The performance materials business of Merck KGaA, Darmstadt, Germany operates as EMD Performance Materials in the U.S. and Canada.

Advanced Delivery System Challenges

Electronic Specialty Gas Conference 2020

Jeff White
Head of Delivery Systems and Services
13 October 2020

EMD Performance Materials

Agenda

01 **The Big Picture**
The Scope of Delivery Systems in the Fab

02 **The Market & Fundamentals**
Delivery System Requirements

03 **The Leading Edge**
Materials Delivery Challenges and Opportunities

Big Data Interface

Automation of Systems / Processes

Ultra-high Volume & Flow Systems

Solid Sources, Low VP Liquids, & Energetics

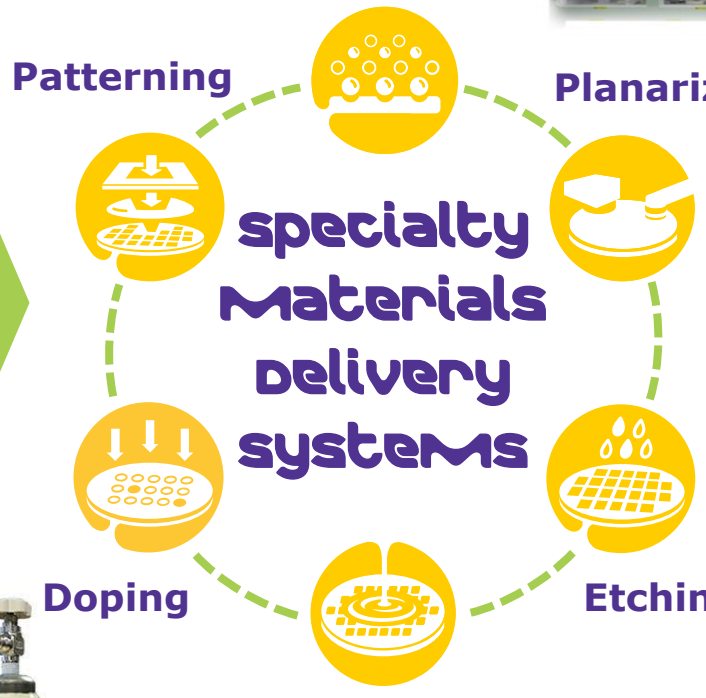
The Big Picture
Delivering Materials to the Fab

Related Systems & Technologies

- Containers
- Filtration (bulk, intermediate, POU)
- Metrology (mobile, in-line)
- Abatement

01

Deposition



safety is the product

delivery systems fundamentals

1. **safety** Safeguarding materials to ensure the health & safety of personnel in the fab, sub-fab, and gas /chem rooms is mission one

2. **reliability** Advanced through prognostics, diagnostics, preventive maintenance, and redundancy

3. **cost-effectiveness** beyond system price, optimize cost of ownership factors such as efficient material usage, operating costs, facilitation costs, operations labor, sub-fab footprint, and ergonomics

The Big Picture
The Delivery Systems Market

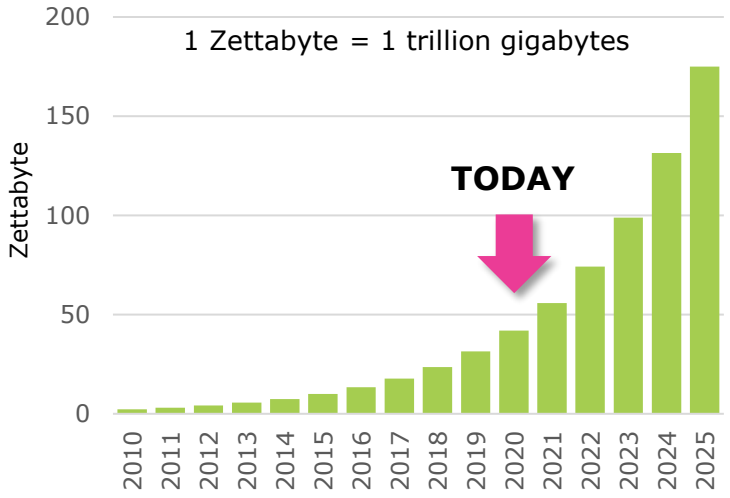
02

Market Dynamics – Driving the Industry Forward

Data growth is gaining speed driven by global digitization, affecting all segments of data application

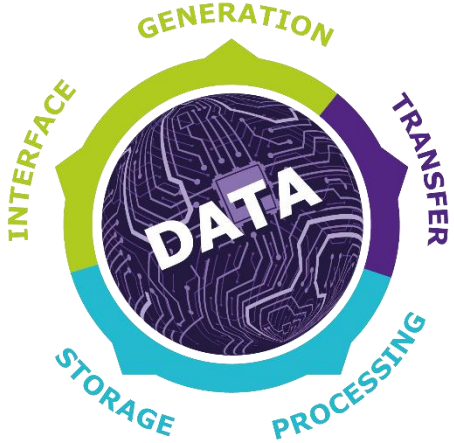
Data created worldwide
is growing >30% annually

Size of global data sphere



Source: IDC DataAge 2025 Whitepaper

Global data growth
affects all segments of data application



Data application segments
drive enabling technologies growth

Technology market growth

5G Technology[1]
>122% CAGR

Artificial Intelligence[2]
>33% CAGR

IoT Sensors[3]
>24% CAGR

Data Center[4]
>10% CAGR

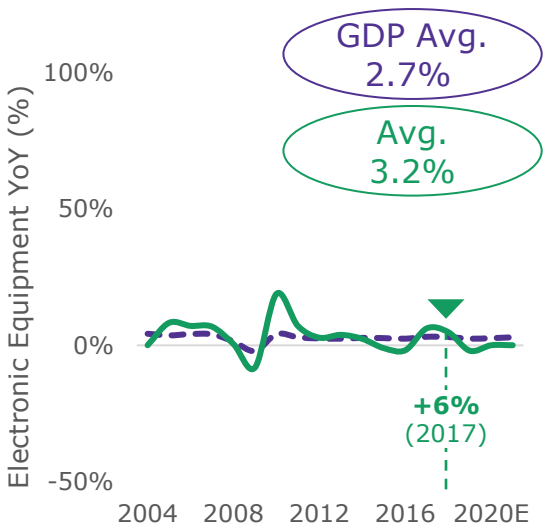
Flexible Display[5]
>28% CAGR

1) alliedmarketresearch.com; 2) fortunebusinessinsights.com; 3) mordorintelligence.com; 4) wboc.com; 5) grandviewresearch.com

Market dynamics present challenges to Delivery Systems Businesses

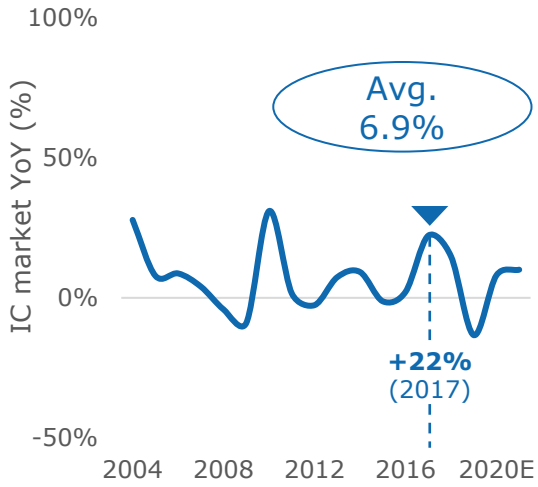
WFE – and the correlated Delivery Systems market growth – is at the end of the tail of the value chain, is significantly more cyclical

Electronic Systems Market
(2019 Market size: **1,000+** bn€)



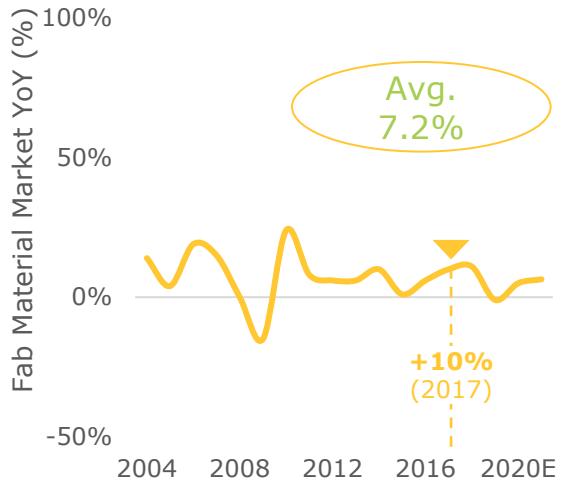
Relative constant growth with strong link to GDP

Global IC Market
(2019 Market size: **350** bn€)



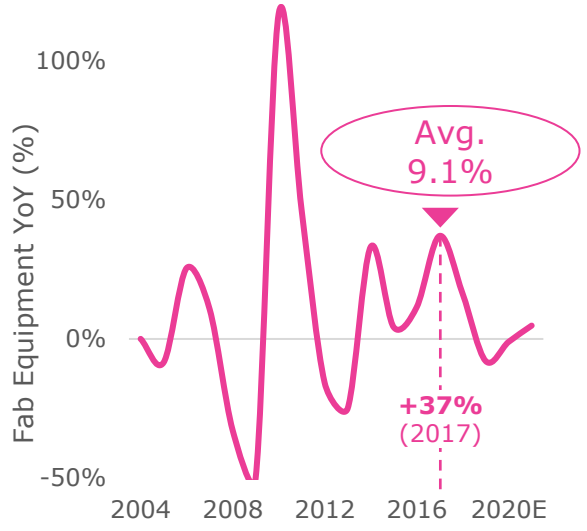
Cyclicality driven by over/under capacity and price fluctuation

Fab Material Market
(2019 Market size: **19** bn€)



Correlated with production volume & less cyclical than semiconductor market

Fab Equipment Market
(2019 Market size: **3** bn€)



Very cyclical with years of huge & limited investments

Source: IC Insights, SEMI, Gartner

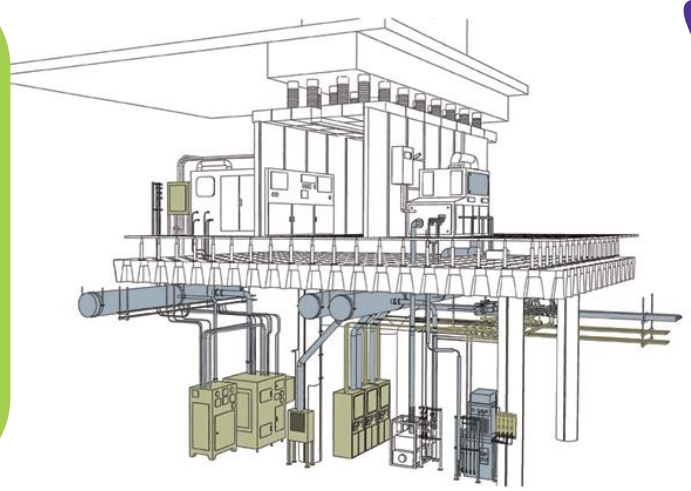
The Semiconductor Wafer Fab Equipment (WFE) Market
Drives the Demand for Fab Delivery Systems

Semiconductor Materials

Supplying OEM tools and fab processes

Delivery Systems

Supplying the sub-fab

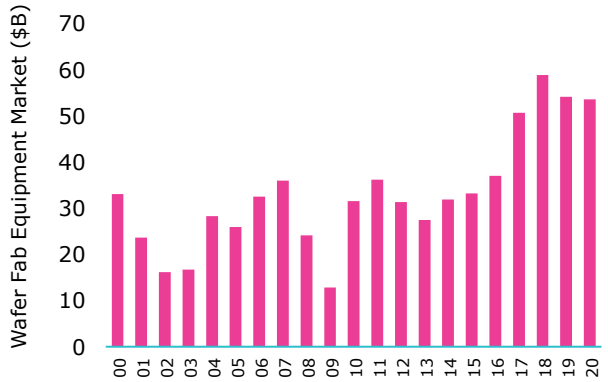


2020

WFE $58B

Delivery Systems ~$2B

Fab Equipment Market
(2019: ~$55bn[2])



	2000-2009		2010-2019		2020-2029F
Ave. WFE/YR	**$25B**	+65%	**$39B**	>55%	**$65-70B**

Process drivers for step-function changes in WFE above end-market demand –

- 3D structures / VNAND
- Double / Quadruple patterning
- EUV

[1]Wafer processing materials - excludes silicon wafers and packaging materials;
[2]Sources: Gartner, LINX-Consulting

The Leading Edge

Materials delivery challenges and opportunities

03

Advanced Delivery Systems
Challenges and Opportunities

Big Data Interface

Big Data and Smart Manufacturing

The Future – "Smart" Factory

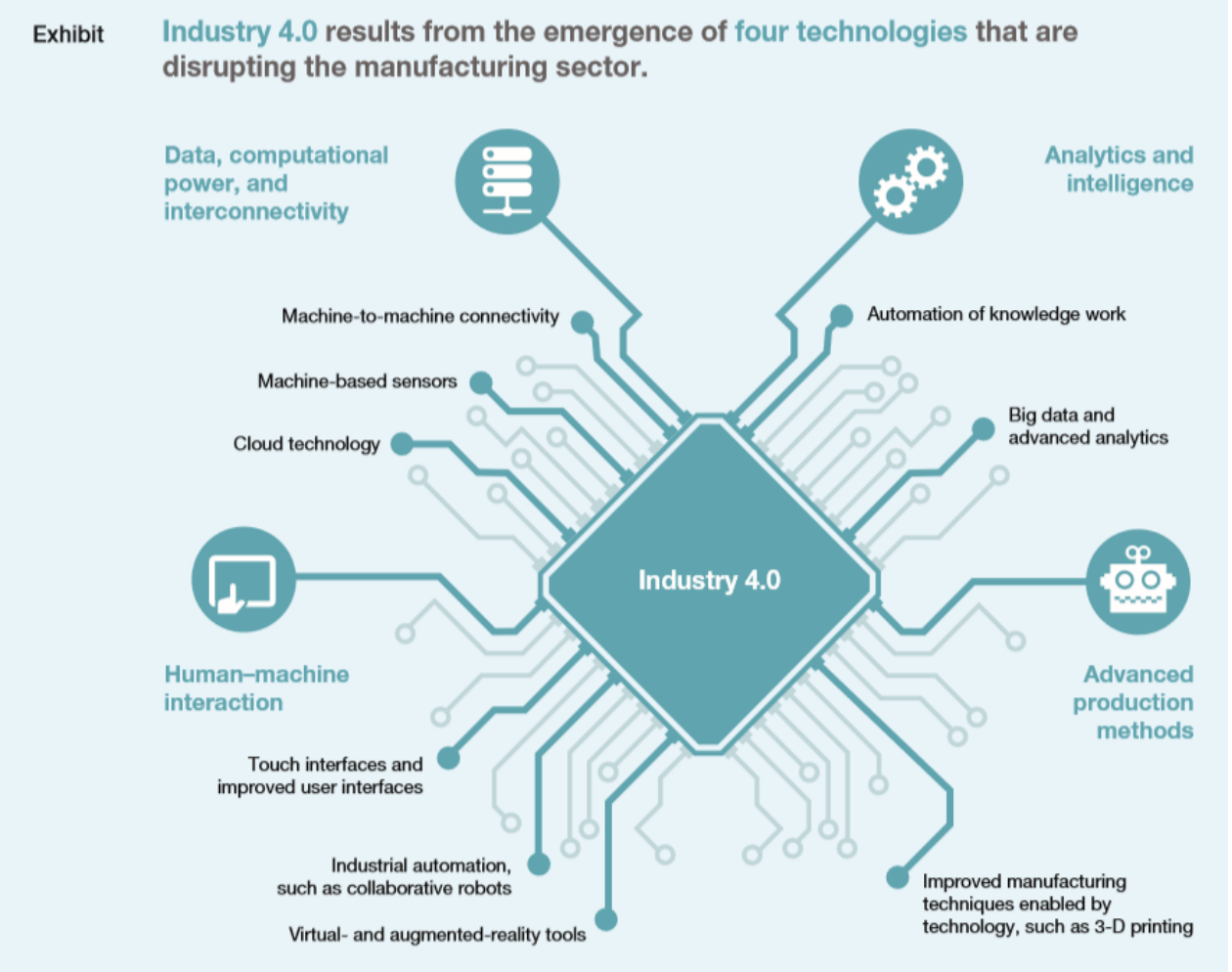
"Improvement in manufacturing operations through integration of systems, linking of physical and cyber capabilities, and taking advantage of information including leveraging the big data evolution."

- *Professor James Moyne, keynote speaker SEMI ASMC*

Key SEMI Industry Trends

Semiconductor Smart Manufacturing & the "5 Vs" of information management:

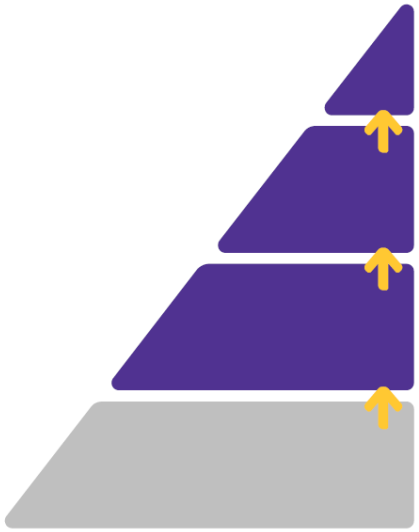
- **Volume** of information
- **Velocity** of information
- **Variety** of data
- **Veracity** or quality of data
- **Value** or application of the analytics



getting more production out of an existing facility while reducing manufacturing costs, improving efficiency, and maximizing asset utilization

Big Data and Smart Manufacturing

Four stages of Data Analytics



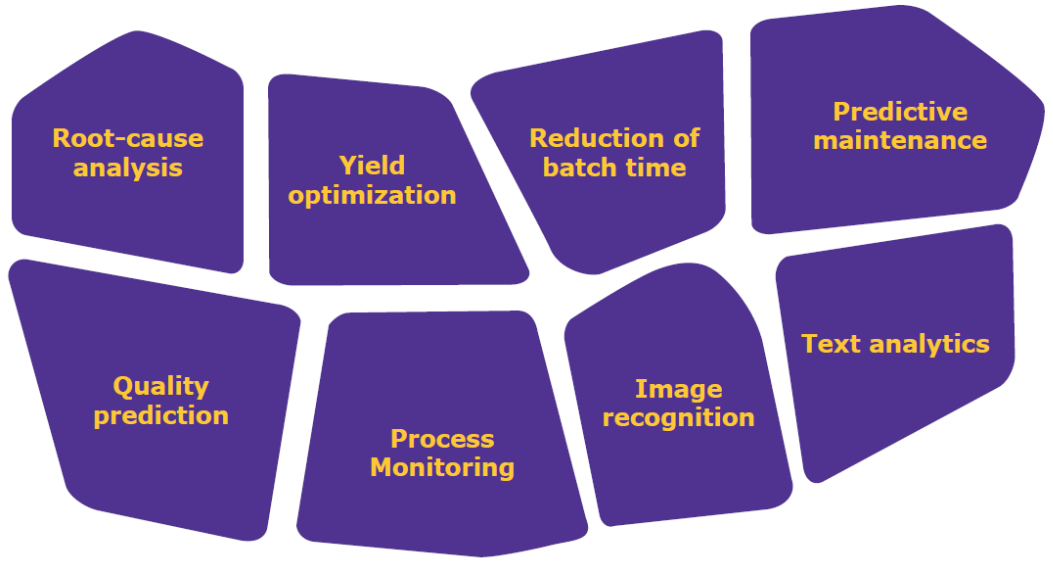
Prescriptive Analytics
How can we make it happen?

Predictive Analytics
What will happen?

Diagnostic Analytics
Why did it happen?

Descriptive Analytics
What happened?

Data Science Use Cases in Production and Manufacturing



Smart Manufacturing benefits –

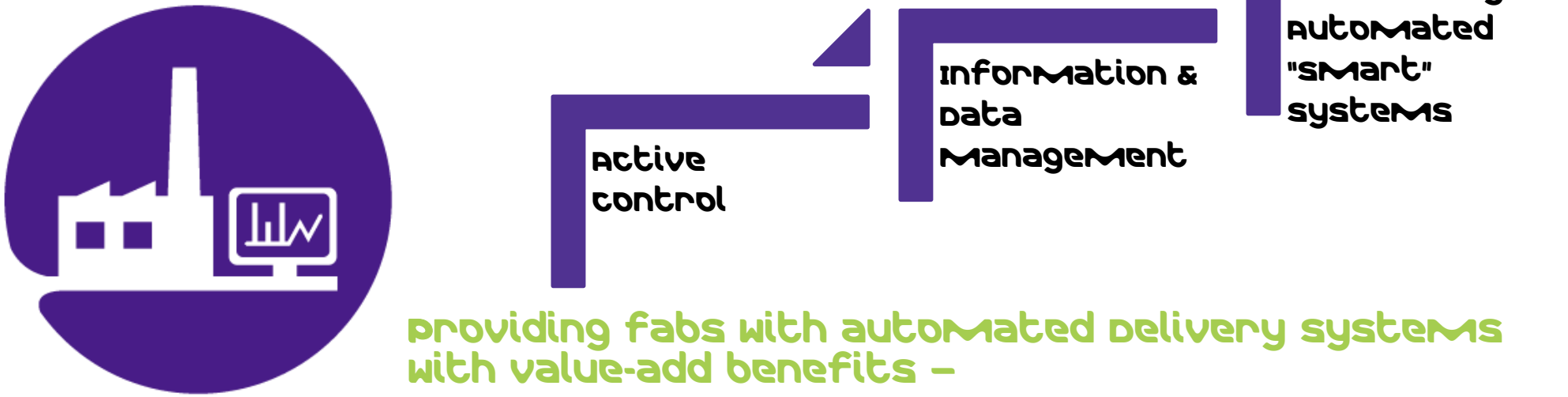
- Preventive Performance Maintenance
- Predictive and Advanced Analytics
- Order replacements through the controller or hand-held device
- Optimizing materials use and efficiency, correlation to container changeouts, equipment uptime, delivery parameters, interconnectivity, operator history, and correlation to downstream quality & yield

delivery systems automation

Continuing Down the Product Automation Pathway

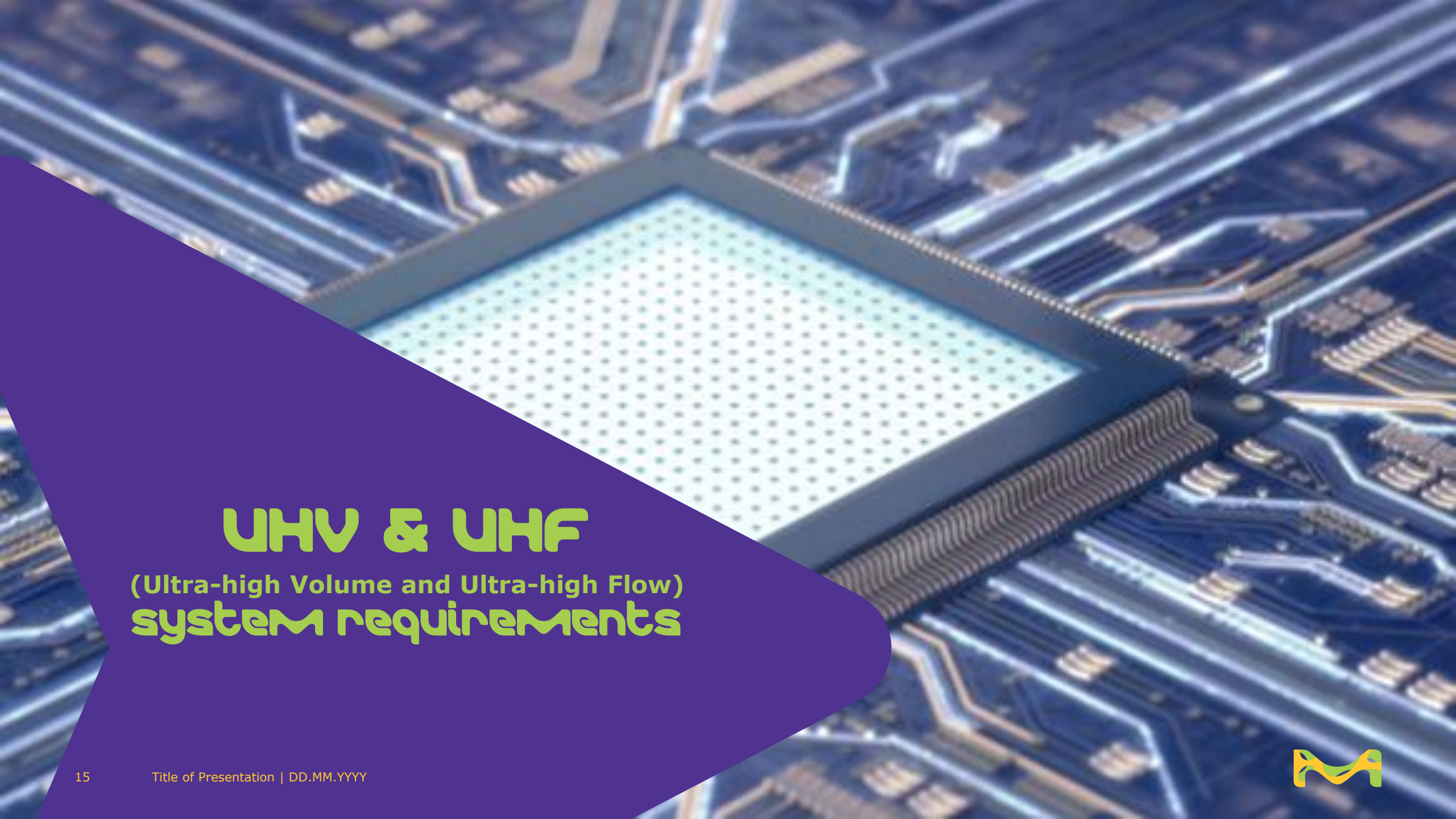
problem statement

addressing the key SEMI industry trends of *improving manufacturing efficiency* as measured by productivity, quality and cost; *optimizing capital* through lost time reduction, process improvements, through-put, and back end automation; *refining resource (labor) use* and allocation; and the advancement of "smart" factories.



providing fabs with automated delivery systems with value-add benefits –

- Operator-free operation and control
- Advanced user interfaces and applications
- Precision pressure control
- Diagnostics of problems
- Advanced analytics
- Maintenance prognostics with parts ordering capability
- Lowest cost of ownership



UHV & UHF

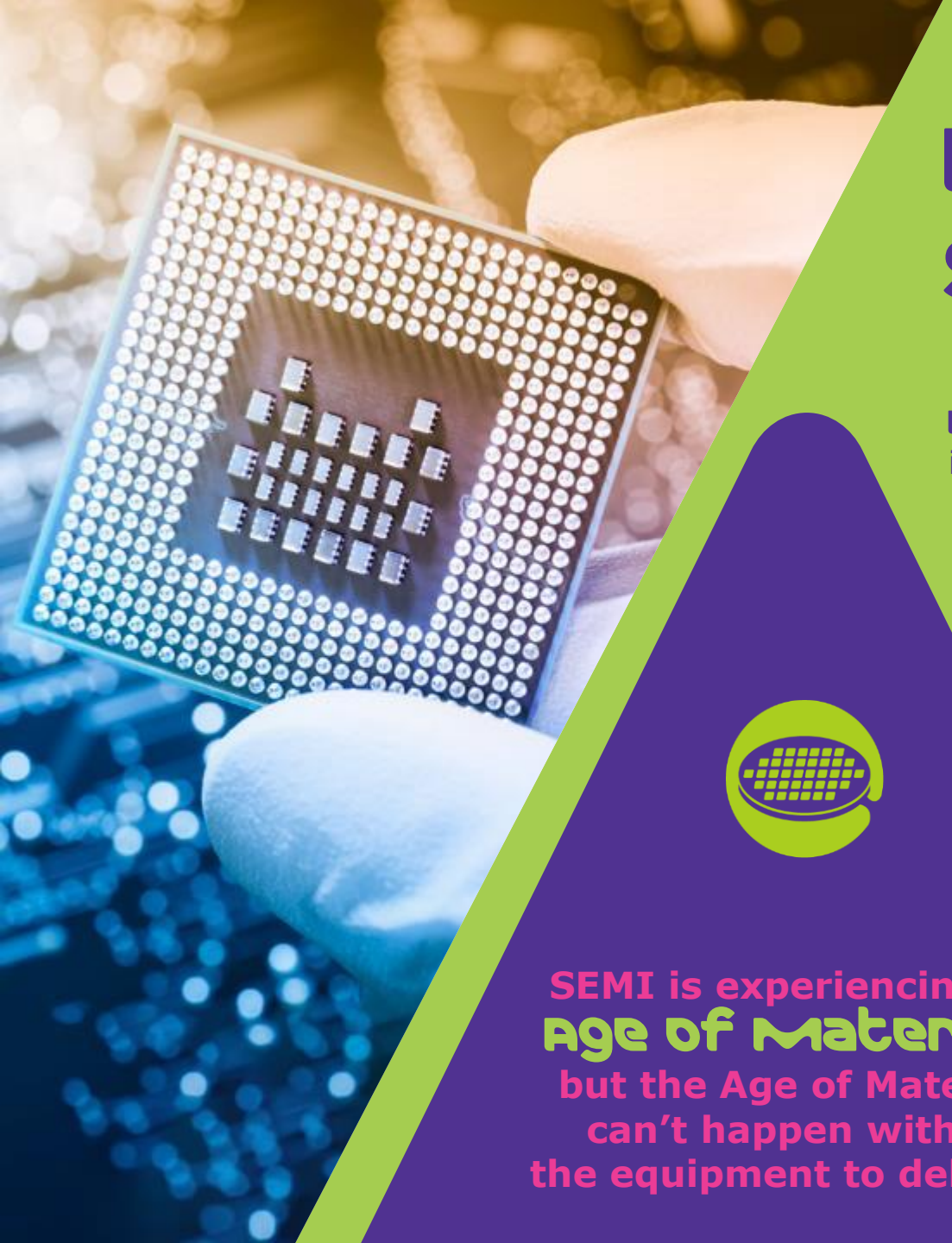
(Ultra-high Volume and Ultra-high Flow) system requirements

Specialty Gases Delivery at Large Scale

Delivery to Point-Of-Use distance can range from centimeters to kilometers

Ultra-High Volume & Ultra-High Flow Materials Delivery
Taking Advantage of Economies of Scale

High Flow in Standard Form Factors	**Large Volume – Bulk Containers**
Flow rates up to 1,000 SLPM Delivery from tube trailer or “Y” or “tonner” cylinders Generally being installed adjacent to the fab, as opposed to in gas rooms inside of a customer FAB building To supply ~100 times more consuming specialty gases such as NF_3, Silane, N_2O, NH_3	Outdoor facility for ISO tube trailer docking stations “ISO-BSGS(Bulk Specialty Gas Supply)” To supply ~100 times more consuming specialty gases such as NF_3, Silane, N_2O, NH_3 Connected the whole FAB building



Advanced Delivery Solution Challenges

High Purity, Solid-Source Delivery
in High-volume Manufacturing at Sub-atmospheric Pressures

Aligning and Accelerating Delivery Solutions
with Latest, Cutting-Edge Advanced Materials Market Timing

Safer Delivery of Highly Energetic Materials
in All Phase States (Liquid, Gas, Solid)

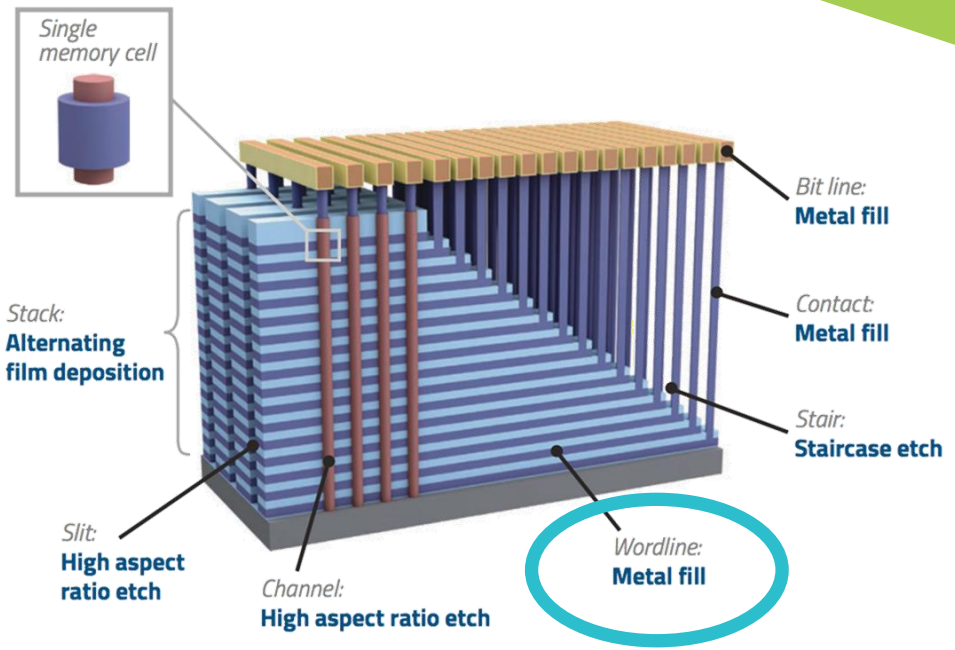
Low Vapor Pressure Liquid Delivery for Highly Reactive Precursors
While Avoiding the Use of Solvents

SEMI is experiencing the Age of Materials but the Age of Materials can't happen without the equipment to deliver it

challenges in high purity solid source delivery

driven by the need for semiconductor processes with improved and scalable precursors for memory applications

VNAND Memory



WF_6 Alternatives

	Fluorine Fee	< Resistivity	CoO	Subfab Option
WCl6	✓	–	–	X
WCl5	✓	–	X	X
MoCl5	✓	✓	–	X
MoO2Cl2	✓	✓	✓	✓

Semiconductor Digest
https://sst.semiconductor-digest.com/2017/07/overcoming-challenges-in-3d-nand-volume-manufacturing/

Advanced Delivery Solutions Challenges

Safer Delivery of Highly Energetic Materials in all Phase States (Liquid, Gas, Solid)

- Alignment and partnership is needed between multiple parties in SEMI (OEM, IDM, local regulations, and delivery) for the safter delivery, use, and abatement of highly energetic materials

High Purity, Solid Source Delivery in High Volume Manufacturing at Sub-Atmospheric Pressures

- Solid source systems operate in excess of 150C from the delivery system to the process tool
- Ensure best uptime while avoiding condensation and tool-down in these complex systems
- Intimate tool handshake and communications

Low Vapor Pressure Liquid Delivery for Highly Reactive Precursors While Avoiding the Use of Solvents

- Solvent use creates sourcing and waste stream challenges
- Unique technology can avoid the use of solvents while improving reliability and lowering cost-of-ownership

Aligning and Accelerating Delivery Solutions with Latest, Cutting-Edge Advanced Materials Market Timing

- Ongoing, formal channels of communication between molecule and equipment experts are required to accelerate time to market for solutions

Delivering the 'age of Materials'

- safely
- reliably
- cost-effectively