

## Technology Trends in the Environmental Testing Laboratory

Environmental testing laboratories provide a critical service to public health and our surrounding environment. Many different analyses can be performed, including chemical, radiological, genetic and microbiological, on a wide array of environmental samples and matrices. These tests support the environmental protection functions of government agencies across the globe.

As environmental testing evolves, changes are made to regulations that govern sampling methods, establish new and stricter detection limits and introduce emerging contaminants to screening lists. Economically, the industry has suffered through a period of consolidation, intense price competition and declining profitability.<sup>1</sup>

For a laboratory to survive, it must anticipate and plan for any potential regulatory changes and adapt to unexpected events – for example, the recent COVID-19 pandemic. To tackle SARS-CoV-2, the virus causing

COVID-19, we have witnessed an unprecedented global effort to develop novel therapeutics as well as detection and monitoring protocols. This has highlighted the need for centralized data,<sup>2</sup> to facilitate scientific collaboration and harness the power of machine learning (ML) and artificial intelligence (AI) technologies.<sup>3</sup>

Additionally, as seen during COVID-19 as well as other crises, laboratories need to have the ability to pivot their normal operations – adding additional personnel or shifts to address increased testing needs or alternative scheduling as well as adding remote access to instrumentation and data for internal and external use. Advances in remote communications technologies have been successfully implemented globally to facilitate communication with and between personnel and customers, maintain instrument operations and critical data flow and manage laboratory operations safely and effectively.

Aside from the COVID-19 pandemic, laboratories are under enormous pressure to reduce the cost and turnaround time for analytical services. Consequently, any technologies that can facilitate this are likely to be adopted rapidly. This article highlights current and future technology trends that will enable environmental testing laboratories to adapt to predicted and unforeseen future issues.



## Automation

In recent decades, automation has revolutionized many human activities – including the way we work, shop and bank. As regulations tighten, cost pressures increase and a shortage of skilled personnel emerges, the scientific sectors are also looking to automation. Environmental laboratories can incorporate automation into the workflow during sample processing, sample preparation and environmental testing. For example, barcode labelling or radio-frequency identification (RFID) can be used to identify and track samples through the analysis journey. Sample preparation can present challenges to automation in that some complex protocols require scientists to use visual cues to determine if a step is successful before proceeding. Machinery can mimic the human eye using a camera to identify the state of the sample, e.g., if there are any pellets in the sample vessel, the color of any liquid or the volume of the sample. The data collected from the camera is imputed into an algorithm enabling the machines to make decisions on what to do next.<sup>4</sup>

Introducing automation into laboratories can create some pain points for laboratory managers. Such as:

- 1. High upfront cost:** Considerations during the implementation phase must be made for the following: upfront hardware costs, creating a suitable environment (i.e. soundproofing, air conditioners), the laboratory “down-time” necessary for system installation and an increased cost for supplies (i.e. energy, equipment and maintenance).
- 2. Change in the layout of the laboratory:** New equipment can change the structure and layout of the laboratory by decreasing foot space and precious bench space as well as potentially increasing noise, heat and vibration – which can all impact staff welfare.
- 3. Time cost in training:** Extra training is likely to be required on the new equipment and accessories.

- 4. Legacy hardware may not be compatible:** The transition from a manual to fully automated laboratory can be more challenging if the legacy hardware is not compatible, however, there are software solutions available that can help address this problem.<sup>5</sup>
- 5. Systematic failure in the laboratory:** Systematic failure in a total laboratory automation (TLA) environment can cause more significant challenges than in partially automated laboratories. This can be a devastating issue for environmental labs, which rely on uptime, high throughput and are pressured by time-sensitive analyses. However, backup power supplies, retention of redundant non-automated equipment for emergency use, hardware, software, and emergency procedures can help to overcome these issues.<sup>5</sup>

Despite the challenges, the benefits often outweigh these concerns. Automation technology is gradually becoming affordable for most environmental laboratories. The return on investment (ROI) can be increased by the long-term savings (i.e. efficiently solving congestion issues brought on by new equipment).<sup>6,7</sup> Human errors produced by repetitive tasks and differences in data analysis outcomes due to staff discrepancies are limited by automation, resulting in increased efficiency, output, productivity and reproducibility. In some instances, sample collection or testing may be hazardous, therefore automation can perform these steps and reduce the risk to staff.



## Cloud computing and cloud laboratories

Cloud computing makes numerous IT resources available to a user, without the requirement for direct management or hosting by an operator. It also enables data transfer and storage without the need for human-to-human or human-to-computer interaction.<sup>8</sup> The collection of cloud-based tools is known as the ‘Internet of things’ (IoT), and they benefit a

laboratory by connecting multiple elements of the laboratory (such as manuscripts and protocols), to devices and monitoring supplies and equipment using a “smart” shelf. These smart shelves can help labs to automate their inventory control of reagents and working standards, sample use-by dates and maximum hold times, waste identification and disposal protocols.<sup>9</sup> In a survey conducted by Environmental Business International (EBI), it was revealed that 54% of environmental companies are likely to invest in the IoT in the 2020s, with 82% of surveyed companies claiming that IoT will be influential to the evolution of the environmental industry in the 2020s.<sup>10</sup>

Cloud computing usually facilitates three types of services:

1. **Software-as-a-service (SaaS):** Which provides software and applications on a pay-as-you-go basis<sup>11,12</sup>
2. **Platform-as-a-service (PaaS):** Which provides the tools necessary to design bespoke apps within the cloud infrastructure<sup>12</sup>
3. **Infrastructure-as-a-service (IaaS):** Which allows the user to leverage the power of high computing through the cloud<sup>12,13</sup>

A centralized cloud platform provides a laboratory-specific open platform that facilitates remote communications and dispersed operations. In multi-laboratory companies, the cloud merges diverse workflows of multiple laboratories into one single product. In larger environmental companies, it encourages collaboration whilst discouraging the generation of data silos – an insular collection of data that is stored and managed for a particular reason. Using cloud computing, large quantities of legacy data can be rapidly uploaded, enabling *all* laboratories to have *total* access to past and present data, thus removing the need for data silos. Using the cloud, laboratories across all industries have been able to store and retrieve data and standard operating protocols (SOPs) – which has increased standardization, saved time on data analysis and allowed an unalterable audit trail that is critical for regulatory compliance.<sup>14</sup>

Whilst the mismanagement of cloud services in the past led to concerns regarding security, IT services today use world-class technologies to protect SaaS applications. These can be outsourced to experienced providers that are certified data security specialists, which is an advantage for smaller companies that lack IT expertise. The cloud is more secure than non-cloud systems, as security updates are applied faster and more efficiently through automatic patch management. A global threat intelligence report revealed that 76% of exploited vulnerabilities were two years or older, which means that these companies are not updating security features on a regular basis.<sup>15</sup>

Much like automation, personnel can face challenges with the introduction and implementation of new systems. However, these systems are designed with user-friendly interfaces and platform design, whilst maintaining similarities with pre-cloud protocols. Other benefits of adopting a centralized cloud-based system include:

- **A centralized task force:** If the cloud system is run in-house, independent staff in each separate geographical laboratory/data storage location can be merged into one team to reduce IT spending in global companies.
- **Better accessibility and traceability of data:** Unaltered data is essential to regulatory compliance.
- **Access and storage of large data sets:** The physical storage of large amounts of data can be expensive. The cloud offers companies a large virtual data repository.
- **On-demand and scalable resources:** Laboratories can purchase additional resources when needed, this can include end-user licenses, additional storage and features for applications.
- **Fast implementation:** Installation of the cloud takes less time than on-site applications.<sup>16</sup>



### Artificial intelligence (AI) and machine learning (ML) in the lab

AI refers to the ability of a computer program to learn and think. In laboratories around the world, AI is being paired with robotic and automated technologies to expand the scope of science by harnessing ML and hypothesis generation to improve experimental design and data analysis.<sup>17</sup>

In the US, between 2016 and 2018, there was a significant decrease in laboratory technicians – a statistic that is reflected

in the environmental testing industry. However, automation, AI and ML can overcome this by taking over parts of the workflow. The integration of AI into these companies is facilitated by an increase in the employment of data and computer scientists.<sup>18,19</sup>

AI in environmental testing laboratories may introduce some challenges in the workplace. Similar to automation and the cloud, there may be substantial upfront costs and training may be required for staff. Additionally, data silos can limit the abilities of AI systems. Data silo examples include personal or shared excel spreadsheets, email as a per-experiment communication method and file-based systems –they can be difficult for audit trails and collaborations due to the lack of traceability.<sup>20</sup> Data silos can be removed if a centralized data storage system is created and combined with a management system.<sup>21</sup> Another limitation is the ethical considerations; the UK's science academy raised the concern that ML will only benefit a select few, and that to make all advantages inclusive, ML required supervision from scientists.<sup>22,23</sup> Another ethical concern, is that AI-enabled systems will replace workers across the industry, however, this may mean that companies will be free to put their human resources into higher-value tasks – for industries experiencing a decrease in skilled workers this may be a positive.<sup>24</sup>

AI and ML are an emerging interest in environmental laboratory investment for the 2020's, with 56% of companies planning to invest in AI and 86% in ML<sup>10</sup> – this is mainly due to the advantages they present, and the implementation success stories. When programmed correctly, AI produces fewer errors and biases than humans. This has resulted in successful implementation into environmental testing protocols; AI has been used in mineralogical composition prediction, which, combined with simple infrared spectrophotometry testing for chemical and physical properties, can reduce the testing to a fraction of the cost.<sup>25</sup>



The British Antarctic Survey Artificial Intelligence Lab (BAS AI Lab) have already adopted various ML techniques to interrogate data collected from environmental science.<sup>26</sup> In 2020, PerkinElmer released two free-access online COVID-19 data dashboards, which will help the research community to accelerate COVID-19 antivirals and vaccine discovery. These dashboards use an analytics platform with AI functionality to help search, aggregate and visualize complex scientific data.<sup>27</sup>

## Software

Environmental testing laboratories assess a wide variety of samples, and the sample quantity is often large. ISO/IEC 17025:2017 highlights the general requirements for the competence of testing and calibration laboratories.<sup>27</sup> This accreditation is used by laboratories to show that they operate a quality management system and that they are technically competent to do the work that they do. Achieving and maintaining compliance is time-consuming, expensive and complex, therefore, laboratories often use software solutions such as laboratory information management systems (LIMS) and scientific data management systems (SDMS).

A survey conducted by EBI, stated that 95% of environmental companies plan to invest in information systems and software in the 2020s, and 94% of these companies believe that this technology will be influential in the evolution of the environmental industry.<sup>10</sup> The LIMS market is expected to grow by \$705.85 million between 2020 and 2024, owing to the increasing demand for bio-banking and the emergence of SaaS-based LIMS (with PerkinElmer Inc. being one of the major market participants).<sup>28</sup> The SDMS market is also expected to grow between 2020 and 2027, as cloud-based informatics technologies create new opportunities in the market.<sup>29</sup> An anticipated trend in LIMS is the development of greater mobility and mobile LIMS class systems. These applications will enable research to be conducted in the field and the laboratory without a computer. Augmented and mixed reality are innovative solutions that are becoming integrated with LIMS software – allowing scientists to see SOPs and record observations.<sup>30</sup>

Introducing new software into the laboratory can make integration with legacy or proprietary LIMS difficult. Additionally, instruments and equipment might not be compatible with the new software. These issues coupled with a high initial investment and the requirement for periodic software updates can cause delays in laboratory productivity and increase the time and monetary cost of training laboratory members. However, software is typically designed to make human life easier; LIMS and SDMS create less administrative work, allowing scientists to concentrate on more important tasks such as data analysis. The use of LIMS and SDMS can enable compliance with regulations.



## Accreditation for labs

Laboratories secure trust through accreditation, as it ensures that methods comply with certain minimum performance criteria. The location of the laboratory determines which accreditation board they must comply with. In 1995, the UK's national accreditation body (UKAS) was appointed by the government to assess the testing competency, impartiality and the independence of laboratories. In Europe, the European Commission in Regulation (EC) formally appointed the European co-operation for Accreditation (EA),<sup>31</sup> whilst in America, environmental testing laboratories are accredited by the National Environmental Laboratory Accreditation Program (NELAP).<sup>32</sup> These accreditation bodies use established standards to test the laboratories with, such as ISO 17025/ ISO 15189.<sup>33</sup>

Accreditation provides many benefits for an environmental testing laboratory, including an increase in a customers' confidence and consideration for analytical testing services as well as national and international recognition of technical competence. In addition to ensuring compliance with regulatory testing methods, accreditation facilitates standardization across the field.

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