

3D-AERODRY® - LOW ENERGY VERTICAL BIOSOLIDS DRYING

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KEYWORDS

Biosolids Management, 3D printing, Low-energy, Vertical Drying Technology, Energy Management, Circular Economy

INTRODUCTION

Biosolids management represents one of the City of Gold Coast (City)'s largest operational costs. The key factor incurring these high costs is the high moisture content of the biosolids (~12-20% dry solids content) after the dewatering step. The largest sewage treatment plant (STP) operated by the City – Coombabah STP has drying beds in place to further reduce the moisture content on-site prior to transport. However, the drying beds are susceptible to the weather conditions, and as such are subject to low drying efficiencies especially during wet weather. Furthermore, the drying beds have a large footprint and take up site space required for future plant expansions and upgrades. In addition to the above, the increasing concern of the presence of emerging contaminants in biosolids, such as Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) and microplastics, may limit its use for land application in the near future.

While thermal treatment including gasification and pyrolysis of biosolids have gained a lot of interest and have demonstrated the potential in remediating these emerging contaminants, these processes have not found widespread application yet. Key bottlenecks include the high cost and energy requirements of the necessary biosolids drying step prior to gasification and pyrolysis. In fact, the energy requirements of thermal biosolids drying processes typically exceed the energy generation potential of gasification and/or pyrolysis resulting in an overall negative process, especially with biosolids with dry solids contents of $\leq 20\text{wt}\%$ after dewatering.

Considering the above challenges, the City has been actively exploring alternate biosolids drying technologies that can reduce the volume of biosolids produced onsite. Key criteria for the City are that the technology has a low footprint, low energy requirements (i.e. does not rely on external heat sources), and a final dry solids content of at least 80%.

YEAR CASE STUDY WAS IMPLEMENTED

2022 to 2026

CASE STUDY SUMMARY

The City of Gold Coast (City) is seeking low-energy solutions to reduce the operational costs and logistical challenges associated with managing biosolids. Traditional thermal drying technologies require significant energy input, creating barriers to cost-effective biosolids management. To address these challenges, the City partnered with IPMF Technologies to trial 3D-AeroDry®, an ambient-temperature vertical drying technology. Following successful small-scale trials conducted in 2022, the project secured an Australian Accelerating Commercialisation grant to construct a demonstration (DEMO) plant at the Coombabah STP to assess the practical feasibility and economic potential of the technology. Constructed in 2024-25, the DEMO plant incorporates a vertical biosolids printing system that maximises surface area exposure of biosolids to air, enabling rapid and energy-efficient drying. Performance assessment showed that the process can achieve up to 85% reduction in biosolids volume at a final dry solids content of 90% in under three days without any external heat energy. Power requirements were found to be less than 50 kWh per tonne of water evaporated, coupled with a significant reduction in required footprint compared to current drying beds. These outcomes highlight the strong potential of the technology to improve the sustainability of biosolids management for the City (and wider Australian water industry).

CASE STUDY DETAIL

Specific issues: As mentioned in the previous section, key issues with biosolids management include the large (and increasing) operational costs and potential regulatory changes prohibiting land application due to the presence of PFAS and microplastics in biosolids. Assessments by the City highlighted the limitations of thermal drying methods (i.e. costly and energy-intensive) and drying beds (i.e. large footprint and poor drying performance). To address these issues and uncertainties, the City has been actively exploring biosolids drying technologies that (1) reduce biosolids volumes produced and management cost at low footprint and low energy demands, (2) provide flexibility to adopt thermal treatment technologies if required due to regulatory change(s), and (3) increase the capacity for temporary onsite storage of biosolids by reducing biosolids volumes.

Approach: In 2022, IPMF pitched the concept of 3D-AeroDry® to the City. The working principal of the process involves depositing biosolids vertically maximising the biosolids surface area exposed to the surrounding air. Consequently, the rate of heat transfer for evaporation is significantly increased, allowing efficient drying at ambient temperatures only using the sensible heat of the surrounding air. In the same year, IPMF conducted small-scale batch pilot trials with a 3D-AeroDry® prototype using biosolids from two of the City's STPs with different origins (dewatered anaerobically digested and waste activated sludge). These trials demonstrated the practical feasibility and potential economic benefits for the City. The City then agreed to partner with IPMF and applied for an Australian government's Accelerating Commercialisation Grant to establish a 3D-AeroDry® DEMO plant at Coombabah STP for a 1-year trial. The grant application was successful and design and construction of the DEMO plant then commenced in late 2023. The DEMO trial aimed to serve as a "proof of concept" to enable the City to assess the economic benefits upon full scale implementation.

Implementation: The 3D-AeroDry® DEMO plant was capable of processing 0.4-1 wet tonnes of biosolids in batch at solids contents of 12-16%. The DEMO plant consisted of five main process components: (1) biosolids conveyer system; (2) biosolids holding tank; (3) 3D printer; (4) drying compartment with 160 vertical sheets in an automated over/under conveyer system and fans; and (5) dried biosolids collection and storage system. Simplified representations of the system and process are illustrated in Figure 1 and Figure 2, respectively.

The biosolids holding tank was filled manually using skid steers prior to each printing event. Once the tank was filled with biosolids, the tank was slightly pressurized using compressed air. Subsequently, a progressive cavity pump pumped the biosolids towards the 3D printer manifold consisting of 8 printer nozzles that printed the biosolids onto the vertical sheets at the desired thickness. In short, a single sheet was lifted from the lower to the upper level of the automated conveyor system. During this upward movement, biosolids were printed onto the vertical sheet at the desired thickness. Once the sheet reached the top, it was transferred horizontally to the rear of the system. At the same time, a separate sheet lowered from the upper to the lower level at the rear end of the conveyer system. The system then proceeded to print the next sheet using the same sequence. This cycle was repeated until all 160 sheets were printed. Following the printing phase, the drying phase commenced by activating the fans. Once the biosolids were dried to the desired final dry solids content, they were collected from the sheets via vibration falling via gravity into the collection chamber fitted with a screw conveyor that conveyed the dried biosolids into a 1-tonne bulk bag for storage.

The DEMO plant was operated under a range of test conditions to evaluate the impact of the (1) airflow, (2) temperature, (3) relative humidity, (4) biosolids loading and (5) sludge origin on the required drying time and final dry solids content. Throughout the trials, dewatered biosolids from a belt press were used with an initial dry solids content ranging between ~12-16%. The trials were conducted in batches over a 12-month period to capture seasonal variation and its impact on system performance. The goal of the above described testing protocol was to define key design parameters (e.g. required air flow, drying kinetics and power/energy demands) to inform overall process design and footprint for scaling up.

In addition to the above, chemical analysis including Total Solids (TS)/Volatile Solids (VS), Heavy Metals, and nutrients (total nitrogen and total phosphorus), was performed to monitor the impact of drying on the biosolids properties. Dust, methane (CH₄) and hydrogen sulfide (H₂S) formation during the drying were monitored through online sensors.

Outcomes and lesson learnt: The construction of the DEMO plant was completed in April 2025. The plant was transported to the Coombabah STP and commissioned in May 2025. Figure 3 shows the location of the DEMO plant at Coombabah STP.

An overview of the key findings and lessons learnt of the trial are summarized below:

System performance

- **Maximum achievable dry solids content and drying kinetics under different seasonal conditions:** The process achieved efficient drying with final biosolids solids content of up to 90% in less than 3 days achieving 85% volume reduction without external heat input. The latter was independent of the prevalent weather conditions under different seasonal conditions, with similar results obtained during the winter period. In fact, it was found that the diurnal patterns of the temperature and relative humidity had a larger effect on the drying kinetics than the maximum temperature during the daytime. It is evident that drying rate is slower during the nighttime when the temperature is lower and relative humidity is higher than during the day. At times, the observed relative humidity was close to 100% resulting in period of zero drying during these times. A typical profile of the biosolids weight loss upon drying is depicted in Figure 4.
- **Impact on logistics biosolids disposal:** By reducing biosolids volumes by 85%, the City could decrease biosolids transport from 2,000 to about 400 truck transport numbers per year, significantly reducing traffic movement, reduced transport carbon emissions and potential savings in biosolids management.
- **Power consumption drying process:** The power requirements of 3D-AeroDry® ranged between 44 to 289 kWh per tonne water evaporated (Figure 5). The power consumption was strongly correlated to (i) the biosolids load with decreasing power consumption during the drying process with increasing biosolid load and (ii) the configuration of the fans. This can be attributed to the higher volume of water being evaporated (as more biosolids or printed into the sheets), despite the air flow rate remaining constant. Furthermore, the power consumption recorded during the trial was highly efficient, particularly when benchmarked against conventional thermal drying methods such as belt dryers or heat pumps (see Figure 6). The figure clearly shows that 3D-AeroDry® requires considerably less energy, highlighting its potential for low-energy biosolids drying solely using the sensible heat of the prevalent atmospheric conditions. Upon optimization of the fan configuration, the power consumption dropped below 50 kWh/tonne water removed, i.e. at least 10 times less energy intensive than thermal drying technologies with further improvement possible. Importantly, this enables an energy-positive biosolids gasification / pyrolysis solution.
- **Impact of biosolids loading on drying kinetics:** Increasing the biosolids loading from 0.5 to 1 tonne did not significantly affect the drying kinetics, with the drying times required to achieve the desired dry solids content of $\geq 80\%$ remaining at 2-3 days.
- **Impact of dry solids content on the collection process:** The biosolids printed onto the vertical sheets were found to be recovered efficiently via vibration in cases where the dry solids content of the biosolids was ≥ 80 wt% (see Figure 7). Collection of dried biosolids via vibration was found to be ineffective when the moisture content was above 25%, resulting in 'rubbery' and 'sticky' biosolids.
- **Overall process mass balance:** The mass balance of each trial run, expressed on a dry solids basis, was around 95-98%. This confirmed that (1) the dried biosolids were efficiently removed from the sheets and (2) minimal biological activity of the biosolids took place during the drying process. The latter was supported by TS and VS analysis. Chemical analysis also confirmed that the metals and nutrients (expressed on a dry mass basis) are within the typical range of biosolids produced by Coombabah STP and compliant with Queensland End of Waste Code for biosolids for beneficial reuse.
- **Generation potential of hazardous gas and chemicals during drying:** No dust, CH₄ and H₂S formation were measured or detected throughout the trial period. The drying process did not worsen or alter the odour profile of biosolids. The dried biosolids product were not odorous. However, during several trial runs a strong smell of ammonia was observed during the printing process. The latter occurred in situations where 'old' biosolids were used in a trial run (i.e. the biosolids were stored in the holding tank for several days prior to a printing event).
- **System footprint:** Based on the results obtained, it was calculated that 3D-AeroDry® reduces the footprint by a factor of 5 (with the potential to achieve over 10 to 15), when compared to the current drying beds at Coombabah STP (Figure 8).

Design and process optimization requirements for next generation 3D-AeroDry®

While the outcomes and lessons learnt of the DEMO trials were excellent (see section above), the DEMO trials also revealed some process limitations of the current 3D-AeroDry® DEMO design that require design modifications / finetuning. These include:

- Inconsistent extrusion of the 3D printer manifold which resulted in uneven biosolids sheet thickness and non-uniform drying.
- Limited access within the drying compartment which limited airflow measurements to 'reachable' areas only. These measurements revealed substantial difference in air velocity. Hence, it was unclear whether stagnant airflow or 'dead zones' were present in the drying chamber. The latter is important as it is well documented that the air velocity has a significant impact on the drying kinetics and performance.
- The 3D printer design of the DEMO plant was limited to processing biosolids with initial dry solids contents of up to 16%. At higher dry solids contents, the biosolids were not printed properly into the sheets.
- Upon drying of the biosolids in the vertical sheets, some biosolids fell out of the sheet and onto the floor of the drying chamber prior to the collection phase. To mitigate this issue during the trials, a portable container was installed at the bottom of drying chamber to collect dried falling out of the vertical sheets upon drying. Importantly, mass balance analysis showed these dried biosolids only accounted for < 2% of the load input (on a dry mass basis). The area beneath drying chamber could also be designed as a continuous collection channel to capture any dried material that falls through.
- Large foreign contaminants (e.g. stones) > 10mm can potentially damaging the pumps and printing nozzle outlets.

Next steps:

The DEMO trials clearly highlighted that 3D-AeroDry® offers promising practical and economic potential. The City is currently working with IPMF Technologies to undertake an economic assessment to evaluate project feasibility upon full-scale implementation at Coombabah STP and the three other STPs operated by the City.

The City and IPMF Technologies are seeking interest and funding from utilities and industry to further develop and scaling-up the technology through the design and built of a 2nd generation 3D-AeroDry® DEMO plant. The focus of the design of the 2nd generation 3D-AeroDry® DEMO plant is to include the lessons learnt and focusses on minimizing (1) process support requirements and oversight, (2) number of mechanical movements, (3) overall maintenance requirements and (4) system tolerance to variability in feed quality (e.g., initial biosolids moisture content) before progressing to (semi)-commercial scale implementation. In the context of variability in initial biosolids moisture content, it is important to highlight that 3D-AeroDry® has the potential to handle thickened biosolids (>4-5%) making it an interesting option for small (regional) STPs with small(er) biosolids volumes avoiding the need for a dewatering step.

Lastly, the City will work with IPMF to seek opportunities for creating value out of the dried biosolids including converting the dried biosolids into (1) energy through gasification, (2) biochar through pyrolysis (noting thermal treatment remediates PFAS and microplastics contamination) and (3) high quality compost/fertiliser.

Figures and Tables



Figure 1: (top) General layout and (bottom) pictures of 3D-AeroDry[®] DEMO plant.

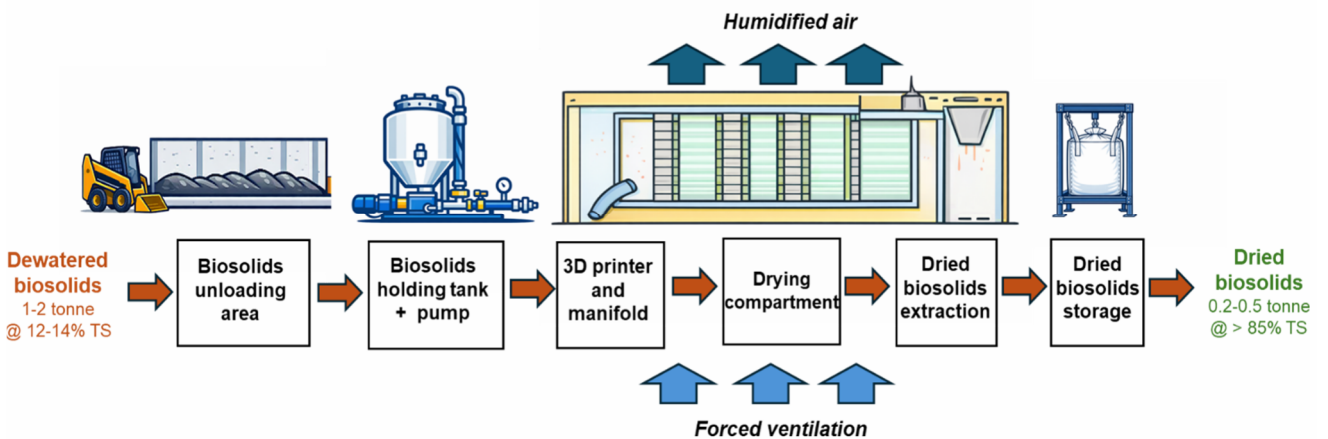


Figure 2: Simplified representation of the general process overview of the 3D-AeroDry[®] DEMO plant.

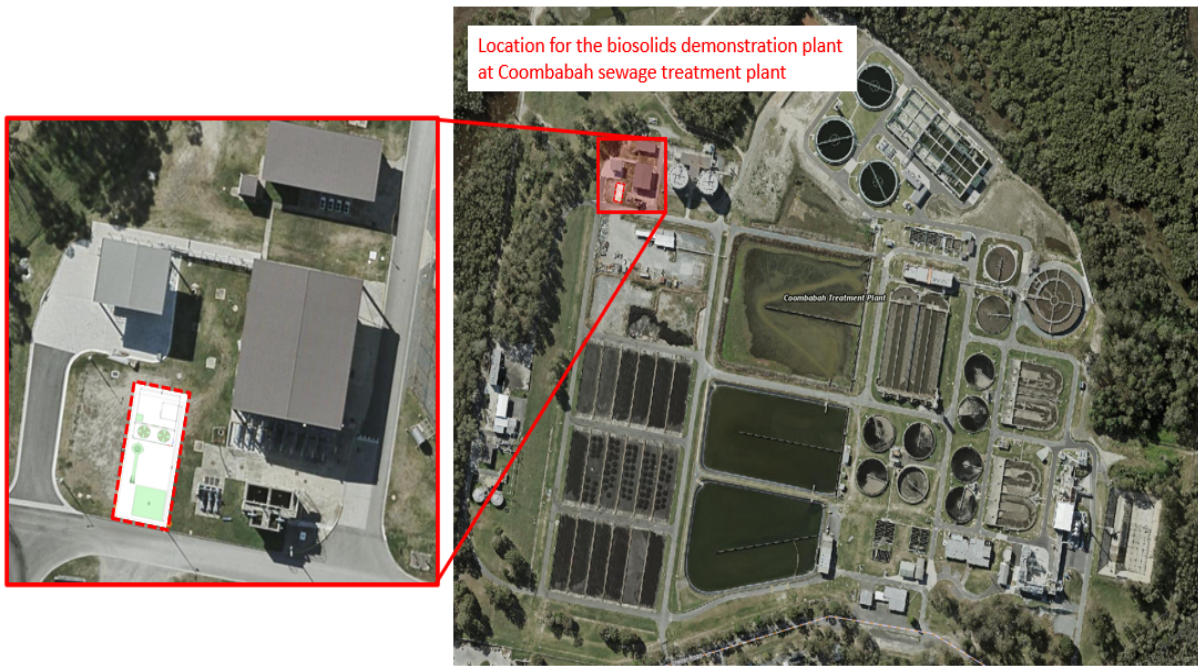


Figure 3: Location of the 3D-AeroDry® DEMO plant at Coombabah STP.

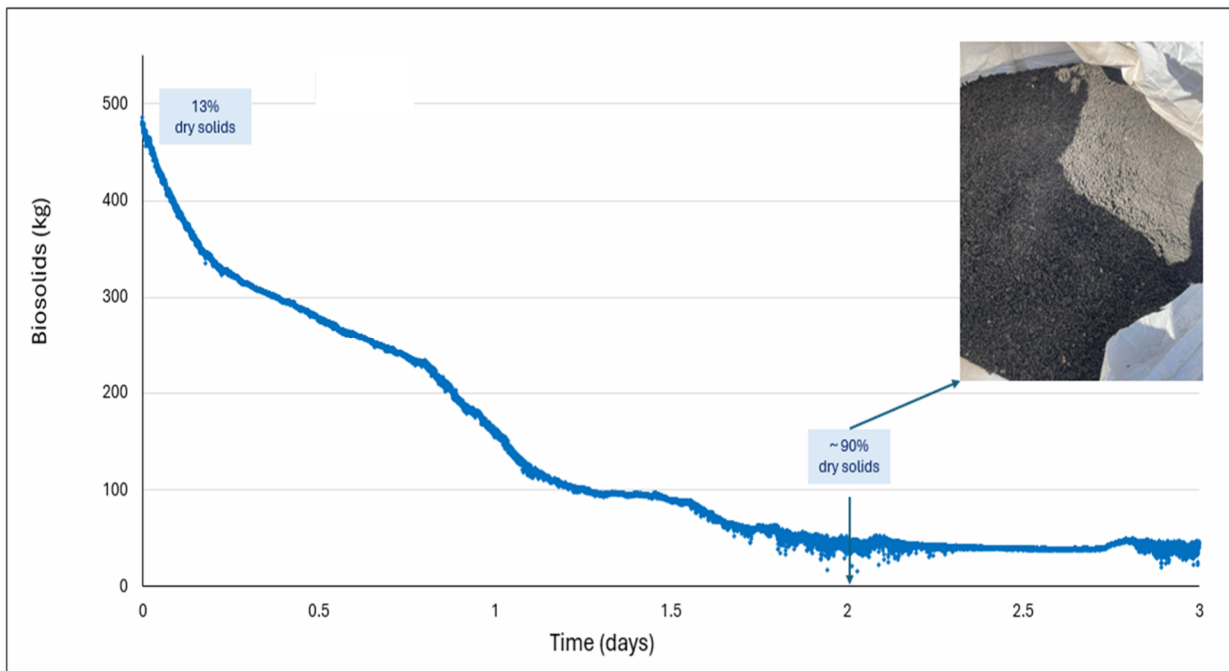


Figure 4: Typical profile of the weight loss upon drying of biosolids (Test 4).

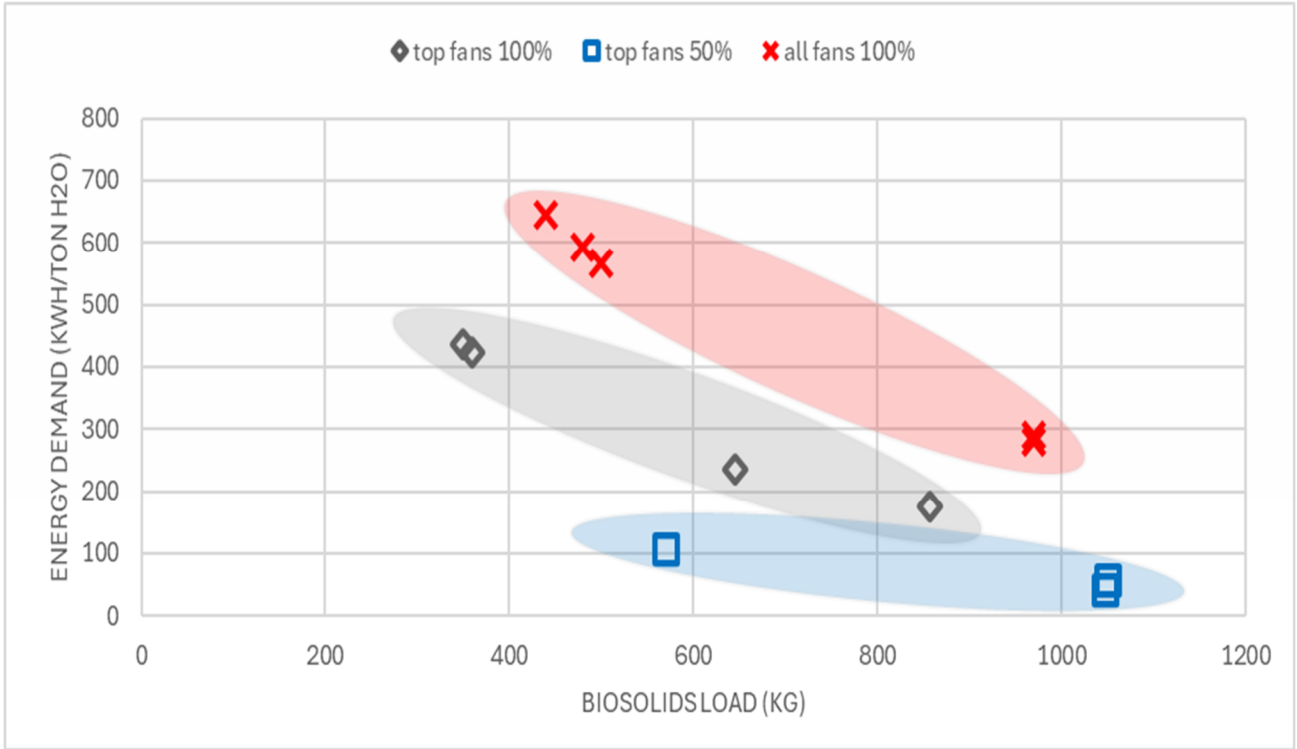


Figure 5: Impact of biosolids load (kg) and air flow configuration (fan location and speed) on the power consumption of 3D-Aero-Dry® (kWh/ton water evaporated).

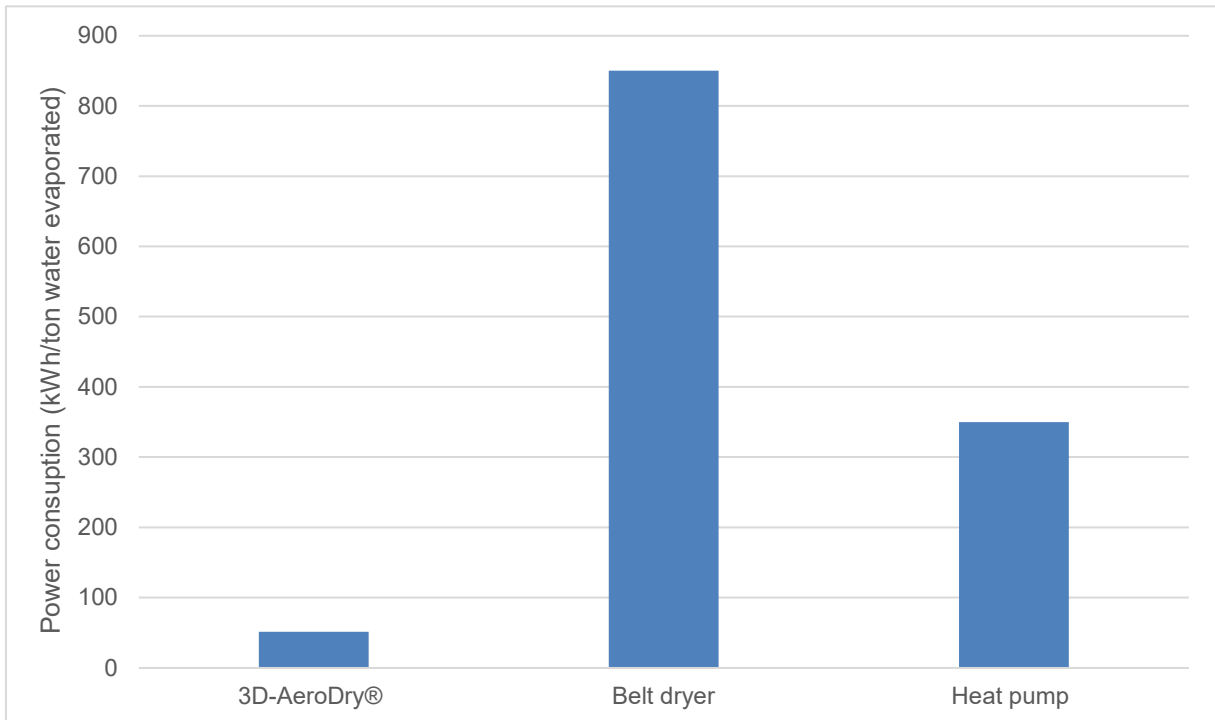


Figure 6: Comparison calculated power consumption (kWh/ton H₂O evaporated) 3D-AeroDry® (based on run 14 and 15) compared with thermal biosolids drying methods.



Figure 7: 3D-AeroDry®'s unique vertical sheet structure enables biosolids to form dried pellet-like materials during the drying process.

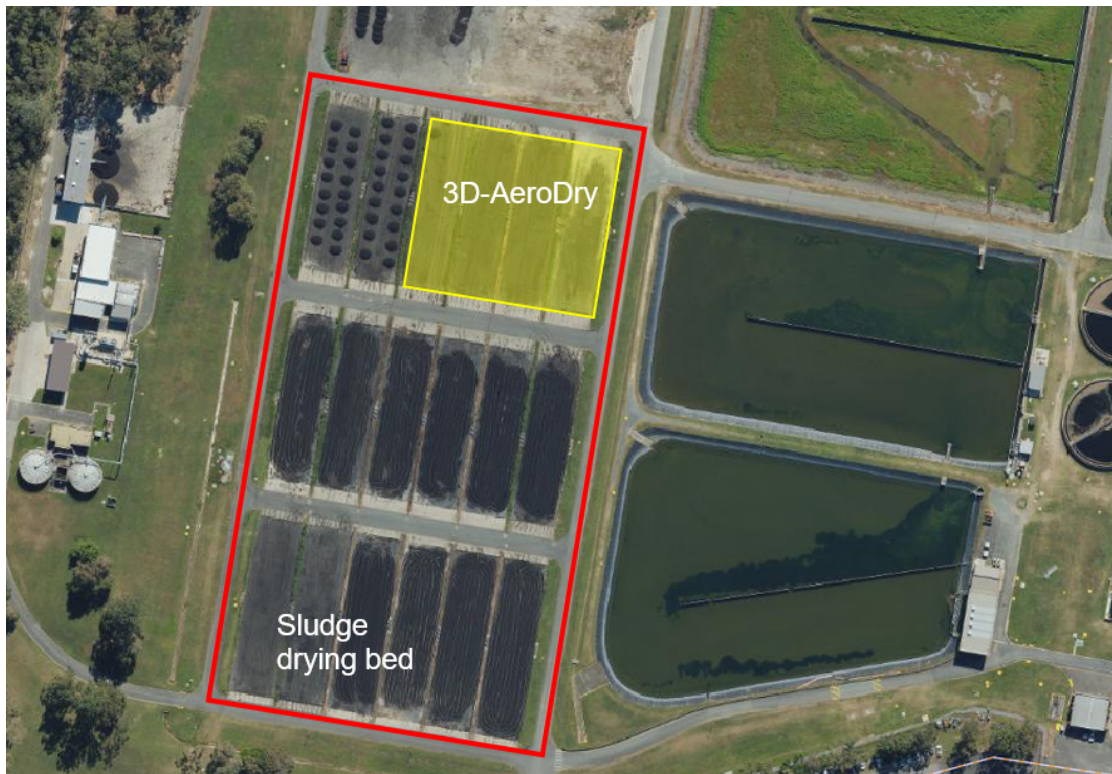


Figure 8: Calculated footprint of 3D-AeroDry® at full-scale compared to drying beds at Coombabah STP to handle same amount of biosolids. Note the calculated footprint includes peripheral equipment such as dewatered sludge hopper and dried biosolids storage tanks.