Trends in Biosolids Handling Technologies: Economics and Environmental Factors

Batstone, DJ, Darvodelsky, P., Keller, J.

Subtitle: Options for biosolids handling at small, medium, and large scale in terms of environmental impact, and economics.

Abstract

Changes in activated sludge technology, with a much greater focus on nutrient removal instead of removal of organics, together with relatively long sludge mean that the primary sludge stream has been lost, and the sludge produced is less degradable. At the same time with the growing importance of sustainable solutions, beneficial agricultural use is being increasingly used. This changes quality measures such that class B stability is required, and class A desired.

Large systems (>150,000 EP) can justify the large capital expenditure to implement advanced anaerobic digestion technologies, including thermal hydrolysis. This is environmentally very beneficial, in terms of greenhouse gas emissions, compared to the most common approach of aerobic digestion, and costs are of a similar order of magnitude. However, much of the costs previously directed at disposal, are now directed to capital depreciation, with the benefits of decreased operating cost, more predictable whole of life costs, and benefits to the environment. In any case, centralised high technology biosolids treatment systems are a real option for long-term beneficial use of biosolids.

The picture is bleaker for small and medium systems, and there are no options that are emissions negative, or neutral. To address this; (a) smaller reactors need to be built at lower prices; (b) smaller scale cogeneration options need to be explored; (c) degradability needs to be improved; and (d) a class A biosolid should be produced. We are doing research to address the last two points, using a new technology that treats the incoming activated sludge at 60+°C for a nominal 2 days to enhance degradability and improve final biosolids quality.

Biosolids sources and production levels

Solids streams are produced throughout wastewater treatment plants, with the major streams originating from concentrated sewage solids, in primary clarifiers, and excess activated sludge, from the secondary clarifiers. Modern plants are producing far more activated sludge than primary sludge. In general, each treatment plant will produce approximately 50-65 grams dry solids per person, per day (5). This depends largely on biosolids handling methods and wastewater process type, rather than upstream consumer habits (in contrast with total sewer flows). Costs of treating, managing, and disposing this solids stream ranges from (in the US and Europe), 25%-50% of total wastewater treatment plant costs (6). Australian treatment plants produce even more biosolids, as local secondary (activated) sludges are known to have poor dewaterability with belt filter press cake solids of 12%-18%, instead 20%-30% in other developed nations (4). The reason for this has not been adequately explained, but could be related to a inert solids input, and/or higher bound water fraction (7). In table 1, some basic guidelines are given for the different sized plants. Costs especially are indicative only, and given localised environmental, social, and logistic constraints, can double or triple.

Table 1: Biosolids production levels from small, medium and large plants

Treatment Plant Size	Persons	Effluent (kL/day)[1]	Biosolids (dry) (kg/day)	Biosolids (wet, T/day)[2]	Indicative Biosolids Cost ($/A)[3]
Small	15000	3500	750	6	$147,000
Medium	50000	12000	2500	19	$421,000
Large	150000	35000	7500	58	$1,053,000

1. Based on 0.23 kL/person/day
2. Based on a belt filter press, operating to 13% solids cake
3. Disposal, basic treatment and dewatering, not including capital depreciation or salaries. $70/T, $60/T, and $50/T for small, medium, and large respectively.

Until the mid 1990s, wastewater treatment plants focussed largely on carbon and pathogen removal, with normally, relatively lenient nitrogen limits. Biosolids consisted largely of primary sludge, with a contribution from secondary sludge. The largest sink was landfilling. Therefore goals towards biosolids treatment were to (a) reduced volume and mass through digestion, and dewatering to reduce disposal costs, and (b) Removal of the gross putrescible material, generally originating in primary solids to avoid nuisances and health risks during storage, transport, and disposal. The presence of primary solids previously made anaerobic digestion relatively practical even at a quite small scale, since it is a relatively good substrate.

Changes in Biosolids Production and Handling Goals

In the last 10 years, the focus of wastewater treatment has shifted more towards nitrogen removal, with a concurrent increase in sludge ages. This has had the following major impacts:-

(a) Removal of primary sedimentation processes, or use of sludge prefermenters, as the carbon is needed for nutrient removal.
(b) Decrease in overall biosolids amounts, due to long sludge ages and loss of the primary stream, though the secondary sludge production normally increases due to increased carbon turnover.
(c) Even poorer sludge dewaterability (5), due to loss of the primary stream.
(d) Decrease in biosolids degradability, both because of long sludge ages, and loss of the primary stream.

While direct costs for landfilling have remained low opportunity costs have increased dramatically, due to limited sites for landfill, and community resistance to increased landfills. Waste minimisation legislation is attempting to minimise addition of organics to landfills, and this will be increasingly enforced in the future. Added to this, biosolids are a high-cost, problematic source for landfills compared with municipal and industrial solid wastes, and with corporatisation of landfills, many are starting to refuse biosolids as a feed stream. Finally, unless a landfill is effectively capped, and the gas captured and burnt, degradation of biosolids in the landfill has a large greenhouse gas impact.

Beneficial use in Australia

Beneficial use in commercial farming has been practiced far longer than wastewater treatment. Ashton, in his 1904 keynote recognised it as one of the only practical methods of biosolids disposal at the time (1). Australia is fortunate to have a community willing to accept the use of natural fertilisers, farmers eager to use it, and a professional and competitive service industry able to effectively receive and utilise the biosolids. This has resulted in widespread beneficial use within Australia, and at least 5 of the 6 state capital cities practice almost total beneficial use (9).

The case for beneficial use is compelling. The use of biosolids in agriculture across Australia is being extensively researched by the National Biosolids Reuse Program (NBRP). Use of biosolids has been generally found to have either no effect, or a positive effect, compared to use of mineral fertilisers at comparable nitrogen loading rates. The net environmental benefit in replacement of mineral fertilisers is large.

One of the main Australian contractors (2) has calculated that by replacing mineral Nitrogen and Phosphorous with its biosolids equivalent results in a 97% reduction in carbon emissions. This equates to 0.86 Tonnes CO_2-e emissions avoided, per tonne of biosolids used. Since the nitrogen in biosolids is released slowly (5), it is likely that less is wasted, or worse from an environmental perspective, lost as N_2O, which has an enormous greenhouse gas impact. Biosolids incorporated in the top 30 cm of soil will have no methane emissions, and in our opinion, both N_2O and methane emissions are minimal in beneficial use, and likely lower than from the application of mineral fertiliser. Transport is expensive, but surprisingly low in carbon emission (6-7 $kgCO_2$/tonne for 100 km), such that transport compares favourably with drying (Table 2).

State guidelines are currently applied across Australia as a legislative framework, and the NSW EPA guidelines (applicable in NSW and Queensland) are used as a guide here. (8). This classifies a biosolid by:-

(a) Contaminant grade. These are elements or chemicals which can cause negative environmental and health impacts in small amounts. Because most are either solids, or adsorb strongly onto solids, they accumulate in the biosolids stream. The NSW EPA guidelines recognise only specific metals, and halogenated organics (almost all pesticides). Other organic contaminants such as endocrine disrupters, polyaromatic hydrocarbons, detergents, and plasticisers are not recognised.

(b) Stabilisation grade (pathogens and vector attraction). These are quite separate criteria. The “vector attraction” criteria is actually a stability criteria, since it evaluates the degree to which the biosolids will rapidly degrade in the environment. The most common measurement is oxygen uptake rate. The pathogen reduction criteria is based both on approved processes, as well as an initial (Enteric viruses and Helminth ova), and long-term (E. Coli, Faecal coliforms, and Salmonella) testing regime. Approved processes include either thermal, and thermal/pH treatment. Non-approved processes can be approved by evaluation against the above criteria. Stabilisation grade A is pathogen free, and will not degrade further, Stabilisation grade B is stable, but may contain pathogens, while Stabilisation grade C is putrescible.

Contaminant grade ranges from A-E while stabilisation grade ranges from A-C. Biosolids must be grade C/B contaminant/stability for agricultural use, and D/B for forestry or minesite rehabilitation. Municipal biosolids produced in Australia are most commonly in the high B to low C range for contaminants, due to high levels of zinc and copper. A number of methods for achieving stabilisation class B are reviewed in the next section. NBRP research has largely confirmed the state guidelines, with recommendations to consider specific plant and soil type, when formulating loading rates.

Changes in treatment requirements for Beneficial use

The changes in wastewater treatment focus to nitrogen removal, with no primary sedimentation, and a long sludge age mean that a largely non-degradable, activated sludge stream is produced, instead of a highly degradable, largely primary sludge. This has made anaerobic digestion far less viable as a process, especially in smaller plants, as it is more difficult to maintain the slow growing methanogens, and because less gas is produced, which can make it difficult to heat and mix the digester. The current default treatment method for biosolids at small-medium scale is aerobic digestion, which produces a product with higher odour potential, and lower overall stability. This is because anaerobic digestion effectively destroys volatile sulphur compounds present in biosolids (6).

The legislative requirements for agricultural use can be met by a wide range of technologies, including drying, lime treatment, composting, aerobic, anaerobic digestion, or even extended aeration provided that operating conditions are met. However, different technologies produce different quality products, and aerobically digested biosolids are recognised as being a relatively poor product, for the reasons given above.

Apart from legislative requirements, odour is the major management issue with beneficial use of biosolids, as they must be stored while tests are done, in order to evaluate soil application rates. Typical response time for samples is 1-3 weeks A recent survey (3) indicated that due to management problems, treatment requirements, and business risks, the major biosolids contractors would either not accept unstabilised biosolids, or would require funding of a full class A treatment system. This is despite the fact that there are legislative routes to allow acceptance of class C biosolids (with extended aeration followed by incorporation or subsurface injection). This raises the possibility that production of odorous biosolids (including aerobically digested biosolids) may become a high-cost activity regardless of legislative requirements.

Finally due to a relatively high population density, it higher risk to use stabilisation grade B biosolids extensively in coastal regions. Stabilisation class B can vary from relatively odorous material, to essentially unvalidated class A material. Risk management makes it far easier to use stabilisation class A in coastal regions. Since class B is most widespread, the vast bulk of biosolids use is remote use, with transport of biosolids over 100km, and consequent increases in cost and greenhouse gas emissions. Consistent stabilisation to grade A would allow local use.

Biosolids treatment options available at different scales

The main options available at different scales are summarised below. These are split into technologies applicable at all sizes, those only at large scale, and those that could be applied as either stand-alone, or additional treatment options to the previous methods. The reasoning for anaerobic treatment options only being applicable at large scale is discussed further below. All small-medium scale options are also available in large scale, but may have undesirable social impacts (e.g., open composting in large scale causes odour problems).

Table 2: Treatment options available in different wastewater treatment plant sizes

Type	Stability Class	Product Quality	Electrical Use (kWh/tonne at 13% dry solids)	Notes
Treatment – applicable at all sizes				
Lime Stabilisation	A or B	++	400-800[1]	Increases dry solids 25% Causes high pH solid
Composting	A	+++	100	High labour requirements. Increases dry solids 50%. Needs conditioner

				stream.
Aerobic	B	-/+	50	25 days.
Treatment – applicable at large scale				
Anaerobic – 30°C-40°C	B	++	-35	Sludge age ~15 days. Cogeneration available
Sonication + anaerobic	B	++	-35	Additional electricity used by sonication process
Thermal hydrolysis (6 bar) + anaerobic	A	+++	-50	Decrease in total volume with dewatering
Post treatment – applicable at all sizes				
Solar Drying[2]	A	+++	30	Based on continuous turning process
Thermal drying[2]	A	+++	1000[3]	

1. Including electrical cost of lime production. Upper level (and Class A) includes heat treatment.
2. kWh Per tonne water evaporated.
3. If gas is used, emissions are equivalent to 200 kWh as electricity.

As discussed above, change in wastewater treatment focus to nutrient removal has raised the bar for anaerobic digestion, especially in smaller treatment plants, due to loss of the primary stream, and increased sludge ages. A number of additional factors make anaerobic digestion, in its current form, impractical in small-medium scale systems:

- Although civil construction costs scale reasonably well for anaerobic digestion, mechanical and electrical (e.g., flare, pumps, gas circulation system, gas storage, heating system) become much more expensive at smaller scale.
- Process intensification (e.g., thermal pretreatment) is capital intensive, and can realistically only be applied in centralised (or very large scale) facilities.
- Conventional internal combustion combined heat and power (CHP) cogeneration engines have a minimum size of approximately 500 kW, and cannot effectively operate at below 70% capacity. This means a system producing secondary sludge only would need a minimum of 200 Tonnes per day at 12% solids. Loss of the renewable energy stream removes one of the motivations for anaerobic digestion.

Environmental Impact

The energy values in Table 2 give an indication of the environmental impact of a process, since apart from fugitive emissions, greenhouse gas impact is largely related to electricity use. The form of energy is also important, and thermal drying actually has a much lower impact, as gas can be used, for which the emissions per kWh are only 20% compared to electricity.

A greenhouse gas impact of a number of different options was done on the 12 wastewater treatment plants in the Sunshine Coast, with plant sizes of 10,000-100,000 persons. The different scenarios assessed are as follows:

Decentralised:

(a) Landfill of biosolids following aerobic or anaerobic stabilisation, without methane capture. A very lenient assumption was made, that only 20% of the organic material degrades over the life of the landfill (uncapped landfill).

(b) Combination of current methods on the Sunshine Coast, including landfill, mesophilic anaerobic digestion, aerobic digestion, and solar drying.

(c) Decentralised stabilisation by aerobic digestion, pressing to 15% solids, and transport to remote beneficial use (~300 km).

Centralised: Pressing to 12% volatile solids (VS) at individual plants, transport to a centralised facility, and either:-

(e) Dilution to 6% VS solids with host plant secondary sludge, and mesophilic digestion, or;

(f) Thermal hydrolysis at 12% VS solids, followed by dilution to 7% suspended volatile solids (9% total volatile solids), followed by mesophilic anaerobic digestion.

The calculated emissions from these different scenarios are shown in Figure 1. The two anaerobic options are net negative, due to produced electricity.

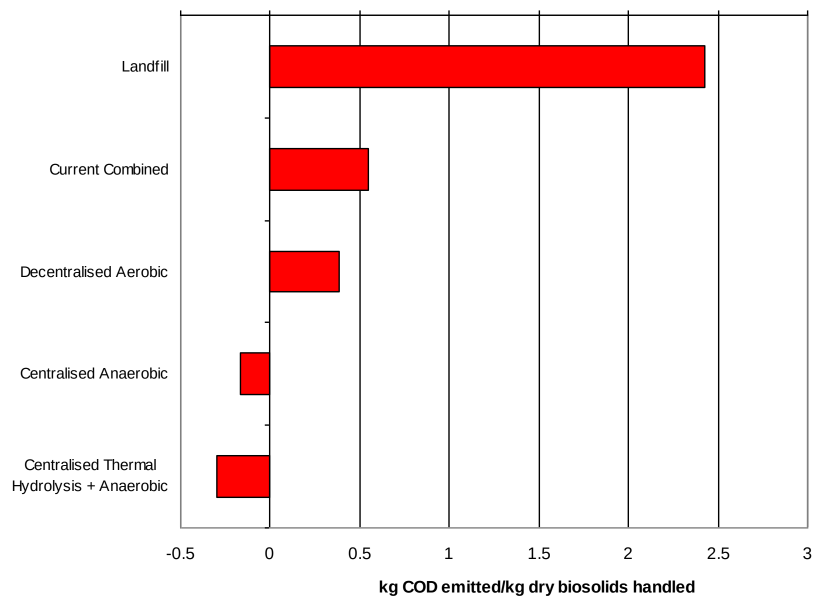

Figure 1: Greenhouse gas emissions for different treatment options.

It is apparent that if greenhouse gas emissions are to be avoided, landfilling is no longer an option. The emissions can also be broken down by activity, as shown in Figure 2. This indicates that emissions causing activities move between treatment, through to sidestream, as volatile solids destruction increases. This is also significant, as sidestream treatment (removal of released N and P) has potential for optimisation.

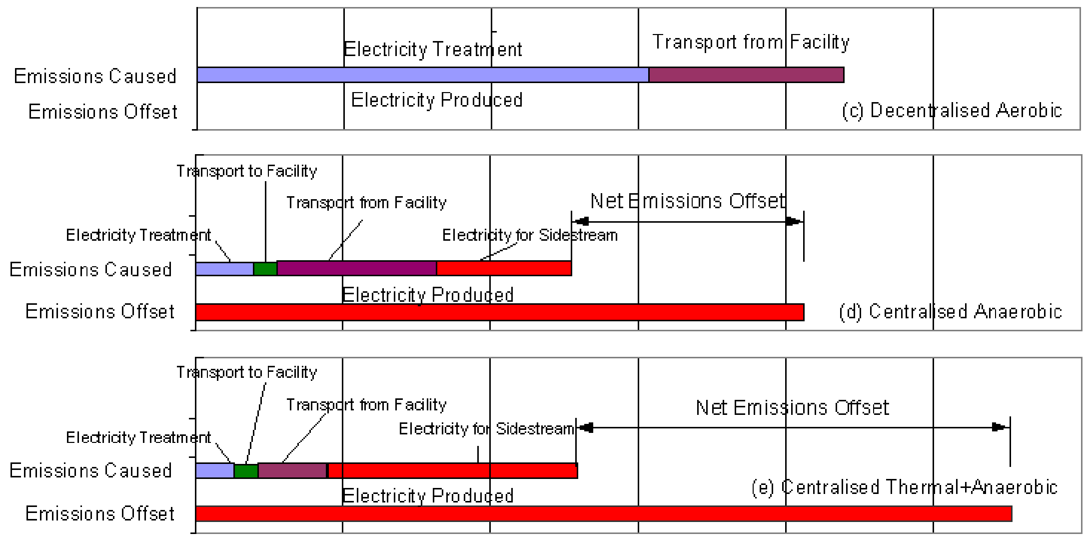

Figure 2: Emissions of selected scenarios by activity.

Cost of Advanced Treatment at Large Scale

The Sunshine Coast study also contained an order of magnitude level economic analysis. The comparison option is to use existing aerobic digesters, with minimal solids destruction, dewatering to 12% solids, and remote beneficial use. The environmental impact of this is shown in Figure 1. The cost of decentralised aerobic (for a comparison basis) is:-

- $5 per wet tonne electricity in aeration.
- $45 per wet tonne for remote beneficial use.

There are also some staff and maintenance costs involved, but these are excluded.

Cost of treatment at a centralised plant, with thermal hydrolysis would mean that instead of 9×20 tonne trucks per day transporting biosolids to Cecil Plains, on the Darling Downs, one 35 tonne B-double per day could transport residual biosolids to local use (Class A stability). The cost of doing so would be similar (Figure 3), with an enormous shift of disposal costs towards capital depreciation. Overall biosolids costs would be approximately $43 per wet tonne (2006 NPV basis on a 20 year project). Costs of transport to the centralised facility are in addition to this, and add an average of $9.00 per wet tonne. A similar project for the Gold Coast, with more conservative capital estimates, but at a larger scale has resulted in estimated costs of approximately 20% higher than this value.

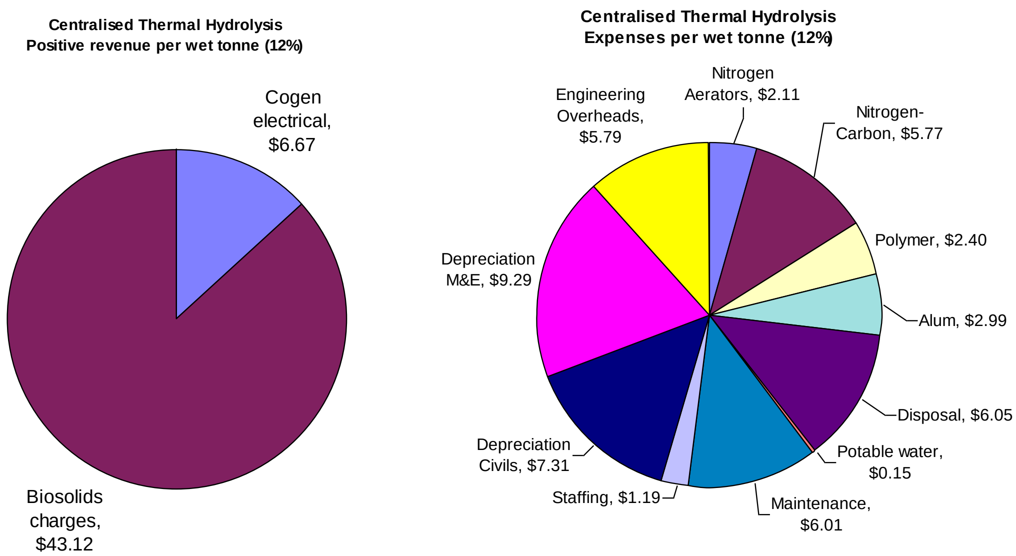

Figure 3: Income and expenses for a hypothetical centralised biosolids plant handling biosolids from the 12 major Sunshine Coast plants.

There are a number of additional considerations:-

- A centralised facility needs to be located at a major treatment plant, to make use of the generated electricity stream (the electricity from this plant would power a wastewater treatment for 50,000 persons, equivalent to Noosa WWTP), treat the reject water, and supply make-up water from effluent.
- Negative social impacts are minimal, and largely related to increased truck movements.
- A centralised facility shared between different councils is likely to have a complex financial structure, with some increased risk.
- Implementation of a centralised facility shifts costs from disposal, to capital expenses, and therefore shifts financial risk from a contractor to the council. Most councils avoid this, and would favour a build-own-operate delivery. This would increase costs considerably, due to an increased discount rate.

Therefore, true costs are likely to be higher than shown in Figure 3, but still of a similar order of magnitude, and competitive with decentralised aerobic treatment. Environmentally, decentralised anaerobic is undeniably better.

What about small and medium scale?

As shown in the previous section, treatment by anaerobic digestion at large scale is environmentally better, and financially comparable to the default of aerobic digestion, and remote beneficial use. However, by far the largest proportion of treatment plants are less than 150,000 persons, and as shown in Table 2, there are very few options that both have a low environmental impact, <u>and</u> produce good product. The best current option is probably aerobic digestion or extended aeration, followed by solar drying or composting, and beneficial use. This accounts for the increased popularity of solar drying.

Another option is to address the technical limitations of existing anaerobic digestion options, in order to make it applicable at smaller scale. This should include:-

- Changes in vessel design and construction to make the process at small scale lower cost, and more reliable.
- A small scale cogeneration option to produce combined heat and power for the process, including pretreatment.
- An economic (preferably thermal) pretreatment option to make the activated sludge degradable enough to make the biological process self sustaining, and supply enough heat to maintain digestion and electricity generation. A steam-based pretreatment option such as thermal hydrolysis is too complex at this scale.
- Class A product to enable local use.

The first point can be addressed by redesign, and concrete construction costs already scale reasonably well. The cogeneration option is already addressed by newer microturbines, with capacities down to 50 kW. These need adaptation and testing on biogas, as they are most often applied to natural gas. One option to address the third and fourth points are low intensity thermal pretreatment (60+°C for 2 days). We have found this to be very promising in increasing the degradability of activated sludge substantially e.g. from 25% VS destruction to 40% destruction, hence making the process more sustainable. As the process is thermal, the heat is free from the cogeneration system. This is an area of research being pursued in our research centre.

Conclusions

- At large scale (>150,000 persons), centralised treatment of biosolids by advanced anaerobic technologies (such as thermal hydrolysis) is environmentally better, and economically comparable.
- In a large centralised plant, expenses are transferred from disposal costs to the depreciation of the increased capital costs. While this increases capital risks, it greatly reduces operating risks (fixes costs by buying capital), and has substantial environmental and social benfits.
- There are currently no options for small and medium scale applications that are carbon emissions neutral, or negative. Aerobically digested biosolids have significant carbon emissions (from energy needs) and are generally of low quality.
- An anaerobic option at small scale should be: (a) economic, (b) produce electricity (and heat), (c) have enhanced VS destruction, in order for the process to work, and (d) produce class A biosolids.
- The first two objectives can be addressed by engineering, and adaptation of newer generators, such as microturbines.
- To improve degradation and biosolids quality, low intensity thermal pre treatment has been found to offer some significant promise for smaller applications.

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