Minerals Research Institute of Western Australia

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Wetland in a Box (EnPhytoBox®) – A smart water treatment system to support the decarbonisation of water in mining

Results of research carried out as MRIWA Project M10447

at Syrinx Environmental Pty Ltd

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Executive Summary

Syrinx Environmental Pty Ltd (Syrinx) developed the EnPhytoBox® ('wetland-in-a-box'), a nature-based decentralised technology for treating at source polluted water and wastewater for beneficial reuse. The EnPhytoBox is a modular and remotely deployable mobile unit that uses green chemistry and phytoremediation to treat various mining, industrial and contaminated wastewater streams. The technology is net zero for both waste and emissions and generates reusable products, such as water and biomass, utilising circular economy principles.

Prior to commencement of this project, Syrinx had developed a working prototype of the EnPhytoBox® installed at a landfill leachate site in Tasmania. The prototype had fitted sensors to monitor water quality, levels and flows. However, the issue remained as to how to extract, analyse and visualise the data from the array of sensors within the system. In addition, the ability to control the unit remotely remained largely unsolved.

In March 2022, the Minerals Research Institute of Western Australia (MRIWA) awarded a grant via MRIWA project M10447, to support Syrinx in the development of an Industrial Internet of Things (IIoT) system for the EnPhytoBox®. Using a suite of smart sensors and controls, together with a data gateway platform via the IIoT, this key capability was intended to connect the system sensors from the local network to the Syrinx network (via the cloud) for remote monitoring and operation. Development of this system was intended to enable deployment of the EnPhytoBox® in remote locations, including mine tailings storage facilities.

The aim of the project was to develop an IIoT system for the EnPhytoBox® that would move the Technology Readiness Level (TRL) from a 7 (System prototype demonstration in operational environment) to a 9 (Actual system proven in operational environment). This has been achieved within the project, although it is worth noting that the project methodology was adapted during the project to capitalise on technological advancements and adapt to research limitations.

As a result of this project, Syrinx now has a fully tested and deployable IIoT system that can remotely monitor and operate the EnPhytoBox® on remote sites. This system has been fully designed and tested in situ, on the prototype. It comprises a microcomputer on the EnPhytoBox®, with a Smart gateway and, which uploads data to a server in real-time. It also contains a PLC (programmable logic controller), which was originally used as the main computational unit but was demoted to manage critical operations at the device level, due to its inflexibility for handling water quality and other information sensor data. The IIoT system developed in this project, enables remote control of the EnPhytoBox® and visualisation of the data in near real time. It is now possible to check and adjust basic water quality parameters and flows, activate recirculation, reuse, shutdown, as well as activate the harvester and adjust associated harvester frequencies, through the direct IIoT smart gateway solution, used to connect the system sensors from the local network to the Syrinx network.

As a result of this project, Syrinx is now preparing to deploy an EnPhytoBox® in France as part of a global mining organisations' project for end of mine restoration.

Acknowledgements

Syrinx Environmental Pty Ltd would like to acknowledge the financial support provided by MRIWA and thank them for their assistance throughout this project. A special mention is made to Nicole Roocke (MRIWA Chief Executive Officer) and Erin Grero (MRIWA Research Portfolio Manager) for their encouragement, support and advice throughout the project.

Syrinx Environmental Pty Ltd would also like to acknowledge the time and effort provided by Rachel Cardell-Oliver (Associate Professor at the University of Western Australia – UWA) and Benjamin Longbottom (Student at UWA) throughout this project.

1. Introduction

This research project was developed as a result of Syrinx taking part in the CSIRO/MRIWA METS Innovate to Grow program in 2021 to explore development opportunities for its “wetland-in-a-box” or EnPhytoBox®. The EnPhytoBox® uses green chemistry and phytoremediation processes, now with integrated Industrial Internet of Things (IIoT) technologies, with the ability to treat various mining, industrial and contaminated wastewater streams.

The EnPhytoBox® is a net zero innovation, designed to reduce waste and greenhouse gas emissions by offering an alternative water treatment method to current energy intensive methods. It generates reusable products, such as water and biomass that can support the circular economy and support adjacent or proximate industries. For example, the technology can process wastewater from mining for use in regional industries i.e. agricultural irrigation. A key opportunity identified for the EnPhytoBox® is the ability for remote, automated monitoring and operation, to support its capacity for deployment in remote locations.

This project focused on creating an Industrial Internet of Things (IIoT) system that would enable the EnPhytoBox® to be remotely controlled. The IIoT system set out to incorporate a common platform, or interface, for the remote extraction and integration of data from various sensors within the EnPhytoBox® prototype. The purpose of this IIoT system was to enable efficient data-driven decisions, through the extraction, analysis, monitoring, controlling and reporting of the EnPhytoBox® data, in near real-time. If successful, the outcomes of this project would allow Syrinx to deploy its EnPhytoBox® to treat contaminated water in any region, no matter how isolated.

1.1. Industry challenge

Water scarcity is a global issue for the mining sector, with responsible water management a particular challenge for regional and remote sites which face increasing competition for remote and alternative water sources. Accessing these water sources often results in high energy, carbon and financial costs, due to pumping distances and a need for additional infrastructure. In Australia, there is also a legacy of contaminated water in tailings dams and mine voids. This combined with the declining access to water in the mining regions can lead to potential conflicts with surrounding communities and represents a major challenge for sustainable mine closure.

Adding to the complexity that mining companies face when accessing water sources, most currently available water treatment technologies are energy and chemically intensive, generate waste streams, ‘overtreat’ and are not suited to remote sites. Water quality testing for reuse often takes time, is labour intensive and lab-dependent for identification of contaminants. Scalable, net zero technologies with real-time monitoring and data-driven remote operation capabilities are not currently available and yet will be critical to the successful reuse of the mining sectors waste and tailings water.

Approximately 100 Giga Litres of tailings water is created in Australia by mining companies every year[1]. If reprocessed effectively, this could provide a suitable water source to support mine rehabilitation and neighbouring agriculture. It is essential that treatment and reuse of mine water is effectively incorporated into strategic decision making for mining companies.

1.2. Objectives of the research

Syrinx’s EnPhytoBox® is a sustainable, net zero alternative to standard water treatment technologies, customisable to specific settings and wastewater chemistry. It is a biological system that uses biosorbent media and plants. Once the biological media reaches the end of its useful life within the EnPhytoBox®, it can be used to support mine rehabilitation, phytostabilisation of solid tailing wastes, and support local business as agricultural soil improvers, compost etc.

Prior to project commencement, Syrinx had a full-sized prototype of the EnPhytoBox® deployed in Tasmania, treating a complex landfill leachate. The EnPhytoBox® was fitted with sensors to monitor water levels, flows and quality, but these required a manual monitoring onsite process by Syrinx personnel, which was labour intensive and time consuming. Syrinx sought to develop the technology further to achieve real-time data extraction, analysis and visualisation to automate remote operation, allowing for deployment where the need of wastewater treatment is greatest, without the need for onsite operations personnel.

The objective of this research project was therefore to develop an IIoT system capable of extracting, analysing, monitoring, controlling and visually reporting on the system data, in real-time. This required testing and integration of various sensor signal types and output capabilities to produce a system that automates required operations remotely, to maximise efficiency.

If successful, this project would enable Syrinx to demonstrate the EnPhytoBox® capabilities to the mining industry and provide evidence of its suitability to remote site application such as tailings dams. The automation and remote operations would allow the EnPhytoBox® to be controlled from Perth with minimal site intervention.

2. Methodology and findings

The project methodology was divided and managed in five distinct parts:

- Milestone 1: Contract execution and personnel
- Milestone 2: Sensor performance and optimisation
- Milestone 3: Define and complete data processing for heterogeneous sensor network
- Milestone 4: Data fusion and analysis
- Milestone 5: Decision making, visualisation and data security

2.1. Milestone 1: Contract execution and personnel

Alongside contract execution with MRIWA, a University of Western Australia (UWA) student was selected to participate in project delivery through the UWA CEED program (Co-operative Education for Enterprise Development). UWA Associate Professor Rachel Cardell-Oliver supported the project as a co-mentor for the student together with Syrinx personnel.

2.2. Milestone 2: Sensor performance and optimisation

During completion of Milestone 2, the suite of currently used sensor technologies in the prototype EnPhytoBox® were identified and profiled according to their technical data accessibility and availability for research purposes or commercial use. The sensor types were grouped by four specific technologies: control system sensors, control system actuators, the AquaTroll sensing equipment (designed for use in water quality management) and cameras. An additional sensor suite, (lab-on-a-chip) developed by the University of Tasmania was installed within the prototype but did not directly interact with the control system.

Once the technologies were identified and catalogued, a design for the IIoT System to service the EnPhytoBox® was developed. Following a literature review and environmental scan, a state-of-the-art IIoT system architecture from Jasmin et al., (2016) was adopted for the design to decompose the system into components. The proposed architecture design can be seen in Figure 1.

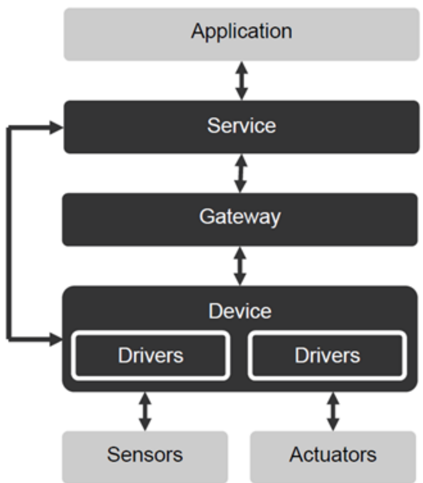

Figure 1. *EnPhytoBox® IoT System Architecture*

The dark shaded components in Figure 1 identify prescribed requirements for the system based on both Syrinx and state-of-the-art requirements, that were addressed as part of the CEED project. The light grey components were undertaken by Syrinx separately. It was important to ensure careful consideration was given to ensure the state-of-the-art requirements did not contradict or lead to over design of Syrinx's requirements, particularly when considering the EnPhytoBox®, has low computational and power needs, unlike conventional IIoT devices.

The device's sensors and actuators are operated using an industrial PC (off-the-shelf, globally available), and can be adjusted on-site as needed. The gateway allows the IPC to connect to the Syrinx server via the cloud, to enable data transmission. The service level enables data visualisation, analysis and remote control and operational adjustments back through the Cloud and gateway.

2.3. Milestone 3: Define and complete data processing for heterogeneous sensor network

Milestone 3 evaluated the sensors within the prototype to ensure suitability for future applications. During this phase, detailed operational and water quality monitoring information for each sensor was captured. This includes data on flow volumes, recirculation times, harvest cycles completed, pump runs, power used, alarms and water quality parameters. From this information the specific role and functionality of each sensor in automation and data collection was evaluated. The sensors were also evaluated to ensure suitability for remote deployment, including monitoring for any gaps in performance to ensure remote operation and data collection capacities were safeguarded.

The water quality sensors were also calibrated and tested against laboratory analysis of collected water samples. This method was used to determine the reliability of the collected data and to assess the potential for sensors to replace mechanical sampling methods. It was found that the AquaTroll sensors used in the EnPhytoBox® performed well, with the average data correlation within 10% of the lab data for Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), pH and temperature (see graphs in Figure 2 and Figure 3 for some examples of the comparative data). Sensor values for TDS were occasionally more conservative (higher) than the lab data, and more reduced for redox measurements. The sensors are therefore likely to be far more accurate for redox given these are likely to be disturbed by oxygen mixing in the sampling process.

In summary, the AquaTroll probe was considered a suitable sensor for the EnPhytoBox®, where the data is a trustworthy substitute for lab testing.

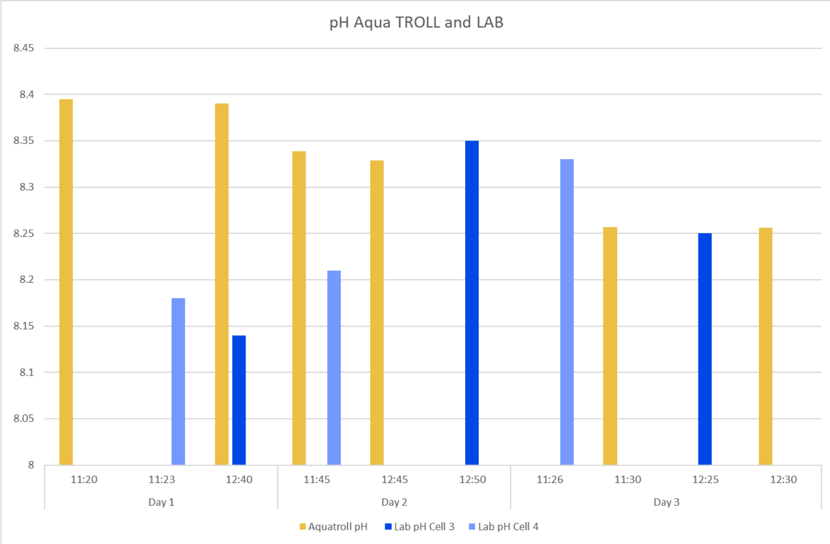

Figure 2. *pH levels of the AquaTroll Sensor vs Laboratory Testing*

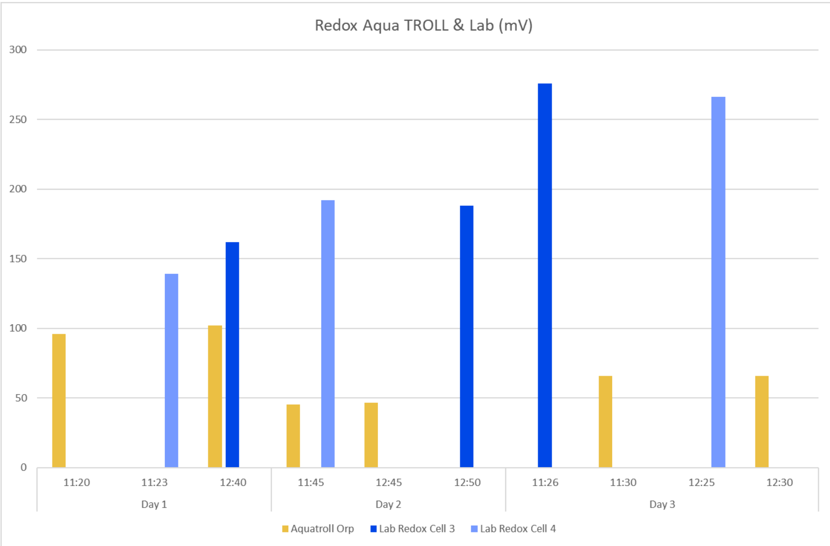

Figure 3. *Redox levels of the AquaTroll Sensor vs Laboratory Testing*

2.4. Milestone 4: Data fusion and analysis

This milestone focussed on building the hardware components for data fusion at the local device level (within the EnPhytoBox®), as the priority stage, without a middleware layer (i.e. direct to Cloud). A performance specification for the full control system was developed to enable selection of communication technologies for different settings. The built components were designed and programmed by Syrinx and a third-party provider - Kapp Engineering, with the software design undertaken by UWA.

The initial approach was to integrate operational (e.g. actuators and alarms) and informational (water quality) sensors within a Programmable Logic Controller (PLC) with a microprocessor programmed to enable two-way programming via a wireless gateway and virtual protocol network (i.e. direct to Cloud without a gateway integration layer). This was successfully built and tested; this system enabled remote monitoring and control of the

EnPhytoBox and visualisation of data in real time, including checking the basic water quality parameters, adjusting flows, activating recirculation, activating reuse or shutdown, activating the harvester and adjusting harvester frequencies.

The integration of the data into one platform was created with a computer model, or Digital Twin, developed for visual representation of the EnPhytoBox® system. The Digital Twin shows the near real-time function of the sensors and can be used to change settings remotely, as required. A screenshot of the Digital Twin can be seen in Figure 4, below.

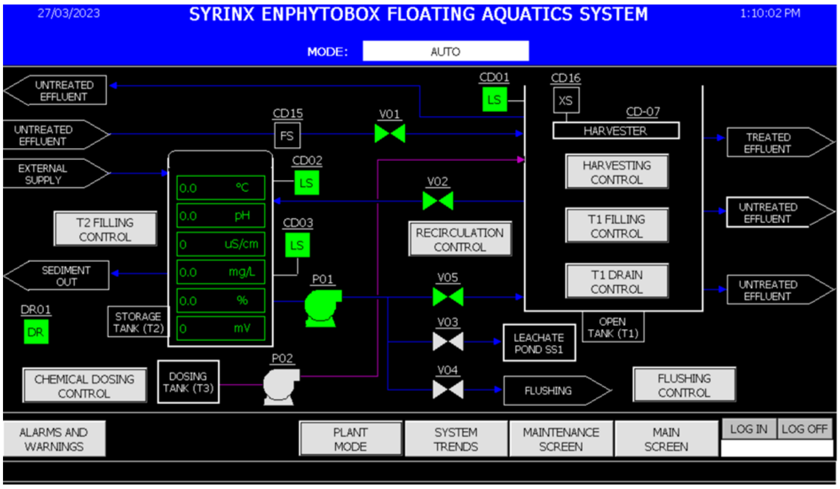

Figure 4. *Screenshot of real-time data that enables control remotely*

During completion of Milestone 4 the water quality and operational sensor data was integrated into one platform, for automating the operation of the EnPhytoBox®. However, there were issues with integrating the water quality sensor within this PLC configuration, which included the need to reprogram the PLC when the sensor needed to be unplugged for servicing for instance, as well as issues in being able to position the sensor optimally within the constraints of a wired in network. To overcome these challenges, it was decided to remove the information sensors (water quality, plant biomass) from the PLC and retain the PLC only for control of operational tasks, which would allow the PLC's to be designed as a standardised and replicable unit across all EnPhytoBoxes anywhere.

To achieve this design requirement, the following design improvements were adopted:

1. Retain the PLC only for automation of *operations* at the device level. This ensures that the essential functions of the EnPhytoBox can run as long as there is a power supply.
2. Incorporation of edge computing for managing the *informational* data at the device level in terms of analysis and critical instructions. Edge computing enables the processing, analysing and storing of data, close to where it is generated, avoiding issues associated with network interruptions in remote sites, and to keep the cost of exporting and manipulating data in the IIoT cloud network to a minimum. The edge computing enables all water quality sensors (which may vary unit to unit depending on the water chemistry and regulations) and variable water quality limits to be easily programmed and adjusted, and this aggregated data to be used at the device level to manage any instructional tasks (for example, if a parameter exceeds allowable reuse criteria the computer can instruct the EnPhytoBox to recirculate and prevent sending water to reuse). The advantages of edge computing include:
    - enabling rapid, near real-time analysis and response of a system,

- avoidance of issues associated with network interruptions in remote sites, and
- to keep the time and cost of exporting and manipulating huge amounts of data in the IoT Cloud network, to a minimum.

3. Use of a smart gateway to integrate water quality sensor data and operational data in a common platform for export; only the necessary data is transferred from the edge devices to the cloud. Smart IoT gateways act as a bridge between data collection (from the sensors and PLC) and analysis (by sending data through the network to a centralised location for storage and analysis). The IoT gateway exists in the middle, connecting the two together enabling two-way commands.

Each of these technologies have been adopted for the next generation of IoT enabled EnPhytoBoxes, since they deal with the issues of mass data transmission through the Cloud and the risk of relying on the network for critical operations.

2.5. Milestone 5: Decision making, visualisation and data security

During this project, the data visualisation was programmed within the Phoenix microcomputer component of the PLC. Visualisation via the HMI is accessed via VPN using the sited based 3G Modem. The problem with disaggregating the water quality sensors form the operational sensors meant that WQ sensor data is viewed on a separate dashboard (HydroVu), which while adequate, is not ideal. Hence, we are progressing a new software platform to integrate the various data types in a visual platform. Data is transmitted via smart gateway to the Cloud in real time (which may be combined with non-real time data stored in the edge computer to establish trends), and pulled into Syrinx's software system (GAMEs™), a complex software tool Syrinx has been developing for a different application outside of this MRIWA sponsored project. Syrinx has previously received a Federal Government Grant to develop this platform. GAMES™ has been designed to accept data in various forms, where it can assess and analyse data for the creation of graphical and visual spatial outputs and reports. Since GAMES™ is wholly Syrinx owned technology, Syrinx has decided to utilise this platform to process the EnPhytoBox® data, for rapid assessment, correlation of data and to make remote adjustments across multiple EnPhytoBoxes. Additionally, this system provides for better security, since the data is controlled throughout by Syrinx and not a third party.

Syrinx has also progressed a partnership with Krucial to connect the edge computer to the Cloud using their use smart K-Connect gateway, which uses Long Range Wide Area Network (LoRaWAN) communications protocol. This integrated technology enables EnPhytoBox applications in remote sites where communication reliability is a key issue, and also maintains security of data via this decentralised network. It uses a Low Power, Wide Area (LPWA) networking protocol designed to connect devices to the internet in regional, national or global networks and is designed to connect users or businesses to carry more data using less power[2]. The Krucial communications system has already been accredited in terms of cybersecurity standards, which reduces the risk of other providers that do not use decentralised communications technology.

Collectively this technology mix provides a more standardized, simpler, robust, low energy and more flexible system for remote control of the EnPhytoBox®, where an optimal mix of Cellular WIFI and Satellite communication can be used to ensure seamless data transmission as needed. This enables use in remote operations such as mining, without the high cost associated with solely satellite connectivity.

3. Discussion

Overall, this project has delivered a system design and specification framework for the EnPhytoBox, and a new IIoT system design that can be deployed across any application. This IIoT system is currently being developed for two commercial/trial applications, planned for mid-2024 in the Pilbara and France (mine closure site).

The IIoT system comprises the following components:

1. An Industrial PC for automation of operational controls at the device level
2. Sensors and actuators that enable automation and remote monitoring and control
3. An edge computer for integration of water quality sensor data to enable multiparameter data analysis and instructions to be sent back to the device level, and aggregated data to be sent to the Smart gateway.
4. A smart gateway (Krucial CONNECT) for integration of data from the IPC, edge PC (and any other site sensors such as weather stations, soil sensor data etc) and sending and receiving data through the Cloud.
5. A software platform (Syrinx's software tool - GAMES™), connected via an Application Programming Interface (API) to enable analysis and visualization, and remote changes to each EnPhytoBox™ via the gateway.

Through this IIoT system remote monitoring and control can be done from anywhere in the world. The integrated software platform when completed, will also enable analysis of multiple EnPhytoBox® units and potential for integrating AI to automate remote instructions.

Figure 5 shows a visual interpretation of how the IIoT design links the various hardware and software layers to enable seamless, near real-time remote EnPhytoBox® control.

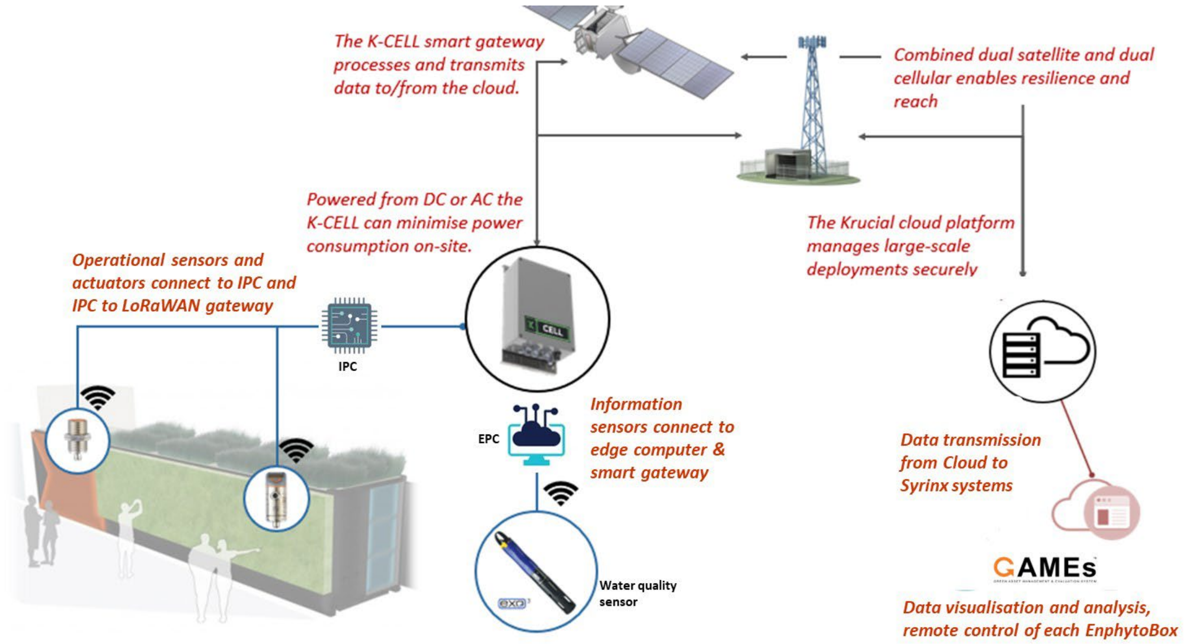

Figure 5. *EnPhytoBox IIoT layout*

It should be noted that throughout the development of the EnPhytoBox®, low energy demand has been an important design priority. The predominantly passive water treatment processes are coupled with a single low energy variable pump which can be used for more than one control function. Maintaining a low energy use case has been paramount throughout this research, to ensure the various components of the EnPhytoBox® can be solar powered with a battery backup unit.

As with many research plans, this project did not completely follow the original proposal. A major pivot occurred to maximise the efficiency for collection of the data to a single point for analysis and adjustment, using the K-CELL smart box and embedded computer, rather than a PLC. This occurred following the build and programming of the PLC which identified several issues (outlined above) affecting its suitability for remote deployment. This development did however present the opportunity for analysis of sensor data through the Long-Range Wide Area Network (LoRaWAN) communications protocol, which has been relatively recently developed and commercialised. It allows near real-time analysis at the device level, and aggregation of data for transmitting to the Cloud for analysis and visualisation using Syrinx's GAMES™ software. The use of edge computing and LoRaWAN addresses the complex data types and sizes, reduces power demands, reduces risks associated with network reliability, and meets data security standards.

The University of Western Australia (UWA) completed the design of the system architecture and communications planner. The detailed algorithms and programming needed to collate various water quality parameters to instruct the box to respond in different ways, was strategically taken out of the original project plan, in preference of receiving a detailed design specification from UWA.

Overall, whilst Syrinx needed to adjust its methods and pivot its thinking to achieve the desired results, it is satisfied with the outcomes of this project and will be incorporating the new design into its next phase prototype, to be deployed in the Pilbara, Western Australia in 2024, and potentially at a mine closure site in France.

4. Conclusions and recommendations for further work

This project has delivered an IIoT system design enabling Syrinx to deploy its EnPhytoBox® to remote regions for remote control.

Syrinx is currently building its next EnPhytoBox® for deployment in a local economy seed orchard project for an Indigenous community the Pilbara, WA, in 2024. This will incorporate the IIoT system designed in this project. Whilst much of the IIoT components were tested through Syrinx's prototype in Tasmania, the new EnPhytoBox® will be the first opportunity to test the new architecture in a remote setting. It is expected that a refining process will be required to "fine tune" the EnPhytoBox® to its location and associated environmental requirements. In addition, further development of the system may incorporate Machine Learning protocols in the future, in order for the system to refine its operation automatically. As the EnPhytoBox® will be tested in a remote community in the Pilbara, all refinements necessary for deployment in a remote mining facility, will already have been completed, making it mining sector ready.

Further work will be required to assess the different water contaminants, where the EnPhytoBox® will likely require adjustment of its phytoremediation media usage, sensors and IIoT configuration, dependant on the major contaminant and levels of impurity. These adjustments will depend on the resulting required level of remediation required and the subsequent use of water from the reprocessing. For example, if the water from the EnPhytoBox® is to be used back into a mining or processing facility, it does not necessarily have to be at the same level of remediation as water for irrigation of food crops.

It is likely that the EnPhytoBox® can be used in simple circuits to bring contaminated water to a level where it can be used as potable water. This will require further work and the design adjusted so that there is one EnPhytoBox® "Master" with the IIoT and the other "Slaves" can be run from that (rather than having every EnPhytoBox® running independently with its own IIoT system). Each unit will be configured for particular contaminants, so that all contamination materials are removed to accepted quality levels.

The EnPhytoBox® can treat between 20Kl and 100 Kl of contaminated wastewater a day. It can be used on its own or can be used as part of a larger suite of modular style solutions. More and more companies are developing portable solutions (for example mobile green power generation units) which can work together with the EnPhytoBox® to provide power and water solutions in remote regions. Syrinx is always looking to develop its networks further to harness these technological synergies.

Additionally, the IIoT system has become a potential product/service that can be marketed in its own right. This system could potentially be used to automate other remotely operated technologies, where data is available but requires collection, analysis and processing for decision making purposes.

5. Key Learnings

This project did not proceed entirely as per the plan as there was a high research and development component. There were pivots along the way, caused by a number of factors.

Technology is rapidly advancing. The IIoT system was able to incorporate protocols such as edge computing and LoRaWAN as these technologies become more accessible for applications such as the EnPhytoBox®.

The technology that was originally planned for this project, specifically the PLC combined with direct wireless connection to the service layer, was inflexible, suffered from network unreliability, and limitations of integrating water quality data into the ladder logic framework of the PLC. It was therefore decided that the PLC would only be used for critical operational automation functions at the device level moving forward.

The concept of an automated and remote controlled “wetlands in a box” was originally pitched to industry prior to the Innovate to Grow programme. At the time this generated interest but limited understanding. Now, with a shift towards circular economy solutions for low carbon and energy solutions to treat contaminated water in remote regions, Syrinx is finding a raised level of awareness and associated interest in the technology, together with other aspects of its core business - Nature based Solutions. Syrinx has been approached by a Global Organisation that wishes to deploy the EnPhytoBox® overseas, to assist with the treatment of contaminated water as part of land rehabilitation of an end-of-life mine site. It is expected that this will be deployed mid-2024 and is very important as it may lead to wider deployment of the EnPhytoBox® globally. Additionally, Syrinx is having discussions with a mining company for deployment of the EnPhytoBox® within their site.

Syrinx was recently selected in the top 10 global sustainable innovations for the EnPhytoBox® in the AcceliCITY program, which is considered among the top 5 government acceleration programs worldwide. It was also selected as the winner of the QBE AgTech stream.

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