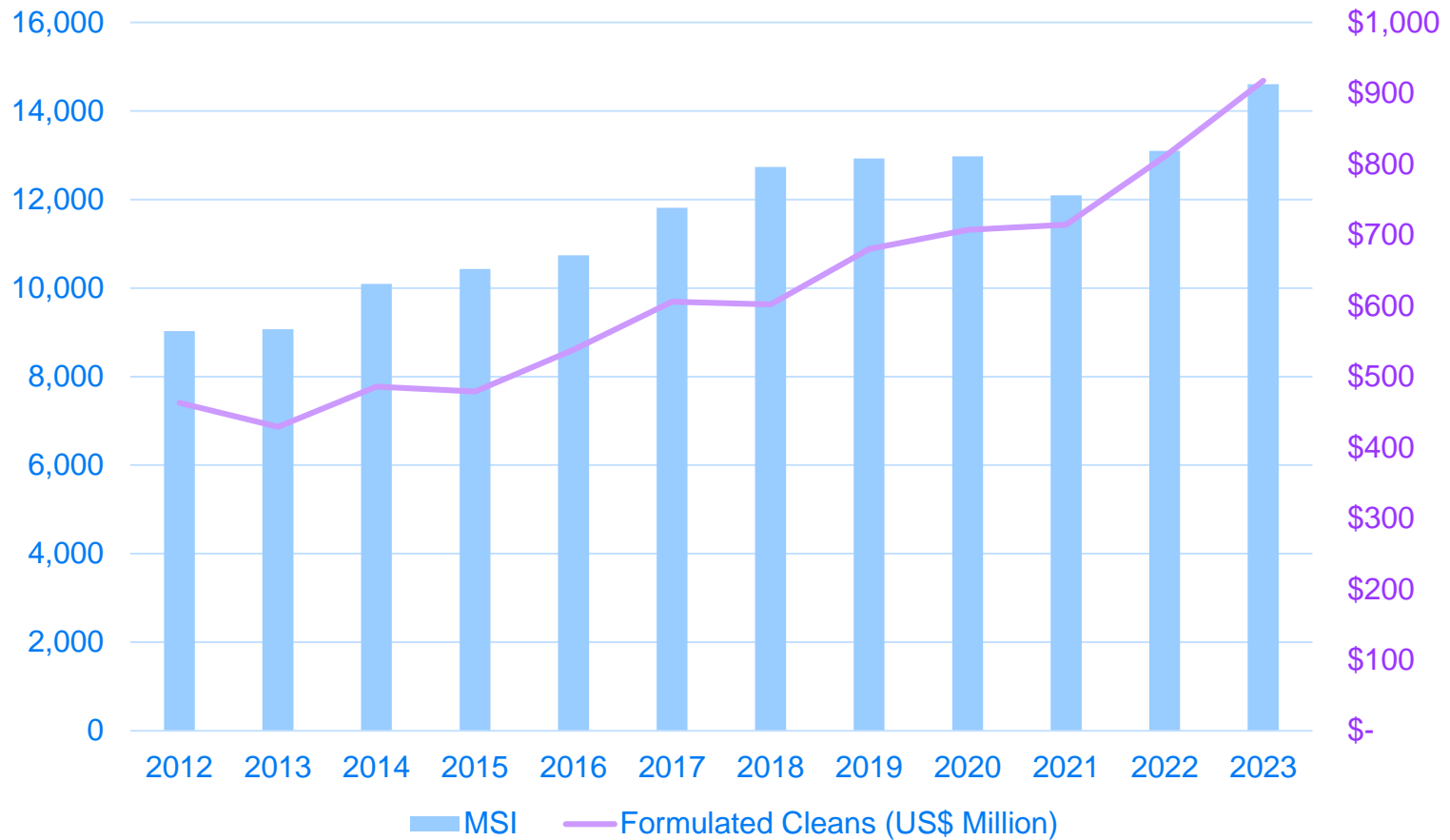
- The total market size of the segments studied is \$2,378 million in 2018 and is expected to grow to \$2,945 million in 2023. Overall AAGR of 4.4% during forecast period driven by new products.



- Key challenges around metrology, defectivity and particles will lead to increased management of supply chain.
- There is minimal impact from Chinese suppliers at this time.



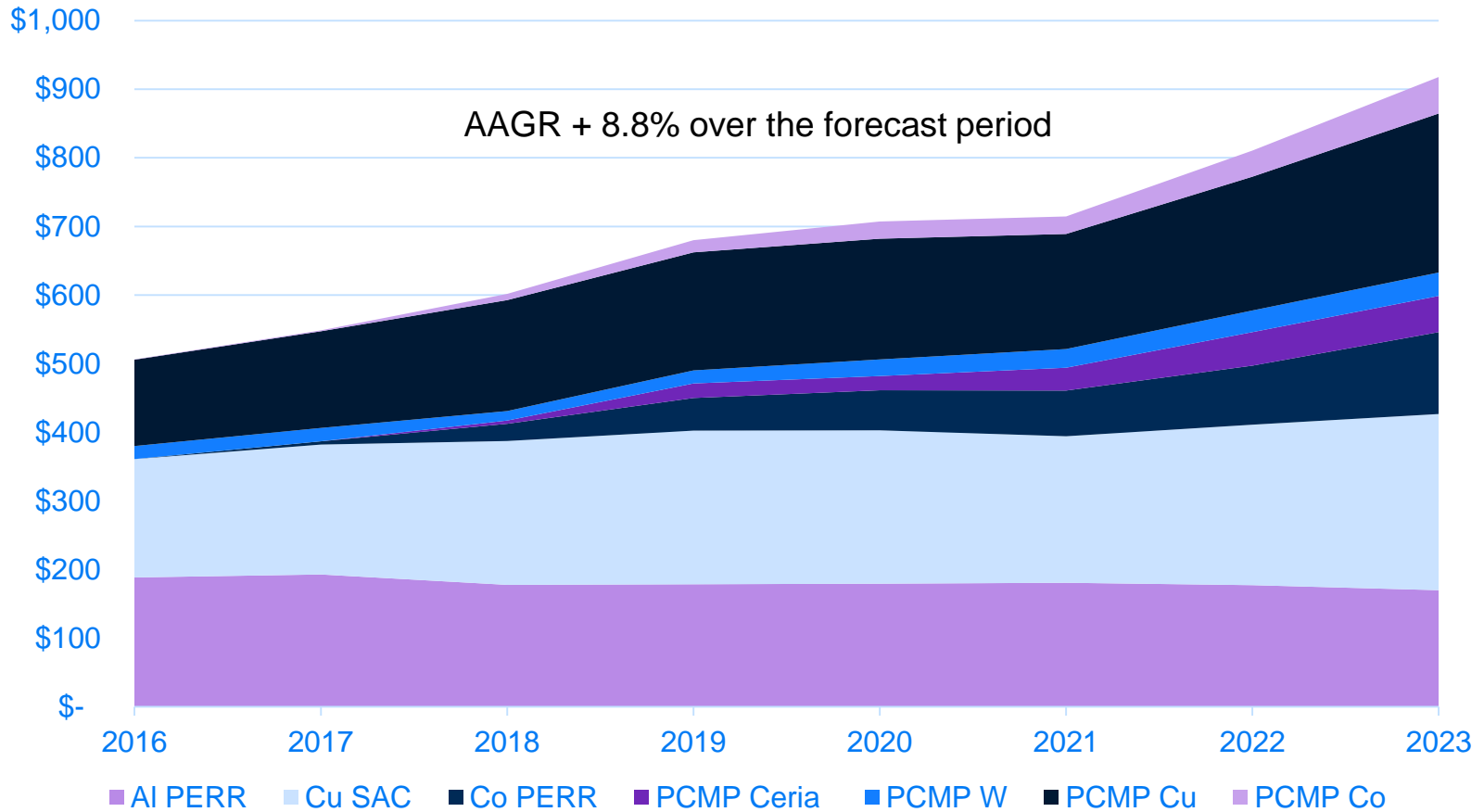
MSI Vs. Formulated Cleans





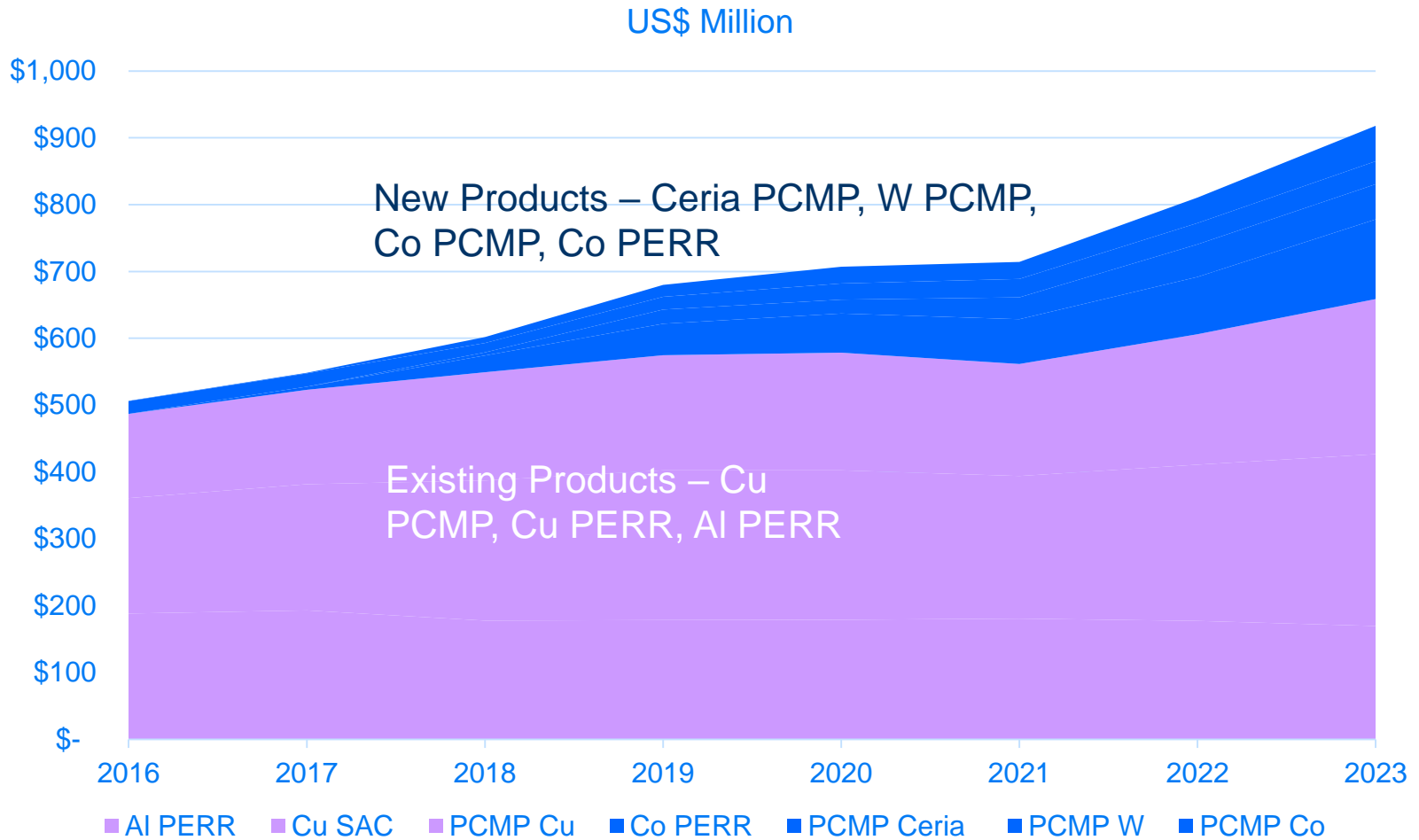
All Formulated Products

US\$ Million

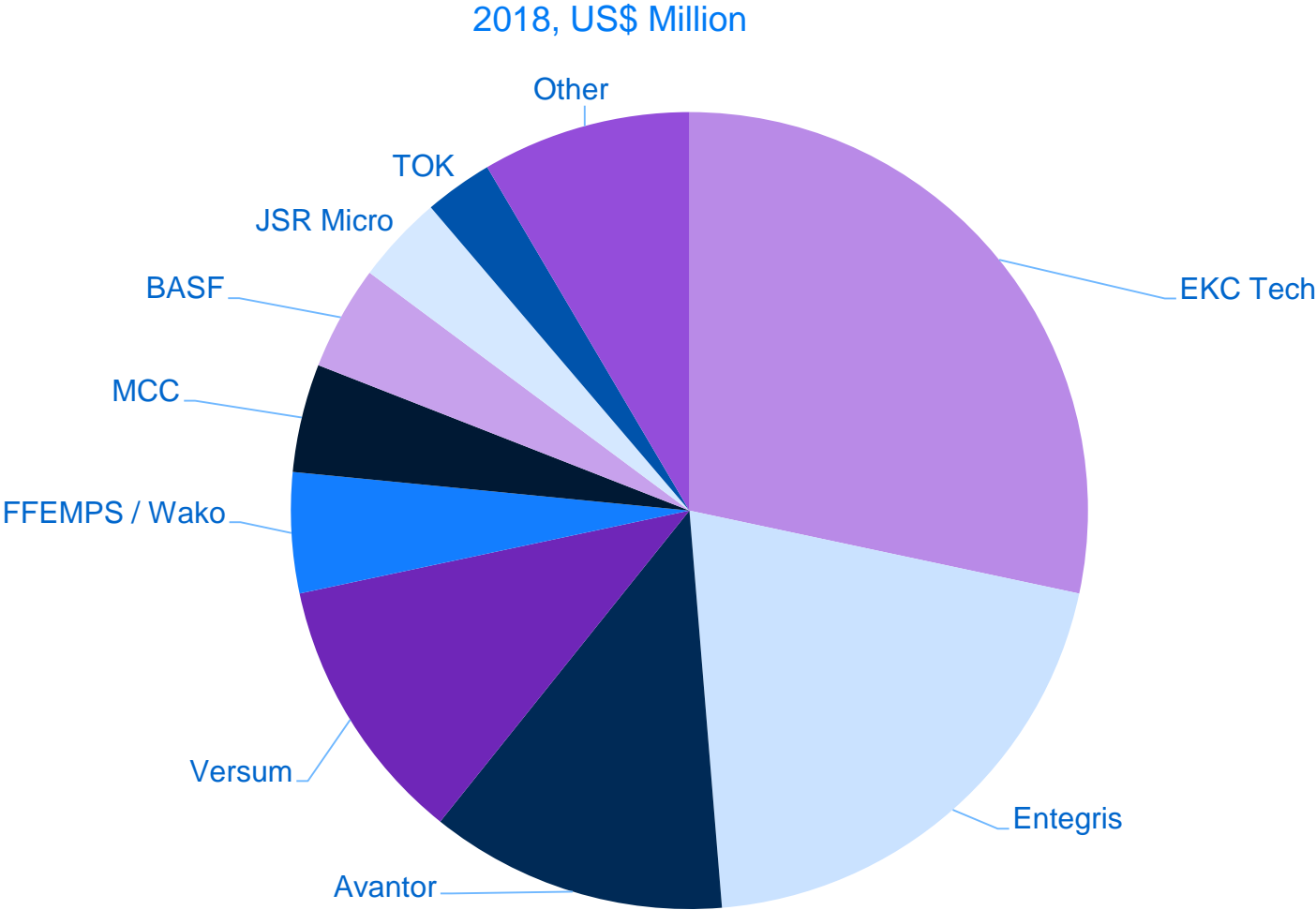




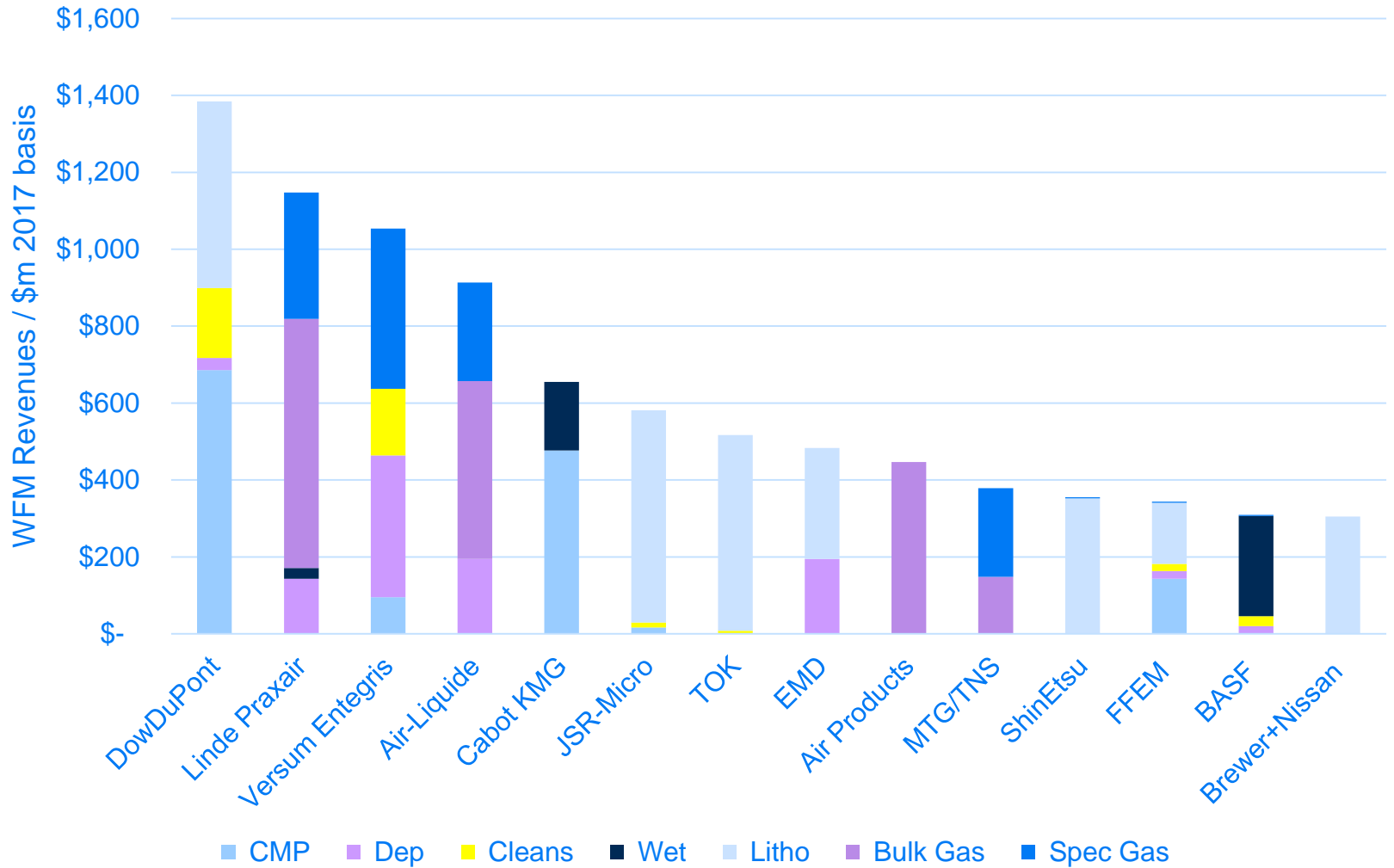
"New" Formulated Products



Leading Suppliers Formulated Cleans



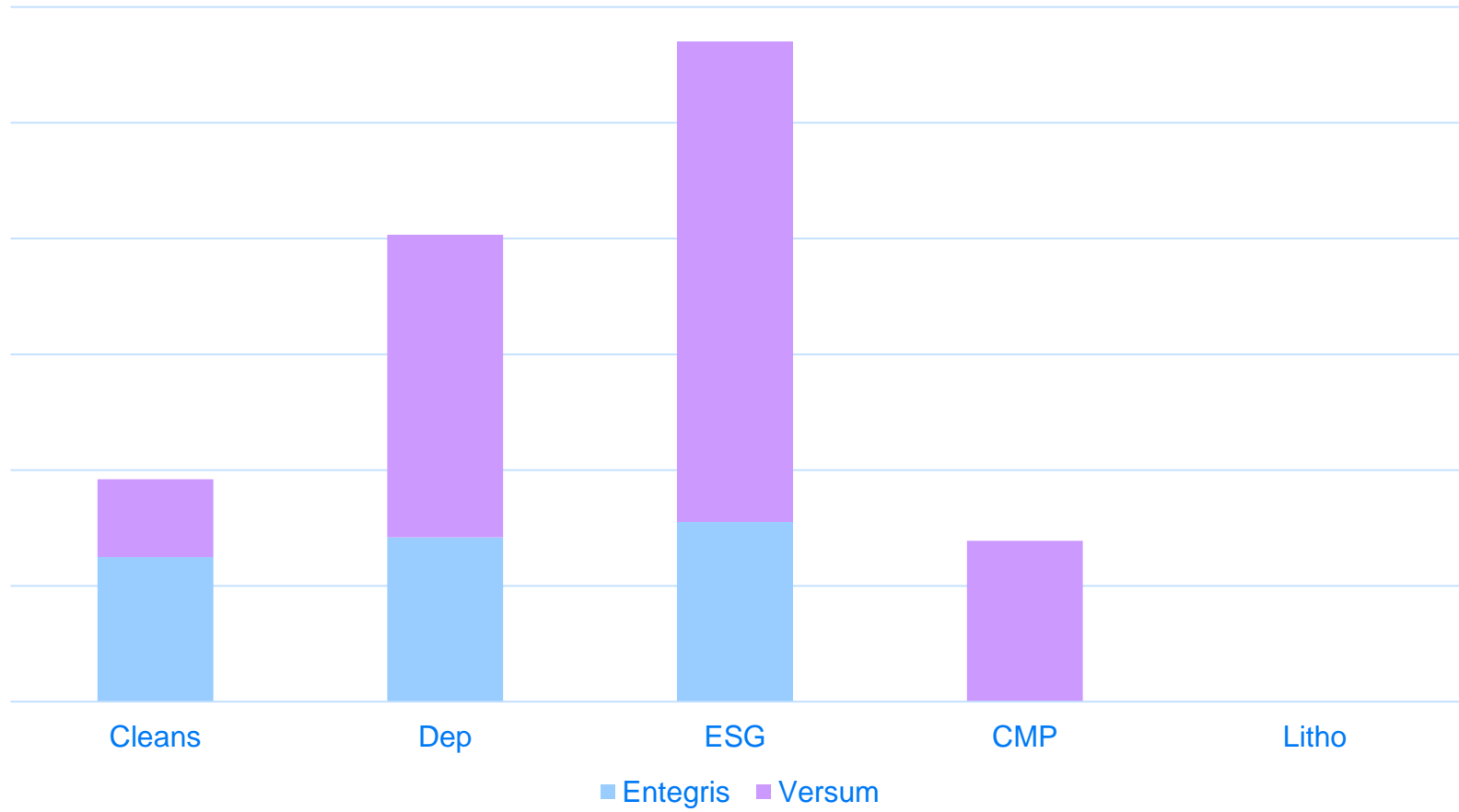
Leading Electronic Materials Suppliers in Semi



Versum and Entegris Combined Materials Business



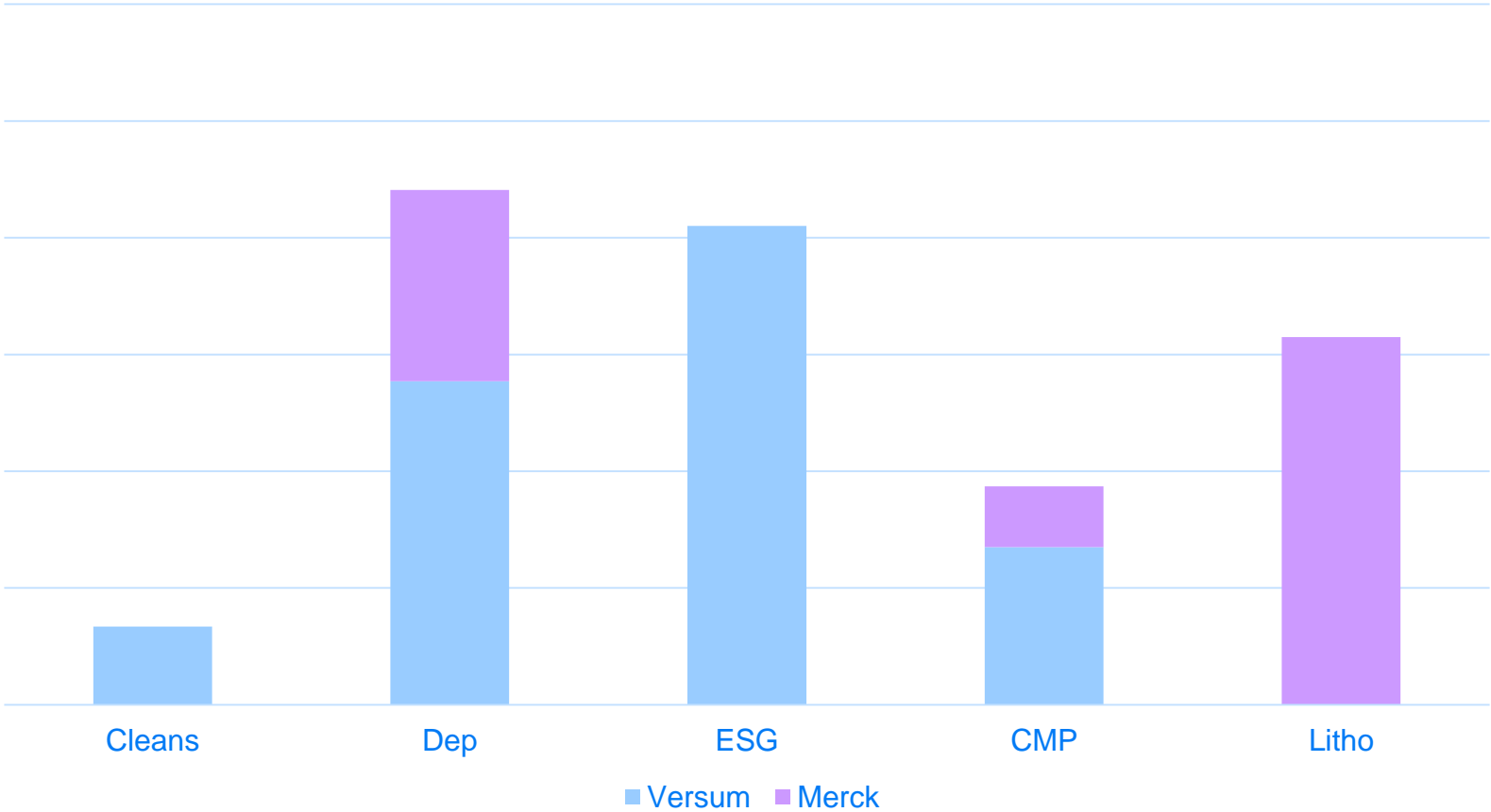
\$M





Versum and Merck Combined Business

\$M





Conclusions



Conclusions

- Downturn expected in a few years but overall strong outlook for semiconductor industry
- Still many technical challenges ahead that will drive demand for new cleans in PERR
- Critical challenges for PCMP will continue and drive needs for more cleans here as well
- Good growth outlook for cleaning chemicals, which require continuous investment to meet end-user needs
- Regional suppliers are not meeting leading edge fab needs for innovative solutions
- M&A will continue to impact cleaning suppliers