Cost Effective and Efficient Energy Recovery from Biosolids for the Largest Plant in the Kingdom of Jordan , Iyad Dahiyat 2 (1) AECOM Water, (2) Ministry of Water and Irrigation

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ABSTRACT

The USAID Water Reuse and Environmental Conservation Project works to protect and conserve Jordan's scarce water resources; one task in that project is to prepare a biosolids management feasibility study for the As-Samra Wastewater Treatment Plant, which treats more than 60% of the country's generated wastewater. The first phase of the feasibility study is to assess existing conditions and to screen and evaluate viable biosolids processing options, with the goal of identifying the best ones. Detailed analysis of those identified option(s) was conducted in the second phase.

The first phase of the study resulted in four shortlisted options that recover energy from the dried biosolids: incineration, gasification, monofill (biosolids landfill only), and use at local cement kilns. Other options such as land application and composting, while potentially remaining viable for a portion of the biosolids, were not further evaluated in detail since the option is expected to process the entire biosolids amount. The second phase's detailed evaluation of the shortlisted options included 20 year present worth, ranking based on established evaluation criteria, and financial analysis. The gasification option was eliminated due to its high capital cost for the size of the facility. The shortlisted options require some form or biosolids drying. Taking advantage of the arid condition of Jordan, solar drying beds of dewatered biosolids followed by mechanical windrow drying allowed cost effective drying of the biosolids for further processing as compared to energy extensive thermal drying.

The results of the evaluation indicated that all three final options are technically viable and could be carried forward. While incineration and cement kiln options scored the highest overall in the evaluation criteria, the monofill scored a reasonably close third with no notable obstacles in its implementation provided it is operated by the private sector. Financially, the monofill with an energy production option proved to be significantly more viable offering the most attractive life cycle cost and return on investment. Accordingly, it is recommended that the project moves forward with the monofill with an energy production option.

BACKGROUND

The 267,000 m^3/day As-Samra WWTP was constructed in 2008 using the latest available technology for achieving high quality effluent for water reuse, and is currently being expanded to a capacity of 365,000 m^3/day. Located north east of the capital Amman, it treats approximately 60% of the wastewater generated in the kingdom. The plant represents the first public private partnership (PPP) for financing the construction and operation of public infrastructure in Jordan, based on a 25-year Build-Operate-Transfer (BOT) approach. Currently the plant is producing about 147 dry tonnes per day of biosolids and is expected to produce about 194 dry tonnes per day by 2034.

Solids Processing at As-Samra WWTP
The plant's combined gravity thickened primary sludge and thickened (dissolved air flotation) waste activated sludge are anaerobically digested. The current biosolids processing after digestion is shown in Figure 1.

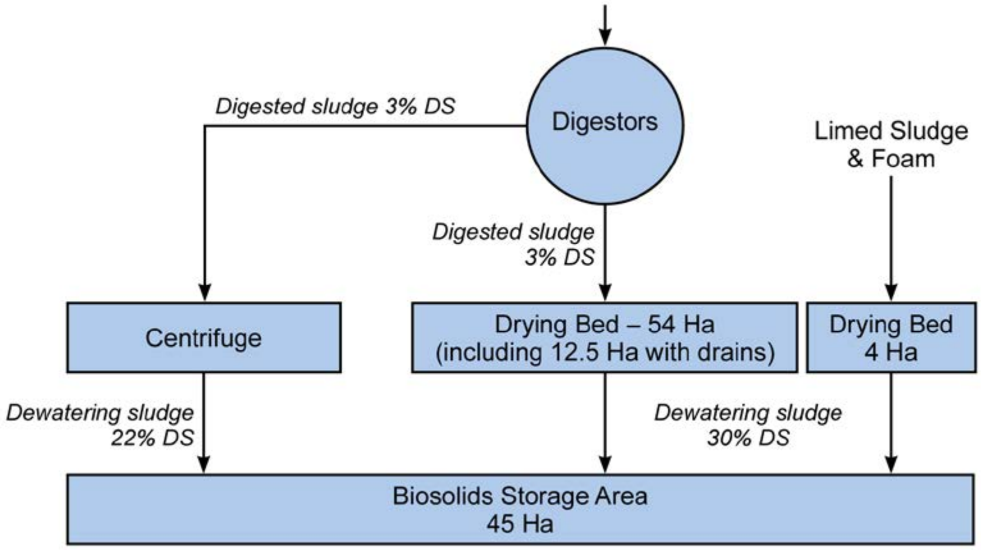

Figure 1. Biosolids processing and management at As-Samra WWTP.

The majority of the produced biosolids (~3% Total Solids, or TS), once digested, is transferred to the solar drying lagoons. Once dried to about 30% TS, the biosolids are transferred to the storage area, where solar drying is continued. A small portion of the digested biosolids is dewatered via centrifugation to concentration ranging from 18 - 22% TS and then transferred directly to the sludge storage area. When the sludge flow is beyond the capacity of the existing digesters, the thickened sludge is stabilized with lime and sent to separate solar drying beds, and is then stored separately in the biosolids storage area.

This current practice is considered short-term and is to end on November 2014 with the installation and startup of a new Belt Filter Press (BFP) dewatering facility, as shown in Figure 2. A medium-term period will follow during which dewatered biosolids will be further dried in a process similar to that used in the short term. In 2018, the long-term solution will be implemented following the identification and construction of one or more permanent disposal or reuse outlet or outlets for the generated biosolids.

Figure 2. Timeline for biosolids management at As-Samra WWTP.

Current and Future Biosolids Management System at As-Samra WWTP
Figure 3 (adapted from Sogreah Report, 2011) shows the biosolids drying lagoons and storage area. The current practice is described as follows:

- The digested biosolids, at a typical concentration of 3% TS, are pumped to 18 solar drying lagoons, 16 without drainage and two (M 2-3 and M 2-4) with drainage systems.
- Dried biosolids are stored in four ponds, namely F 2-3, F 2-4, M 2-1 and M 2-2. Ponds F 2-1 and F 2-2 are both 1.5 meters deep and cannot be used for solar drying ponds because once equipment enters the ponds, it is nearly impossible to get it out.
- Once the biosolids are settled in the solar drying beds, the supernatant is removed and pumped to M1-4; after that the solar drying process is completed in three steps. First, with the ponds completely isolated, the biosolids are settled for a further two months; then mixing with tractors occurs to enhance the evaporation processes; and finally, once the dry solids concentration is greater than 20%, the biosolids are transported to storage ponds.

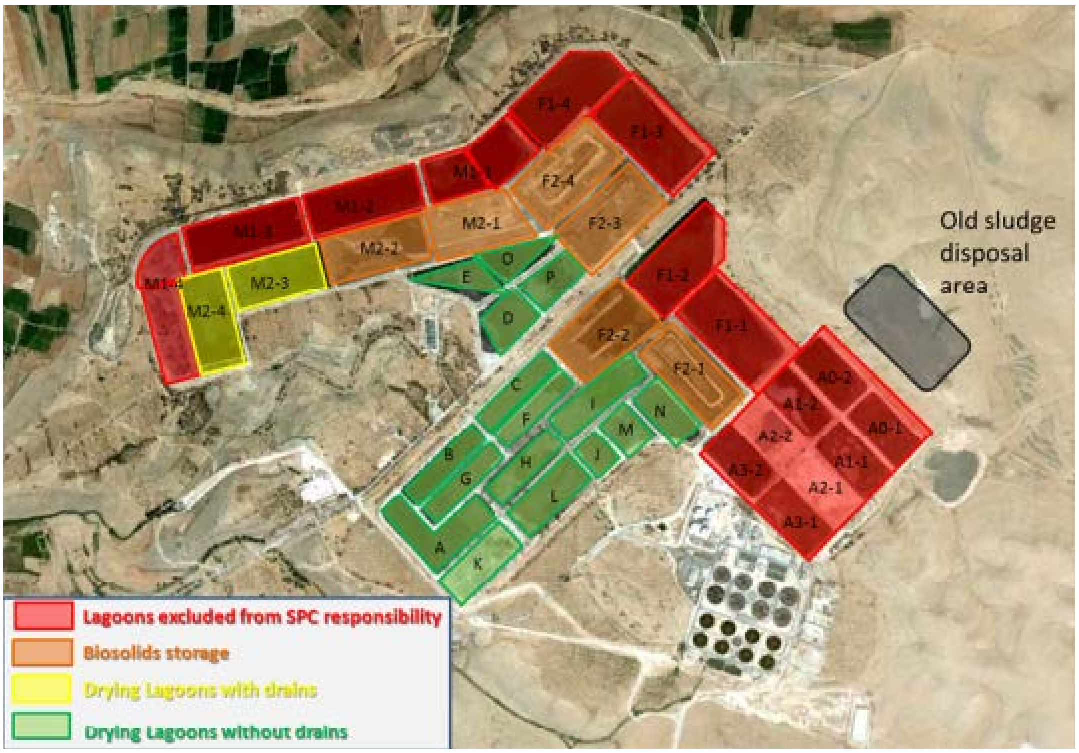

Figure 3. Schematic diagram of the biosolids drying lagoons and biosolids storage area. Source: Sogreah Report 2011

- There are six biosolids storage areas, four of which are currently in use. In these four areas (M2-1, M2-2, F2-3, and F2-4) the biosolids can and are moved around to facilitate further drying. Initially the biosolids for the solar drying are placed in the storage area; after one year, the biosolids are pushed to the side with a front-end loader, creating a pile at the outer edges of the storage area. It can generally be concluded from this practice that the biosolids at the storage ponds' edges are the oldest and that the biosolids start decreasing in age towards center of the pond; it can be assumed that there is a one-year difference in age between the various piles from the edges and moving inwards. However, the lines between piles and number of piles are often not clear.
- None of the four biosolids storage ponds has a liner.
- Storage areas F2-1 and F2-2 are not currently in use. They recently had sludge from the solar drying lagoons placed on top of the sludge that already existed in them. That earlier sludge is

still in a slurry form and thus these lagoons are used only for placing sludges and the material cannot be moved with existing equipment.

- Ponds J, M and N were previously used for storing lime-treated biosolids, but currently pond I is being used due to space limitations.
- Biosolids that have been treated with lime stay almost a year at the same pond before being moved and mixed with other biosolids at storage ponds. Lime-treated biosolids are moved to F 2-3 and F 2-4 for storage (because they are close by the treatment ponds). This means that M 2-1 and M2-2 ponds have purely digested biosolids (i.e. they do not contain biosolids that have been treated with lime).

The management practice described above is expected to continue until November 2014, the date for installing and starting the new BFP dewatering facility. Once the BFP facility is in place, 14 machines (two standby BFPs) will dewater the sludge continuously, 24 hours per day, seven days a week. The BFP facility is required to produce a minimum of 18% DS cake. The following procedures describe the future practice.

- Dewatered 18% cake solids will be transported to drying beds by trucks. Continuous operation of drying will be practiced year-round with no winter or summer cycles.
- From completion of the dewatering facility and until completion of the expansion date, the biosolids should be dried to 50% TS by weight and temporarily stored in a designated temporary storage area for a maximum of three years. The new dewatered and dried biosolids will not be mixed with old biosolids that are already stored at the biosolids storage area.
- Once a final disposal site is identified (on or before July 2018), the biosolids that have been stored for the designated three-year period will be transported to final disposal/reuse.

Figure 4, adapted from the 2012/2013 sludge management plant (SMP) report, shows the medium and long term biosolids management scheme. It is expected that the biosolids leaving the Temporary Storage area to be at least 50% dry.

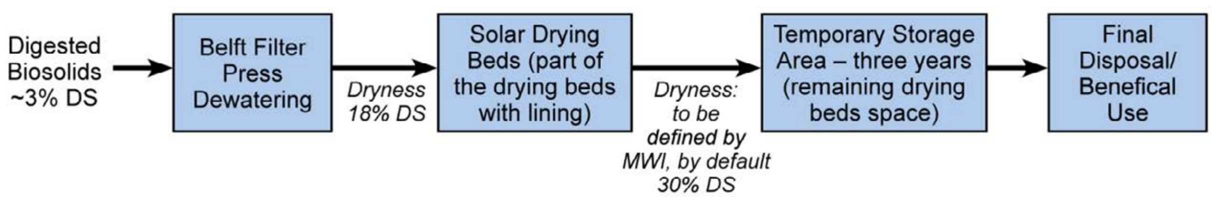

Figure 4. Medium and long term sludge management scheme at As-Samra WWTP (Source, SMP 2012/2013).

OBJECTIVES

The objective of this study is to identify the permanent disposal and/or beneficial use option(s) that should be in operation by July 2018. Energy recovery from the generated digested and dewatered biosolids is a key issue.

BIOSOLIDS PROCESSING ALTERNATIVES

Several processing alternatives exist for As-Samra generated biosolids following BFP dewatering. Figure 5 provides an overview of the pathways along which the As-Samra biosolids must proceed to meet various DS % levels required for various beneficial use or disposal options. As the figure shows:

- Dewatered 18% cake solids can be transferred directly to a disposal or beneficial use outlet such as landfill, composting, land application or incineration.
- Dewatered 18% cake solids can be transferred directly to a drying process to achieve greater than 75% DS for disposal or to a beneficial use outlet such as land application, incineration, or cement kiln.
- Dewatered 18% cake solids can be transported to the solar drying beds where it is allowed to further dry. Dewatered biosolids should not be allowed to mix with the old biosolids in the solar drying beds.
- Solar drying beds can achieve 30% DS and the biosolids then be transferred to a disposal or a beneficial use outlet such as landfill, composting, land application or incineration.
- Solar drying beds can achieve 50% DS and the biosolids then be transferred to a disposal or a beneficial use outlet such as landfill, land application or incineration.
- Solar drying beds can achieve 30% DS and the biosolids then be transferred to the temporary storage area to further dry to 50% before being transferred to a disposal or a beneficial use outlet such as landfill, land application or incineration.
- Solar drying beds can achieve 30% DS and the biosolids then be transferred to the temporary storage area to further dry to 50% before additional further drying to achieve greater than 75% DS for disposal or a beneficial use outlet such as land application, incineration, or cement kiln.
- Solar drying beds can achieve 30% DS and the biosolids then be dried further to achieve greater than 75% DS for disposal or a beneficial use outlet such land application, incineration, or cement kiln.

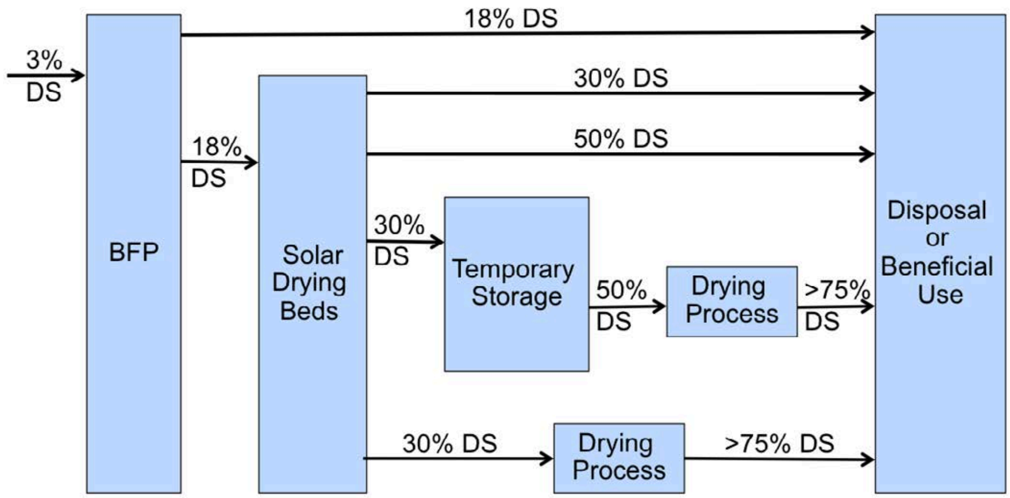

Figure 5. Biosolids processing after BFP for disposal or beneficial use.

Accordingly, six biosolids processing alternatives for the available end use and disposal of the biosolids were identified: land application, composting, cement kiln, incineration, gasification, and monofill. These options need to be able to process the generated BFP dewatered biosolids for 20 years. Other processing and beneficial use options such as thermal drying processing, lime stabilization, reed beds and co-incineration with municipal solids waste were deemed not appropriate. Moreover, using an existing or new landfill with municipal solid waste is not feasible, so the landfill option was evaluated for biosolids alone and is termed monofill.

The evaluation of the six alternatives included required regulatory reform measures, marketing efforts, required public awareness and educational programs, physical investment, required piloting, public private partnership (PPP) potential, and cost of construction. The evaluation was followed by a workshop with the stakeholders, and decision making criteria were applied, resulting in a shortlist of alternatives: *cement kiln, monofill, incineration, and gasification*. The use of any of the short listed alternatives should result in energy recovery from As-Samra biosolids. It should be noted that although land application of biosolids was not shortlisted, it remains a viable alternative should existing governing regulations be modified, but discussion on this topic is beyond the scope of this paper.

Biosolids Characterization

Fresh digested biosolids samples from the four existing digesters were collected for characterization to investigate suitability of the biosolids for the various end uses. The biosolids samples were analyzed for three main purposes: compliance with Jordanian Standards for land application, viability for incineration/gasification, and agronomic value. The samples were analyzed by a local certified laboratory (Royal Scientific Society, RSS) and Hazen Research Laboratory (Colorado, USA) for ultimate and proximate analysis.

The results showed that the digested sludge samples, once further dried, are able to meet Category I and Category II requirements, which are similar to Class A and Class B categories of the USEPA Part 503 Regulations. The results of the high heating value (HHV), as measured, are typical for digested biosolids; with proper dewatering and controlled solar drying, the biosolids should therefore be well suited for further gasification or incineration. Accordingly, the biosolids produced from As-Samra WWTP were shown to meet the existing Jordanian standards for use as organic fertilizer and soil conditioner in terms of heavy metals limits, nutrient composition, salinity, and pH. However, in terms of pathogens content, the biosolids require further stabilization to meet Category I standards.

DETAILED EVALUATION OF ENERGY RECOVERY ALTERNATIVES

Detailed evaluation of alternatives included conducting energy and mass balance, obtaining vendor quotes for various equipment, estimating construction costs, and estimating operating and maintenance costs.

Further Drying Evaluation

As Figure 5 and its accompanying text show, various end use options require different levels of biosolids dryness. Existing solar drying beds, which are capable of producing dryness between 30-50%, are a component process of each option. Monofill can be practiced at either 30 or 50%, so no further drying is needed. Gasification and cement kiln options require dryness of greater than 75% TS; thus further drying is required. Further drying is also required to make incineration an attractive option. Using the Water Environment Research Foundation energy recovery model for incineration, Figure 6 presents the potential energy recovery as a function of the solids content of the biosolids. As the figure shows, 50% or greater dry solids is needed for energy recovery, with the most energy recovery occurred between 75% and 90% DS. Thus, for practicing incineration for energy recovery, the biosolids should be dried to greater than 75% similar to the requirement for the cement kiln and gasification options.

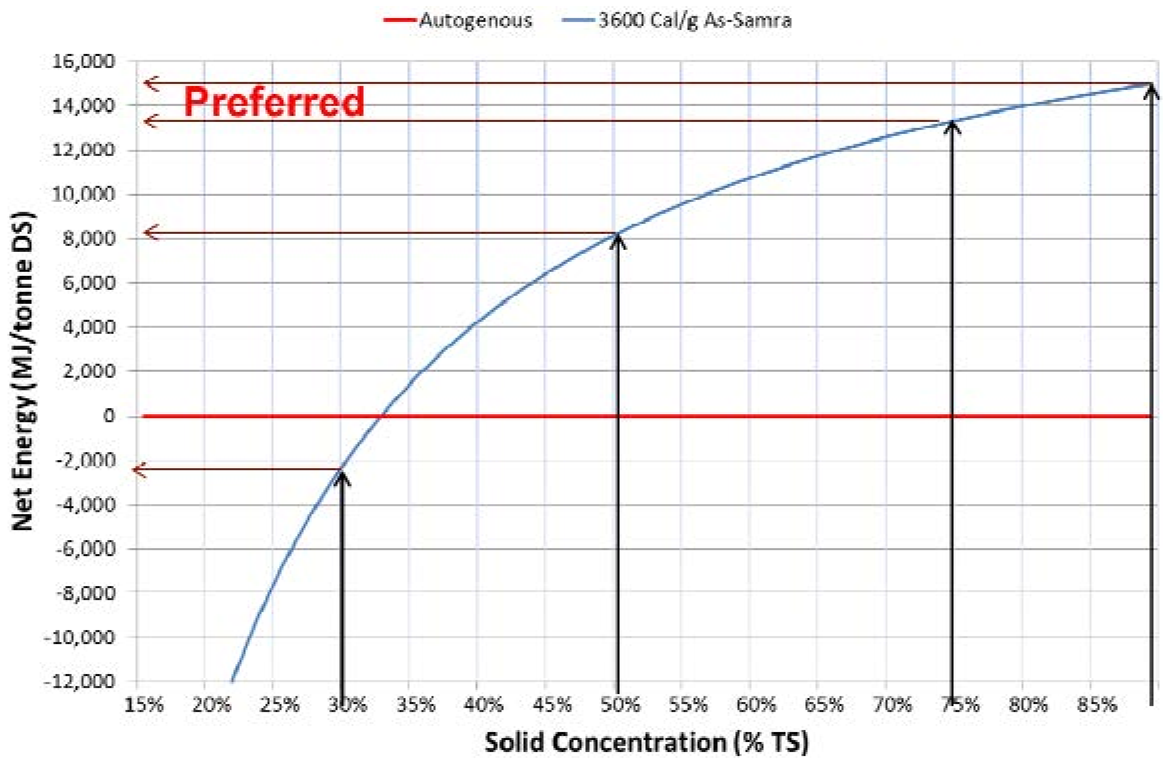

Figure 6. Net energy in MJ per tonne dry solids as a function of solids concentration in the biosolids for As-Samra digested biosolids of a measured calorific value of 6,300 Cal per gram.

To achieve 50% dryness, cost evaluation showed that drying the biosolids to 50% at the solar drying beds is better than transferring 30% from the solar drying beds to the temporary storage area and further drying to 50%. To further dry the biosolids to greater than 75%, two technologies were evaluated: mechanical windrow drying and greenhouse drying.

Mechanical windrow drying is a simple and low tech process whereby dewatered biosolids are formed into windrows typically on a concrete, asphalt or even dirt or clay surface. The drying efficiency, however, is improved when the windrows are applied to a hard surface. The biosolids are periodically turned and aerated with mechanical turners (typically once or twice a day). The turning process breaks the surface crust, aerates the biosolids and exposes the moist solids to air and the sun to enhance the drying process. There are several mechanical windrow drying reference facilities in the US, including some used for biosolids drying in large cities such as Phoenix, Arizona; Miami, Florida; Chicago, Illinois; and Parker, Colorado. These facilities use Brown Bear™ turners for the windrow drying process to produce a product used for land application, and many claim to meet Class A requirements with the process. Cities in temperate areas with cold snowy winters, like Chicago and Parker, operate the system only in the spring, summer and early fall months when the weather is suitable; during the wintertime period they store biosolids onsite.

Greenhouse drying was cost prohibitive due to the amount of biosolids to be dried despite the favorable arid conditions in Jordan. Thus, it was eliminated from further consideration.

Evaluation of mechanical windrow drying to achieve greater than 75% DS was conducted from the 18% TS produced from the BFP, the 30% or the 50% TS produced from the solar drying beds. Table 1 presents the results of this evaluation, which showed that achieving the required dry biosolids using mechanical windrow drying is most cost effective starting with 50% TS from the existing solar drying beds.

Table 1. Cost Analysis of mechanical windrow drying to greater than 75% TS at various biosolids dryness input.

Parameter	**Drying Option 1:** 18% DS from BFP	**Drying Option 2:** 30% DS from solar drying beds	**Drying Option 3:** 50% TS from solar drying beds
Construction Cost, M $	65.0	30.4	12.6
Annual O&M Cost, M $	1.45	1.85	1.77
Annualized Capital, M $	4.57	2.14	0.90
Total Annual, M $	6.00	4.00	2.65
Cost, $ per Dry Tonne	85.0	56.4	37.5

Energy Recovery from Various Options

The following is a discussion of the energy recovery potential from the four short listed alternatives.

Monofill

This option was considered for the entire biosolids production for 20 years. Monofill is not widely practiced, and for cost reduction and stability of the landfill, the dryness of the biosolids was selected to be 50% TS or greater. A monofill for biosolids is expected to have high energy efficiency because of the relatively large amount of landfill gas produced. Biosolids landfills can produce double the amount of biogas produced by normal municipal solid waste (MSW) landfills because biosolids have higher methane potential. MSW has a methane potential of around 120 m^3/Mg whereas biosolids have a methane potential of around 240 m^3/Mg. The Land GEM – Landfill Gas Emissions Model (USEPA) was used to project the potential total landfill gas generation quantity, generated quantities for individual pollutants such as methane and carbon dioxide, and the production curves over the active and post-closure period. The collection, flaring or electric generation systems should be designed based on the total estimated landfill gas quantity.

The proposed layout of cells within the monofill involves the construction and filling of four cells each with a 5-year capacity. Each cell is to be closed upon reaching its full capacity at the end of 5 years of operation. Biogas utilization is expected to begin at the closure of the first cell at year 5. The total amount of biogas anticipated to be produced for every cell was calcuated, Figure 7 providing a summary of the methane production and electrical production potential anticipated over the lifespan of the monfill and post-closure. Biogas production would continue only for 5 years after landfill closure.

Electricity recovery from the generated biogas would use internal combustion engine technology. For engine sizing purposes and for cost estimating, the electricity production potential was considered in 5-year increments. As presented in Table 2, about 2.5 MW of electricity is expected to be produced on average over the lifetime of the monofill. Figure 8 is a schematic diagram of the energy and mass balance of monofill option.

Part of the planning process also involves considering monofill as a contingency alternative for all options, though in this case the contingency landfill will be designed to accommodate only 5 year of the biosolids production and not 20 years. Table 3 shows the monofill options as a standalone or as a contingency. Gas recovery and electricity production is considered only for the standalone monofill option and not when the monofill is used as a contingency for other options discussed below. As a contingency, monofill will be used for a single five-year-cell facility. For the incineration and gasification, this monofill will also be used for disposal of the generated ash.

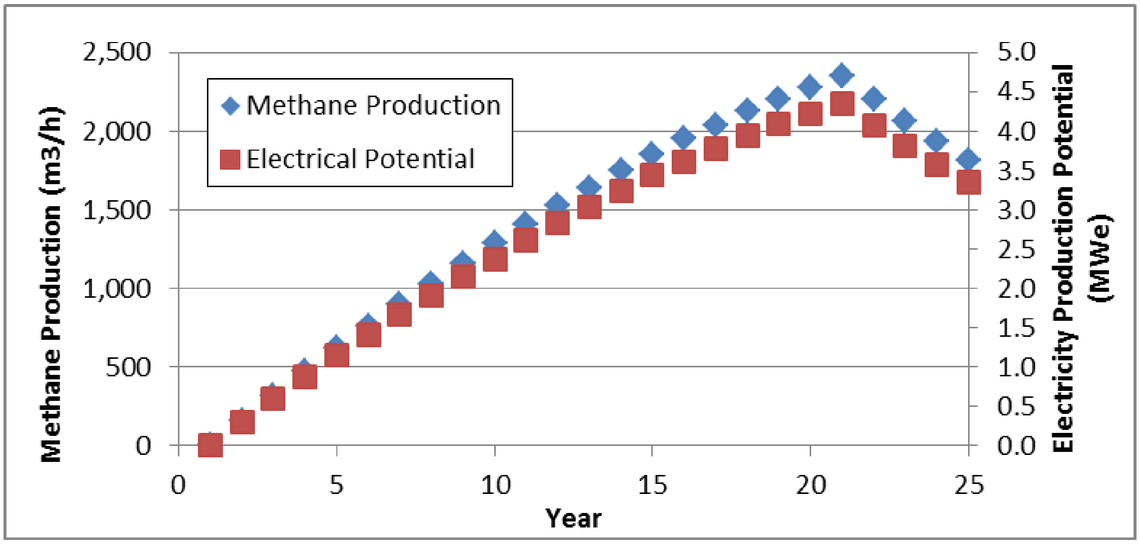

Figure 7. Anticipated methane production and potenital electrical production potential for the monofill overtime.

Table 2. Power generated from biogas based on 5 yr averages.

Years of monofill operation	Power generation
0 to 5 yrs	0 MW_e
5 to 10 yrs	1.6 MW_e
10 to 15 yrs	2.9 MW_e
15 to 20 yrs	3.9 MW_e
20 yr Average	2.5 MW_e

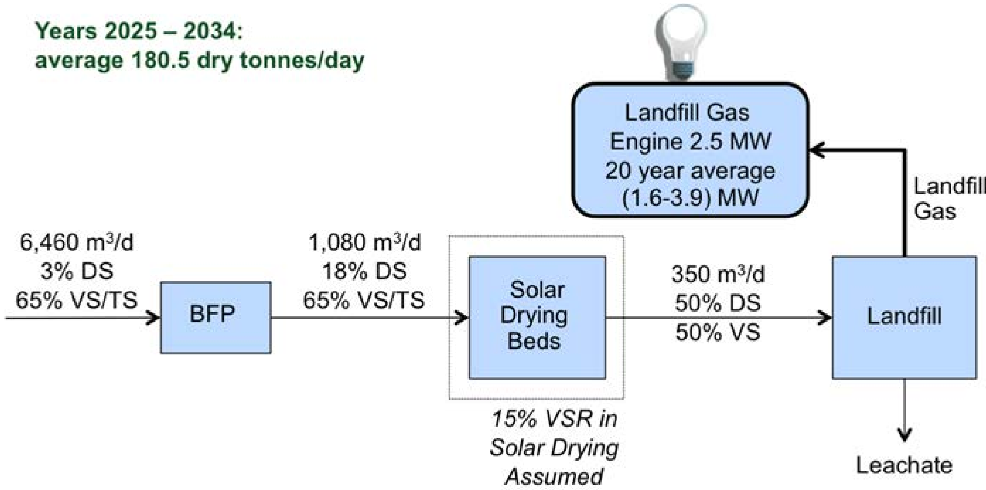

Figure 8. Energy and mass balance for the monofill option.

Table 3. Landfill options as a standalone option and a contingency for other options.

Option	Content	Capital Cost of Landfill for Option Life Cycle			
		Landfill	Initial	Life	Gas Recovery
Landfill Option	Biosolids	Complete	5 yr	20 yr	Yes
Cement Kiln	Biosolids	1st Cell	5 yr	5 yr	No
Incineration or Gasification for Energy Recovery	Biosolids	1st Cell	5 yr	5 yr	No
	Ash	Complete	5 yr	20 yr	No

Incineration

Evaluation showed that incinerating biosolids at a dryer, 75% TS would result in more energy recovery and be more cost effective than incinerating at 50% TS. Figure 9 shows a schematic diagram of the mass and energy balance for this option. A similar mass and energy balance was conducted for all options. The hot flue gas from incineration is proposed to be converted to steam using steam boilers, and the steam is then used in steam turbines to generate electricity. About 4.4 MW of electricity is expected to be generated from biosolids combustion. The produced 70 m^3 per day of ash is expected to be landfilled in a monofill constructed both as an ash landfill and a contingency biosolids landfill.

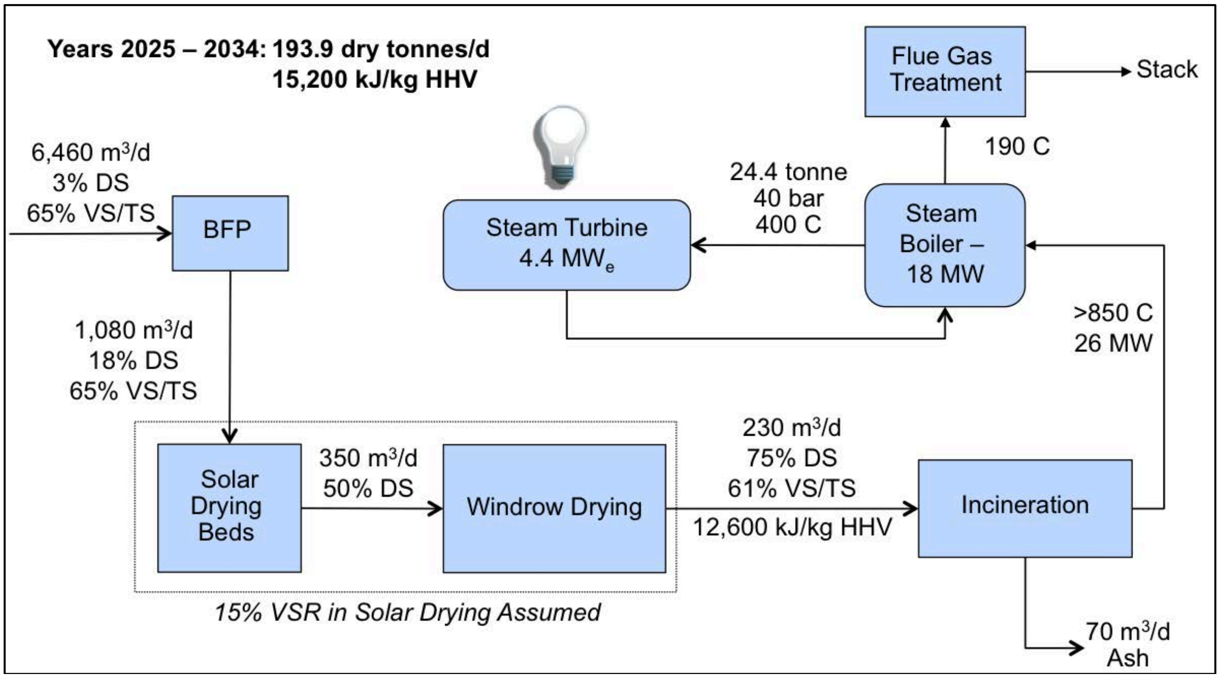

Figure 9. Energy and mass balance for the incineration option.

<u>Gasification</u>
Close-couple gasification as described in Abu-Orf and Goss (2013) was used in this evaluation, assuming processing 75% DS from mechanical windrow drying. The estimated energy recovery from gasification is about 2.5 MW of electricity. Organic rankine cycle technology was used for electricity production from thermally oxidizing the syngas generated from gasification process. Figure 10 shows a schematic diagram of the energy and mass balance for the gasification option.

<u>Cement Kiln</u>
Using dried biosolids in cement kilns to replace coal is widely practiced. Several cement kilns are available in Jordan, with a major facility close to the As-Samra WWTP. Mechanical windrow drying would achieve the required 75% dryness required for cement kilns operation. Coal cost in the Kingdom of Jordan is about three times the cost of coal in the USA; thus using biosolids in lieu of coal can be of great benefit to cement kiln operations, and consequently the As-Samra WWTP. The ash produced from the biosolids is used in the cement production itself. There is no electricity production from the cement kiln option. Figure 11 shows a schematic diagram of the energy and mass balance for the gasification option.

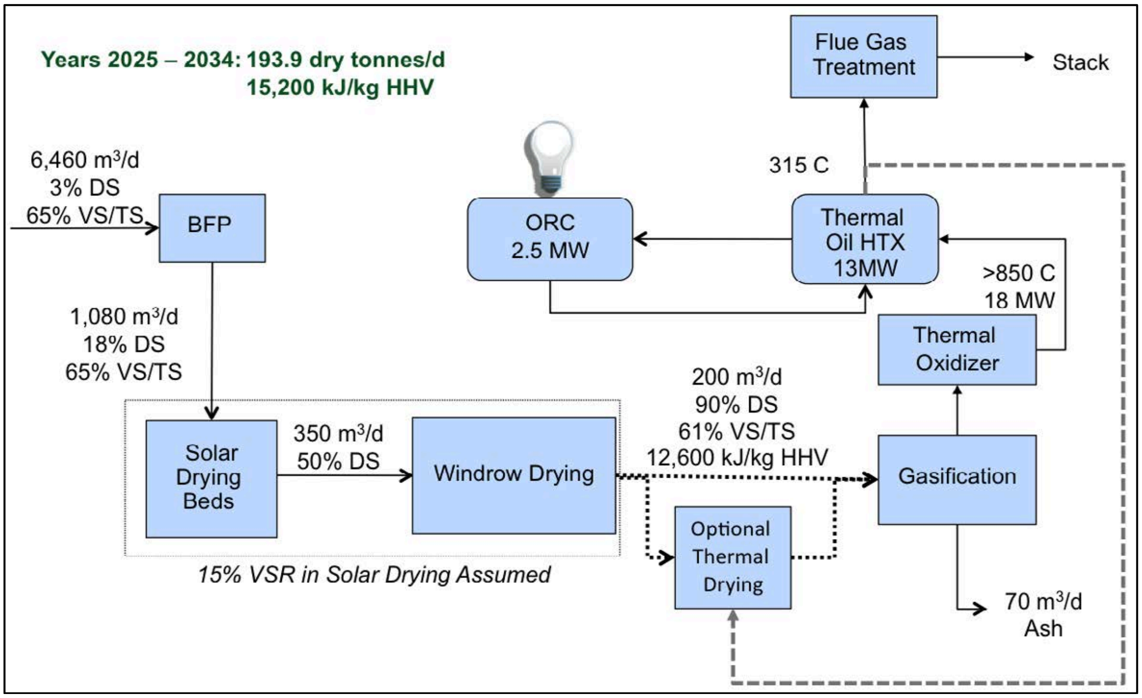

Figure 10. Gasification Process Flow Diagram.

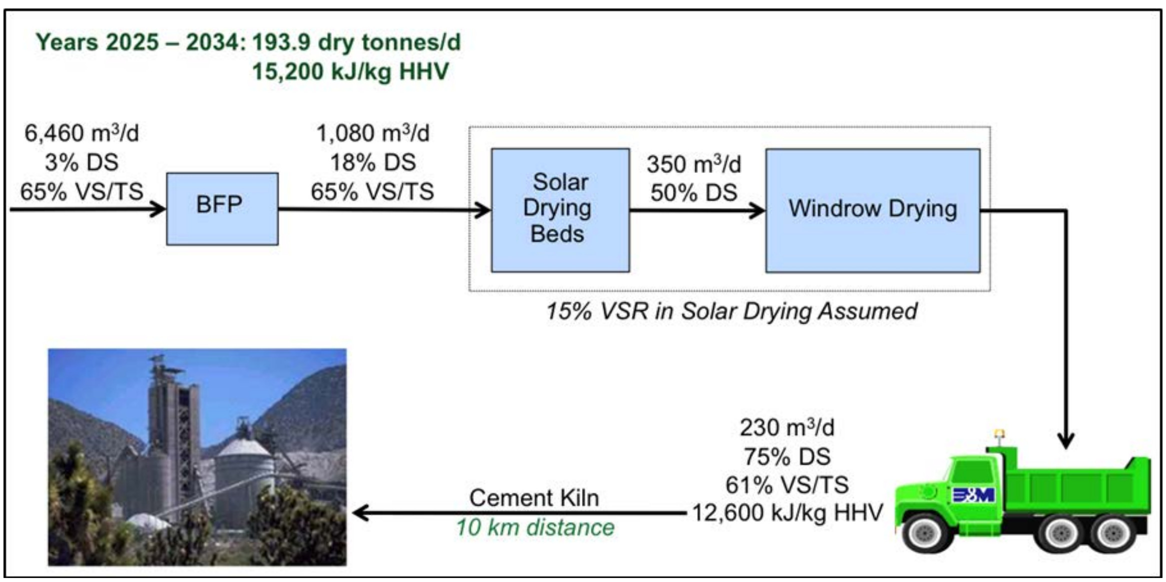

Figure 11. Cement Kiln Process Flow Diagram.

Carbon Footprint Evaluation

The greenhouse gas emission accounting was performed in accordance to the Biosolids Emissions Assessment Model (BEAM), which was specifically developed for biosolids and is one of the most widely adopted protocols in North America. The emissions accounting includes three types of compiled direct and indirect emissions: direct within the fence of the WWTP; indirect, resulting from purchased or generated electricity, steam or heat; and emissions associated with purchased chemicals and offsite hauling. It should be noted that using biogas for generating electricity is considered biogenic, and CO_2 emissions present in the flue gas are not accounted for. However, NO_X and methane emissions are included in the analysis. The analysis was based on the operating parameters only.

RESULTS AND DISCUSSION

The following sections discuss the results of options evaluation including 20 years Present Worth and carbon footprint evaluation of the four shortlisted options; evaluation of the options ranking; and preliminary financial analysis.

Present Worth Cost Analysis and Carbon Footprint Results

Table 4 presents the metric comparison of the four evaluated options. The table presents the construction cost, the electricity production amount, the annual operating costs, the expected cost per dry tonne produced, and the carbon footprint of each option presented as tonnes of equivalent CO_2 produced per year. For the cement kiln option, the table presents two scenarios: one where biosolids are given away and one where $14.1 per tonne revenue is generated from the sale of biosolids (which translates to 10 Jordanian Dinars as of writing this paper). To summarize the results from Table 4:

- The cement kiln option represents the lowest capital investment cost followed by monofill and incineration.
- The actual costs and potential revenue from the cement kiln option will depend on the terms negotiated with the cement kiln.
- The incineration option provides the highest electricity generation followed by gasification and monofill. As indicated, incineration provides the highest revenue in terms of annual operating cost, followed by gasification and then monofill. The cement kiln option does not provide any electricity generation on site.
- The least cost alternative per dry tonne of biosolids processed incorporating capital and operating costs is the monofill option, followed by the cement kiln option with $14.1/tonne revenue, followed by incineration, followed by cement kiln with no revenue, and then gasification.
- The carbon footprint is a significant environmental impact indicator for the respective options. The cement kiln would result in the highest carbon credit, followed by incineration. The monofill has the highest carbon footprint even with the electricity generation, primarily as a result of methane gas escaping during landfilling of the biosolids and prior to construction of a cover for the respective landfill cells.
- The gasification option for the design biosolids loading is estimated to be approximately 1.5 times the cost of the incineration option while providing only 60% of the electricity production of incineration. Given that environmental, social, and technical considerations for the two options are essentially the same, and the significant difference in cost and electricity generation, gasification was therefore not considered further in the selection process.

Ranking Criteria Options Results

Evaluation of options focuses on four major criteria: technical considerations, environmental considerations, financial considerations, and socio-economic considerations. Weights for these criteria were established during initial workshops with stakeholders and then each criterion was given a score of between 1 to 5 with 5 being most favorable. Table 5 presents the criteria evaluation results. As previously indicated, the gasification option was not carried forward for this evaluation.

As the total score presented in Table 5 shows, the incineration and cement kiln options are essentially equal. However, the three options ranked within 15% of each other and all of them should be considered further. Notable differentiators for the three ranked options are presented in Table 6.

Table 4. Metric comparison of the four evaluated options (M represents Million $).

	Monofill	Incineration	Gasification	Cement Kiln (Zero Revenue)	Cement kiln ($ 14.1/tonne Revenue)
Capital Cost, M $	26.7	90.9	93.3	16.1	16.1
Electricity, MW	2.5	4.3	2.5	0	0
Annual Operating Cost, M $	(1.88)	(5.08)	(0.99)	(0.96)	(0.37)
20 year PW, M $	(16.5)	27.5	165.4	42.0	15.4
Cost, $/dry tonne	(17.3)	19.5	116.9	29.6	10.9
CO2 eq. tonnes/yr	6,668,000	- 16,675	- 833	-56,970	-56,970

Table 5. Scoring or shortlisted options per considered criteria.

Criterion	Weight %	Score of Options		
		Incineration	Monofill	Cement Kiln
Technical	22%	95	81	110
Environmental	25%	104	75	97
Financial	30%	100	100	100
Socio-economic	23%	86	81	84
Total score		**395**	**337**	**391**

Table 6. Overall options comparison.

Incineration	Monofill	Cement Kiln
• Greatest capital cost required to initiate program. • Based on the sensitivity analysis, the net return on the investment would increase notably with increase in energy costs and revenue. • Greatest carbon credit and would be available to the GoJ. • Reliable technology in a P3 scenario. No risk associated with reliance on outside industries.	• Medium capital investment. • Lowest overall cost option assuming 50% methane gas recovery for energy generation. • Additional drying beyond current SPC requirement of 50% not anticipated. • Could strategically begin as an interim option. • Not likely to be viable as a BOT opportunity. • High operations risk requires involvement of a services operator contract due to complexity of methane gas extraction in a sludge/biosolids only landfill. Not recommended to be operated by public entity. As previously discussed, monofills are not widely practiced.	• Least capital investment required for the GoJ. • Requires negotiation with a limited number of cement companies and possibly as few as one given the significant distance to transport biosolids for most companies, and some could use only a relatively small percentage of the generated biosolids. • Required dryness and desire to transport varies between cement companies, complicating negotiations. The process of drying from 50% to 75% or as desired could be deferred to the cement companies, and performed either on their own sites, or on a dedicated area of land at the As Samra facility. • Some risk associated with the solvency of the cement companies. • Would not require landfill of ash, as the ash would likely be utilized in the final cement product. • The cement company nearest to As-Samra is modifying its facilities to accept alternate fuels such as biosolids. Modifications are expected to be complete in late 2014

Preliminary Financial Analysis

For a clearer understanding of the potential financial implications to Jordan's Ministry of Water and Irrigation (MWI) for the remaining three options, a preliminary financial analysis was performed. Table 7 presents the analysis for the various options considered (including two each for monofill and cement kiln alternatives), as follows:

1. Incineration with energy recovery at 75% dryness
2. Monofill without energy production, for the purpose of biosolids disposal

3 Monofill with energy production
4 Cement kiln option with biosolids at 75% dryness with no fee to the cement companies
5 Cement kiln option with biosolids at 75% dryness and a $14.1 (10JD) per tonne fee

Table 7. Financial Analysis Results of Options.

	Incineration with Energy Production	**Monofill without Energy Production**	**Monofill with Energy Production**	**Cement Kiln with Zero Fee**	**Cement Kiln with $14.1 per tonne Fee**
Construction Cost (M $)	90.95	18.47	27.92	16.07	16.07
Total O&M (M $)	66.85	14.38	31.58	19.32	19.32
Total Revenue (M $)	167.23	0	84.46	0	25.95
Salvage Value (M $)	14.95	n/a	n/a	n/a	n/a
Internal Rate or Return	2.0%	Negative	6.2%	Negative	Negative
Net Present Value (M $)	(26.93)	(18.19)	0.99	(26.09)	(11.70)

The above analysis assumes a Jordanian Interest Rate of 5.6% with a 20-year project period for all options. However, the monofill options include cost and benefits for the 4th cell during years 21-25. The results of the preliminary financial evaluation are as follows.

- Incineration, if grant funded by a donor, would provide continuous revenue with very little risk. However, through discussions with MWI, we understand that grant funding is not available for this activity. Because of the low internal rate of return (IRR), the option would not be attractive as a BOT opportunity.
- The cement kiln option would be costly to the MWI given the cement companies' unwillingness to pay an equitable amount for the dried biosolids.
- The monofill option with energy production is the best cost alternative. However, the cost recovery is not expected to begin until year six of the program, and peaks in the later stages of the program. Also based on the resulting IRR, this monofill option would not be attractive to potential investors as a BOT opportunity.

CONCLUSIONS AND RECOMMENDATION

The results of the evaluation indicated that all three final options are technically viable and could be carried forward. While the incineration and cement kiln options scored the highest in the evaluation criteria, the monofill scored a reasonably close third with no notable obstacles in its implementation provided it is operated by the private sector. Financially, the monofill with energy production option is currently significantly more viable. Accordingly, it is recommended that the project moves forward with the monofill with energy production option.

Currently the feasibility study for this option is ongoing and, in parallel with the early stages of the feasibility study, discussions should continue with the cement companies to further determine whether they may be willing to reconsider their current valuation of biosolids produced and dried at As Samra so that the cement kiln option becomes more financially viable.

The arid local conditions in the kingdom favor using solar drying of the dewatered biosolids followed by mechanical windrow drying process to further dry to greater than 75% TS in lieu of extensive use of the energy thermal drying process. The practice of solar drying allowed revenue from monofilling the biosolids at slightly greater than $17 per dry tonne. For incineration, this solar drying followed by mechanical windrow drying resulted in energy recovery from incineration, reducing the cost of dry tonne processing by incineration to about $20. With available funding for capital investment, this cost is nominal and very attractive compared to costs incurred elsewhere (e.g., North America). If energy costs increased in Jordan to 50% of its current value, the incineration option becomes more economically attractive. However, capital funding remains an issue in Jordan for implementation.

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