

ATOMIC LAYER DEPOSITION EQUIPMENT FOR MORE THAN MOORE 2021

Market & Technology Report - November 2021

ALD equipment market surging with 12% CAGR to reach \$680M in 2026, penetrating all More-than-Moore applications.

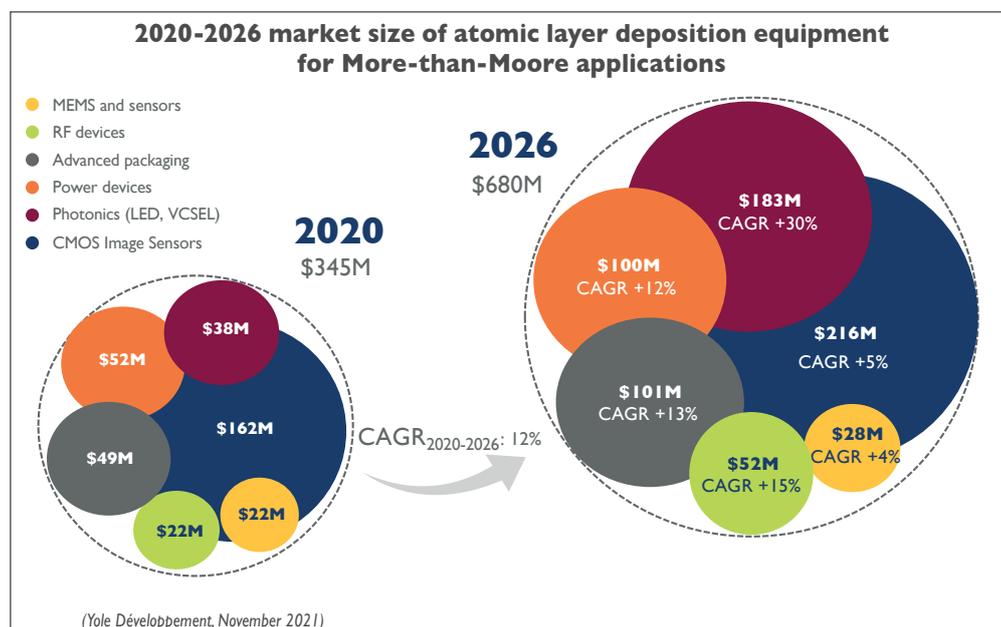
KEY FEATURES

- ALD process requirements and trends for More-than-Moore devices
- ALD equipment benchmarks, including technology, reactor architecture, and average selling price
- ALD supply chain and ecosystem analysis
- 2020 market size analysis with breakdown by market share, wafer size, and device application
- 2020-2026 ALD equipment market forecast with breakdown by device application: MEMS and sensors, power, RF, CIS devices, photonics including mini-LED and micro-LED, and advanced packaging, mainly wafer level encapsulation

ATOMIC LAYER DEPOSITION (ALD) EQUIPMENT PLAYS AN ACTIVE ROLE IN DEVICE PERFORMANCE IMPROVEMENT

ALD has historically been the scaling enabler for mainstream devices such as memory and logic. During the past 20 years of high-volume manufacturing (HVM), 300mm ALD platforms have evolved to address the high throughput needs of mainstream devices despite the intrinsic-to-ALD low growth rate. Regarding More-than-Moore (MtM) devices, CMOS Image Sensors and some Si power applications closely follow logic and memory device production approaches and use similar 300mm ALD platforms. Other MtM devices require 200mm ALD platforms capable of delivering acceptable throughput for smaller batch sizes or single wafer reactors. These deposit excellent quality

thin films, often on non-Si materials such as compound semiconductors (GaN, SiC, GaAs), piezoelectrics, or ferroelectrics, among others. The MtM applications considered here are MEMS and sensors, power devices, and RF devices, as well as photonics (including mini-LED, micro-LED, and VCSEL applications). Amongst other processes, ALD is used for surface and sidewall passivation, trench coatings and gate dielectrics, optical coatings, processing layers, and hermetic sealing. Suitable 200mm ALD platforms have been unveiled during the past few years and are now truly entering MtM HVM, propelled by wafer production volume increase.



WORLDWIDE FAB CAPACITY EXPANSION ACCELERATES INDUSTRIAL ADOPTION OF ALD EQUIPMENT

The ALD equipment market dedicated to MtM device manufacturing totaled \$345M in 2020 and was dominated by CIS (47%). In the coming years, the ALD equipment market is expected to increase with a 12% compound annual growth rate (CAGR₂₀₂₀₋₂₀₂₆), reaching \$680M in 2026.

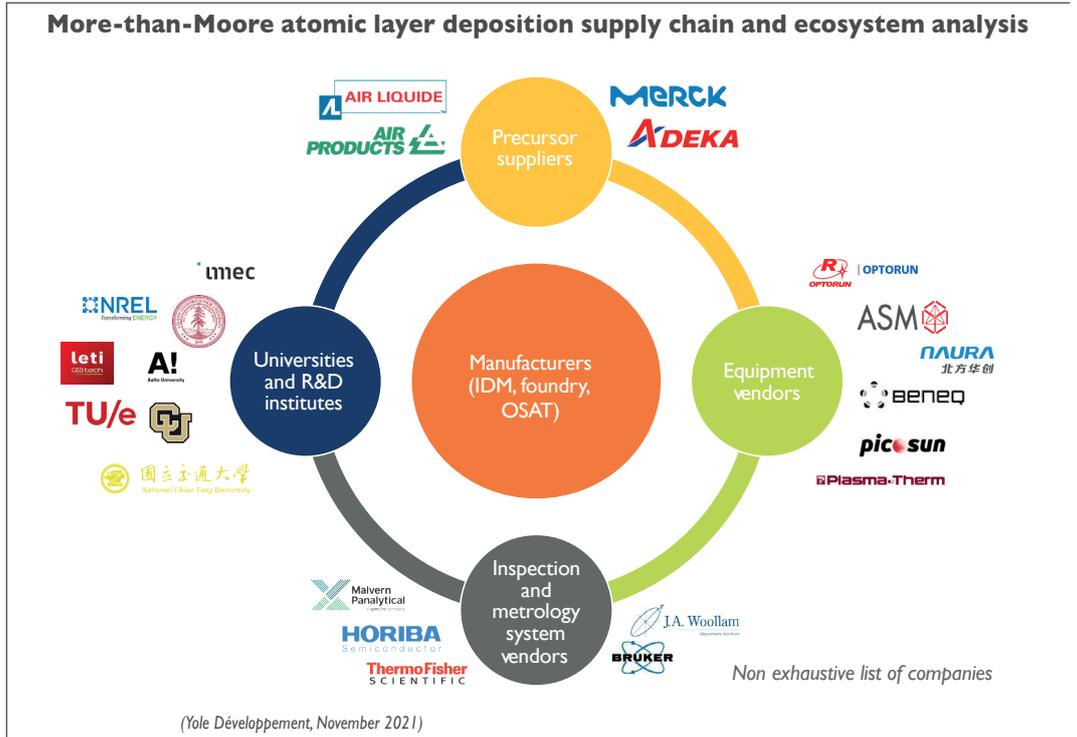
Two main reasons can be given for such high growth. Firstly, manufacturing sites are gearing

up for the production of MtM devices that are gaining importance across all the megatrends: for example, compound semiconductor-based power devices (in particular GaN and SiC), as well as photonic devices (miniLED and MicroLED). Their manufacturing is just rocketing for automotive and consumer applications, with impressive ALD equipment sales expected to increase with 12% and 30%

CAGR₂₀₂₀₋₂₀₂₆, respectively. The growth is further strengthened by the high wafer production volume of CIS devices, Si power electronics, and Advanced Packaging - mainly Wafer Level Encapsulation - used across all MtM applications.

Secondly, the global semiconductor market is favorable. Chip shortages across all markets and MtM devices have pushed manufacturers to announce fab capacity expansion worldwide. This is an excellent opportunity to deploy new materials and processes that improve device performance.

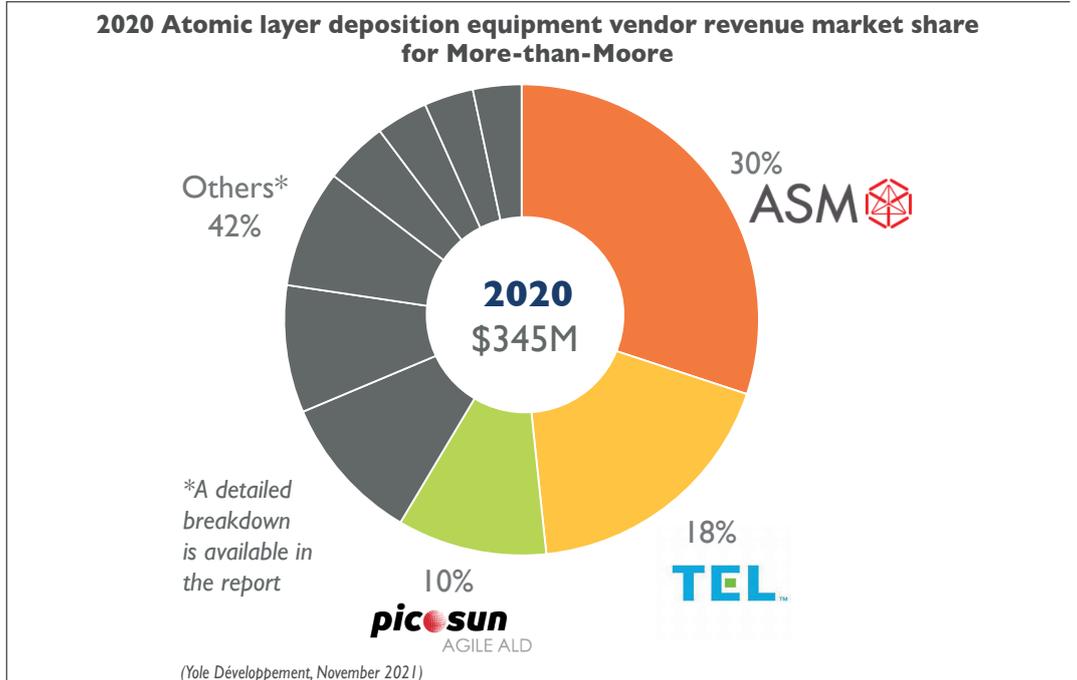
The ALD ecosystem and supply chain actors, traditionally tightly interrelated, now collaborate even more to accelerate ALD adoption. These include ALD process developers such as academic and R&D institutes, precursor suppliers (off-shelf and customized), equipment subpart providers, as well as inspection and metrology system providers. Moreover, fab expansions concern not only the leading manufacturing players, but also smaller production sites giving emerging ALD equipment vendors a growth opportunity.



ALD EQUIPMENT MARKET IS HIGHLY FRAGMENTED, NEW PLAYERS ARE EMERGING

The 2020 ALD equipment market, totaling \$345M, is led by 300mm platforms, i.e. ASM International (30%), TEL (18%), and NAURA, all offering

300mm platforms with high average selling price as well as high throughput. Even though these players also provide 200mm platforms, Picosun



generated the highest market revenue from this platform (10%). The company is, however, closely followed by Otorun, Beneq, Plasma-Therm, Oxford instruments, and Veeco, among others. Moreover, equipment vendors previously active only in ALD research are now developing their machines for volume production in response to the chip and equipment shortages. The ongoing global semiconductor market upside gives an optimistic prospect for MtM ALD equipment

vendors' revenue. Nevertheless, the ALD market is competitive, and market shares can change greatly in the coming years. On the one hand, players such as Beneq, Veeco, Oxford Instruments, and SkyTech, will develop 300mm cluster tools dedicated to increasing the MtM device wafer size. On the other hand, 300mm players will adapt their 200mm batch systems for compound semiconductor processing. Finally, other CVD or PVD deposition system providers may start to enter the ALD arena.

COMPANIES CITED IN THE REPORT (non exhaustive list)

ACM Research, Advanced Energy, AIR LIQUIDE, ALICAT, AnnealSYS, Applied Materials (AMAT), Arriadiance, ASM International, ATLANT 3D, BROOKS, Beneq, BRUKER, Canon, CNI, CVD Corporation, DOW, Dupont, EDWARDS, Encapsulix, Entegris, EREZTECH, Eugene Technologies, Eugenius, FHR, FITOK, ForgeNano, FujiFilm, Fujikin, Gelest, HAMLET, Hitachi, HOKE, Horiba, Huate Gas, INFICON, Imec, Intel, Isac Research, Kokusai Electric, Korea Vacuum Tech, Kurt J. Lesker, Lam Research, Leti, Levitech, Linde, MBRAUN, MERCK, mks, Nata Optoelectronics Materials, Otorun, NAURA, Nouryon, NSI, Oxford Instruments, Pegasus, Pfeiffer Vacuum, Picosun, Samco, Samsung, Sentech, Shenyang Piotech, SK Materials, SkyTech, Sundew Technologies, SuperALD, STREM Chemicals, SVT, Swagelok, TLX Technologies, Tokyo Electron (TEL), Tokyo Ohka Kogyo (TOK), Trion, TSMC, Umicore, VAT, Veeco, Wonik, Plasma-Therm, ZLD Technology and many more.

REPORT OBJECTIVES

- To provide information on the status of ALD industrial adoption for More-than-Moore device production
 - > Comparison with CVD and PVD
 - > ALD process
- To provide an overview of ALD equipment
 - > Technology
 - > Reactor Architecture
- To provide an overview of the ALD supply chain and ecosystem
 - > Precursor suppliers
 - > Equipment Vendors (ALD, subparts, inspection, and metrology)
 - > Process developers (from academia to IDMs)
 - > Potential ALD equipment clients
- To estimate and forecast the future penetration of ALD process into compound semiconductor-based power, RF and LED applications
- To provide 2020-2026 forecast metrics for the ALD equipment market

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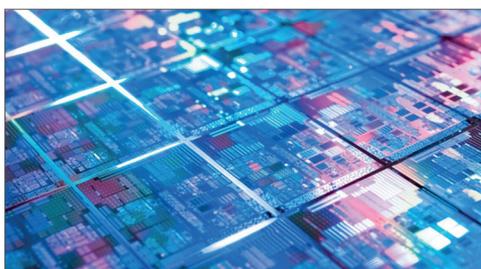
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AUTHOR

Taguhi Yeghoyan PhD., is a Technology & Market Analyst, Semiconductor Manufacturing at Yole Développement (Yole), within the Semiconductor, Memory & Computing division. Taguhi's mission is to follow daily the semiconductor industry and its evolution. Based on her expertise in this field, Taguhi performs technology & market reports and is engaged in dedicated custom projects. Prior to Yole, she worked in world-class European research centers and laboratories, including imec (Belgium), LMI (Lyon, France) and LTM at CEA Leti (Grenoble, France). All along her past experiences, Taguhi has authored or co-authored one patent and more than nine papers. She has graduated from Wrocław University of Technology (Poland) and University of Lyon (France). Taguhi also completed her PhD. in Material Science from the University of Lyon (France).

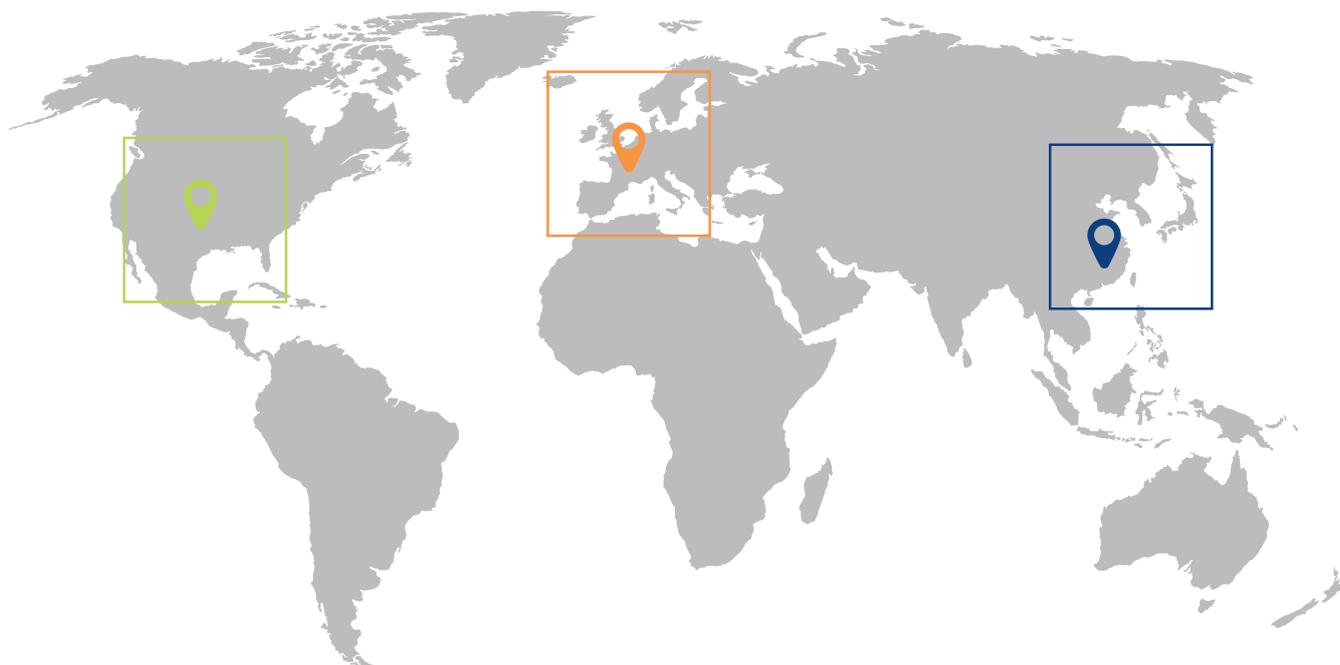
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ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

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“Buyer”: Any business user (i.e. any person acting in the course of its business activities for its business needs) placing an order pursuant to these General Terms and Conditions of Sale, with the exclusion of any individual consumer acting for his/her sole personal interest.

“Seller”: Headquartered in Villeurbanne (France), Yole Développement provides marketing, technology and strategy consulting, media and corporate finance services, reverse engineering/costing services as well as IP and patent analysis. With dedicated teams of technology & market analysts, Yole Développement operates worldwide with the key industrial companies, R&D institutes and investors to help them understand the market and technology trends.

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1.3 Orders are deemed to be accepted only upon written acceptance and confirmation by the Seller, within [7 days] from the date of order, to be sent either by email. In the absence of any confirmation in writing, no order shall be deemed to have been accepted.

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 - Within a few days from the Seller’s confirmation of the order for Products already released and paid; or
 - Within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.
- 2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.
- 2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in Article 3 above.

2.4. The mailing is operated through electronic means either by email via the sales department or automatically online via an email/password. The Buyer is responsible for ensuring that the Buyers platform has the required capacities and authorisations to receive the Product(s) emailed by the Seller. If the Product’s electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that the Seller is informed of the defective formatting within 90 days from the date of the original download or receipt of the Product.

2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the Products and their conformity with the order. Any claim for apparent defects or for non-conformity shall be sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No return of Products shall be accepted without prior written notification from the Buyer to the Seller, even in case of delayed delivery. Any Product returned to the Seller without the Buyer providing prior notification to the Seller as required under Article 2.5 above shall remain at the Buyer’s risk. In no event shall the Seller incur any liability for Products erroneously ordered by the Buyer, or for any request from the Buyer to replace a Product previously ordered by a different Product.

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3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are deemed to be inclusive of all taxes applicable in the country where the Seller is based (except for France where VAT will be added). The prices are re-evaluated from time to time by the Seller. The effective price is deemed to be the one applicable at the time of the order.

3.2 Payments due by the Buyer shall be sent by cheque payable to Yole Développement, or made by credit card or by electronic transfer to the following account:
HSBC, 1 place de la Bourse 69002 Lyon France
Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587

To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except as otherwise specifically agreed in writing by the Buyer and the Seller. If the Buyer fails to pay at the due date and fails to request and obtain from the Seller a payment extension, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the “BCE” + 7 points, in accordance with article L.441-6 of the French Commercial Code.

3.4 The Seller publications (reports, monitors, tracks...) are due for delivery only after receipt by the Seller of any payment due by the Buyer prior to delivery.

3.5 In the event of termination of the contract by the Seller attributable to Buyer misconduct during the contract, the Seller will have the right to invoice all work performed at the time of termination, and to take legal action for damages.

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4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for the choice of the Products purchased as well as for the use and interpretations the Buyer makes of the documents it purchases, of the results the Buyer obtains, and of the advice and acts the Buyer bases thereon .

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- Licensing, leasing, selling, offering for sale or assigning a Product or any derivative thereof.

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6.6 It is acknowledged and accepted by the Buyer that whether purchased in the form of Bundles or Annual Subscription, all unselected reports will be deemed cancelled and lost after a period of 12 month following acceptance of the corresponding order by the Seller in accordance with provisions of Article 1.3 above .

6.7 It is further acknowledged and agreed by the Buyer that any investor in the Buyer Company, any external consultant of the Buyer Company or any joint venture done with a third party in which the Buyer Company is involved , is not entitled to use a Product, without paying to the Seller the full price for a license to the required Product..

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8. MISCELLANEOUS

8.1 All the provisions of these General Terms and Conditions of Sale are for the benefit of the Seller, but also for that of its licensors, resellers and agents. Each of them is entitled to assert and enforce these provisions against the Buyer.

Any notices under these Terms and Conditions shall be given in writing and shall be effective upon receipt by the other Party.

8.2 The Seller may, from time to time, update these General Terms and Conditions of Sale, and the Buyer, shall be deemed to have accepted the latest version of such General Terms and Conditions of Sale, once they have been duly communicated to the Buyer by the Seller.

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- 9.1 Any dispute arising out or linked to these General Terms and Conditions of Sale or to any Licenses or Products purchased in application thereof shall be submitted to the French Commercial Court of Lyon, which shall have exclusive jurisdiction upon such issues.
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