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Triple Bottom Line Evaluation of Biosolids Management Options

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TRIPLE BOTTOM LINE EVALUATION OF BIOSOLIDS MANAGEMENT OPTIONS

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ABSTRACT AND BENEFITS

Abstract:

The overall goal of this energy project was to aid water resource recovery facilities (WRRF) in moving toward "net-zero" energy use through near-at-hand practices and technologies in the areas of energy conservation, demand reduction, and enhanced production. Many WRRFs looking to become *Utilities of the Future* are using Triple Bottom Line (TBL) assessments to inform decisions about opportunities for long term sustainability, and to evaluate common wastewater solids management technologies and processes amenable for energy recovery based on social and environmental impacts, as well as financial metrics.

Funded through a collaborative effort between the New York State Energy Research and Development Authority (NYSERDA) and the Water Environment Research Foundation (WERF), researchers used a TBL approach to evaluate common wastewater solids management technologies and processes relative to their potential for long-term sustainability, including energy neutrality. The TBL assessment began at the point where solids are removed from wastewater (in primary and secondary clarifiers) and continued through the end use, or disposal, of the final product(s). To the extent practicable, the assessment included anaerobic digester sidestream treatment processes.

Benefits:

- Provides WERF subscribers and the ratepayers of New York State with the results from triple bottom line sustainability assessments of numerous biosolids-to-energy and other biosolids management practices.
- Helps wastewater professionals – and the broader community of stakeholders they serve – methodically evaluate economic, environmental, and social implications of different biosolids management options.
- Includes tool to aid utilities who wish to conduct TBL studies on their biosolids-to-energy practices and opportunities.

Keywords: Energy recovery, biosolids, triple bottom line, energy production.

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LIST OF ACRONYMS

AD	Anaerobic Digestion
BEAM	Biosolids Emissions Assessment Model
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BTU	British Thermal Units
CCME	Canadian Council of the Ministers of the Environment
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
DALY	Disability-Adjusted Life-Years
DS	Dry Solids
DSM	Demand Side Management
DTPD	Dry Tons per Day
EE	Energy Efficiency
FBI	Fluidized Bed Incinerator
GHG	Greenhouse Gas
GWh	Gigawatt Hour
HRSD	Hampton Roads Sanitation District
ICLEI	International Organization of Local Governments for a Sustainable Future
IOU	Investor Owned Utility
IRR	Internal Rate of Return
kWh/d	Kilowatt-Hours per Day
LCA	Lifecycle Analysis
LCC	Lifecycle Cost
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
MJ/d	Mega Joules per Day
NOx	Oxides of Nitrogen, especially as atmospheric pollutants
NPV	Net Present Value
NUV	Equivalent Uniform Annual Net Value
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
PM	Particulate Matter

SDI	Sustainable Development Indicators
SIA	Solids Incinerator Ash
SO2	Sulfur Dioxide
SSI	Sewage Sludge Incinerator
TRACI	Tool for the Reduction and Assessment of Chemicals
TBL	Triple Bottom Line
UOTF	Utility of the Future
U.S.	United States
USACE	United States Army Corps of Engineers
U.S. EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WAS	Waste Activated Sludge
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRRF	Water Resource Recovery Facility

EXECUTIVE SUMMARY

As in other sectors in society, sustainability has emerged as a forefront goal for the water quality field. Increasing numbers of water resource recovery facilities (WRRFs) are advancing the sustainability of their operations through energy efficiency measures, renewable energy systems, and resource recovery projects. This study provides details on how existing WRRFs use energy management in order to reach sustainability goals. The energy analyses described in ENER1C12 *Net-Zero Energy Solutions for Water Resource Recovery Facilities* (a companion report to this research effort) illuminate the road toward "net zero" energy consumption and near-zero fossil fuel use. The studies show that, as community resources that recycle water, nutrients, energy, and organic matter, WRRFs can provide solutions to a myriad of community needs (water cleansing, waste recovery) while producing renewable energy and products for agriculture.

This report takes those findings a step further to advance the sector understanding of sustainable solids management through use of a triple bottom line (TBL) analysis. Recognizing that there are diverse options for solids management that claim to be sustainable and given the complexity of solids management, it has proven challenging to determine which current technology options and process configurations can yield the most sustainable outcomes and which hold promise for increasing sustainability. This study confirms that from a net-energy standpoint in today's typical WRRF, anaerobic digestion is often a key component of sustainable solids management configurations. But what about when the scope of what defines sustainability is broadened to include more than just an energy profile?

Sustainability is widely defined in business, industry, and the public sector as standing on three pillars: economic, environmental, and social. These are the three components of the triple bottom line (TBL), as shown in Figure ES-1. TBL is a way of thinking about organizations, processes, and projects that focus on impacts in relation to not only economics, but also the environment and the community. TBL analysis has proven to be relatively simple to grasp and is used widely by corporations and government entities worldwide.

WERF sought to develop a TBL tool and analysis to help WRRF managers and engineers further their understanding of sustainable solids management. The resulting TBL approach and model was designed specifically to assist decision making for wastewater solids management and to inform research priorities for WERF and the industry. The TBL tool gives biosolids managers the capability to adapt criteria and weights to their local circumstances with input from stakeholders. Sensitivity models highlight the impacts of changing criteria weights or the inclusion/removal of TBL sub-criteria unrelated to research prioritization (e.g., state of technology, simplicity).

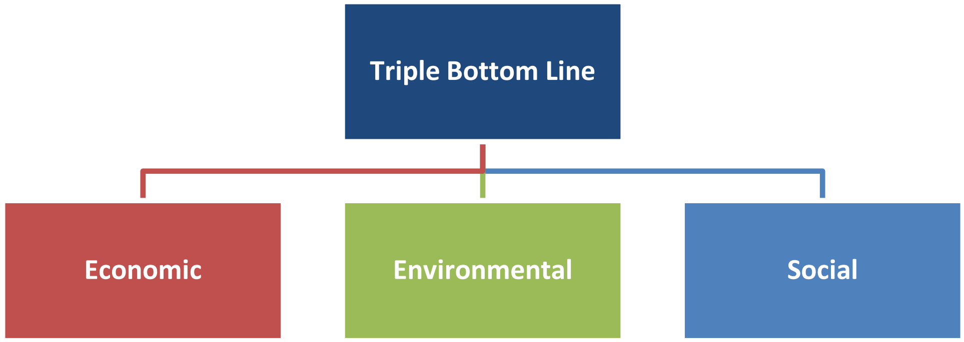
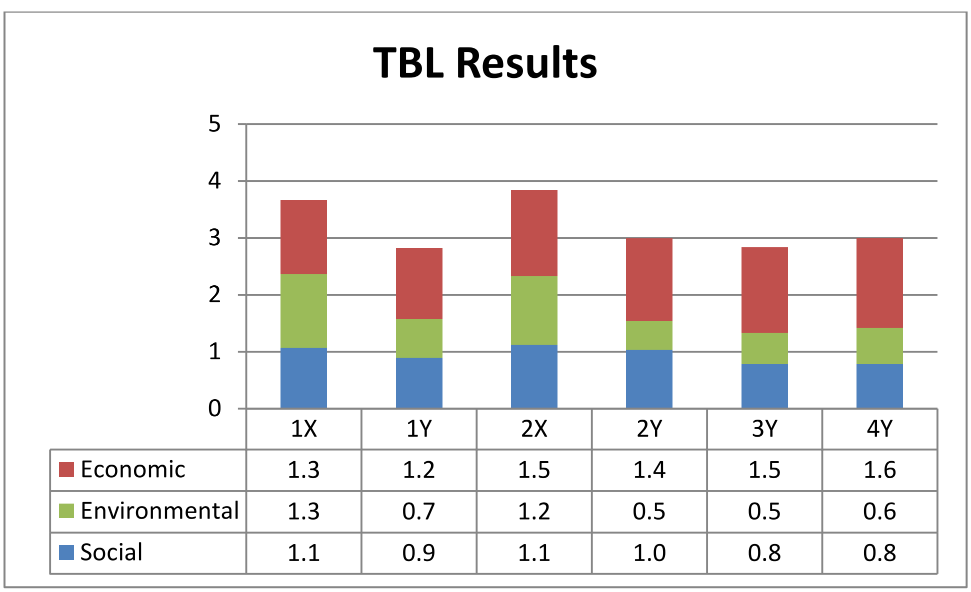


Figure ES-1. Components of the Triple Bottom Line.

This report describes the TBL tool and the results for six different biosolids management options. The six options selected for this evaluation highlight those options with energy recovery potential while being common to the industry.

- 1X – Anaerobic digestion, CHP with pretreatment, with land application.
- 1Y – Anaerobic digestion, CHP with pretreatment, with landfill disposal.
- 2X – Anaerobic digestion, CHP with co-digestion, with land application.
- 2Y – Anaerobic digestion, CHP with co-digestion, with landfill disposal.
- 3Y – Incineration with landfill disposal.
- 4Y – Gasification with landfill disposal.

Each of the evaluated options is based on biosolids management configurations presented in the energy modeling from this project as discussed in the ENER1C12 report. The research evaluates six options with respect to cost, revenue, social, and environmental impacts to the utility. Figure ES-2 shows the summary TBL results for the six options.



	1X	1Y	2X	2Y	3Y	4Y
Economic	1.3	1.2	1.5	1.4	1.5	1.6
Environmental	1.3	0.7	1.2	0.5	0.5	0.6
Social	1.1	0.9	1.1	1.0	0.8	0.8

Figure ES-2. Summary TBL Results for Six Biosolids Management Options.

The most important outcome of this exercise is the creation of the TBL spreadsheet model, which will be useful to biosolids managers and stakeholders alike. The *WERF TBL Tool for Assessing Biosolids Options* is provided as a separate electronic Excel file and is discussed in Appendix B. The model is flexible and can be customized to the user's preference for different criteria weightings, inclusion or removal of criteria, or utility-specific assumptions across a number of variables. The model's built-in flexibility is a critical element that aligns decision-making processes with an organization's or community's values, ensuring that stakeholder needs are considered and best met by the selected alternative.

CHAPTER 1.0

INTRODUCTION

1.1 Assessing Biosolids Management Options

As in other sectors in society, sustainability has emerged as a forefront goal for the water quality field. Increasing numbers of water resource recovery facilities (WRRFs) are advancing the sustainability of their operations through energy efficiency measures, renewable energy systems, and resource recovery projects. This focus on sustainability includes efforts to quantify the impacts of implementing and advancing new and more efficient technologies and processes.

> *"The triple bottom line focuses corporations, not just on the economic value they add, but also on the environmental and social value they add – and destroy. At its narrowest, the term 'triple bottom line' is used as a framework for measuring and reporting corporate performance against economic, social, and environmental parameters."*
>
> – John Elkington, 1998

Because solids contain the majority of recoverable energy and other resources (nutrients, organic matter), they have received considerable attention (Brown et al., 2011(a, b, c); Chen and Beck, 1997; Epstein et al., 2003; Liner, 2009; Marr and Macdonald, 2005; Palme et al., 2004; Peters and Rowley, 2009; Raucher and Garvey, 2008; Roeleveld et al., 1997; Water Environment Federation, 2012(a)). These efforts have increased understanding of what sustainability looks like at WRRFs. At a minimum, sustainability requires two key elements:

- Energy efficiency measures.
- Production of renewable energy (especially from energy-rich solids).

1.2 Background

WERF's 'Net-Zero' project (ENER1C12) is the first research project of its kind to investigate the energy neutrality potential of WRRFs through detailed modeling of the energy and mass balances around individual WRRF unit processes. This study has advanced the understanding of energy balances at WRRFs and provides pathways to maximize energy recovery and reduce energy demand while approaching 'net-zero' at many facility process configurations. The model energy balances and outputs provide input to the TBL study discussed in this report and further informs how existing WRRFs are advancing toward sustainability, especially in relation to energy.

As an extension of WERF's ENER1C12 project, this report focuses on identification of sustainable solids management through use of a triple bottom line (TBL) analysis. The results of the analysis will help inform research priorities for WERF and the industry as a whole, and will inform utility decision making. For instance, biosolids systems that include anaerobic digestion typically optimize the net energy profile of a WRRF. But is anaerobic digestion still most attractive if the analysis is broadened to include more than just an energy profile?

As WRRFs examine sustainability they need decision-support tools, both at the plant site and in the broader, professional community, as their decision making impacts the research priorities and the advancement of innovation. Which technologies and management options can be advanced through research and development without hidden, unanticipated implications, such as greenhouse gas emissions or negative public acceptance? A major goal of this study is to provide sustainability guidance for WERF and NYSERDA on solids management scenarios that warrant further research attention.

1.3 What is a Triple Bottom Line Approach?

A TBL analysis is a method for evaluating the impacts of a project or program on economic, environmental, and social outcomes. The reasons for applying this analysis to decision-making processes for wastewater solids management include the following:

- To provide the broader wastewater management profession a greater understanding of the costs and benefits of various common solids management scenarios.
- To help wastewater solids managers choose the option(s) best suited to their local circumstances with a consideration for all stakeholders.
- To advance the overall sustainability of wastewater treatment operations (water resource recovery).

The goal of assessing a new technology or process is to "realistically answer the simple question: Is this a good long-term investment?" (WERF, 2012c). This begs the question of what makes for a good long-term investment? The term "sustainability" often is used in answering this kind of question.

> *"It is important to note that economic, environmental, and social dimensions of the triple bottom line are interrelated. For example, investments in green building may result in energy cost savings (economic), increased building value (economic), higher occupant satisfaction and productivity (economic and social), and lower natural resource and human health impacts (environmental, social, and economic).*
>
> *A triple bottom line approach to economic development provides a way to consider these connections and configure investments for maximum impact."*
>
> – The Triple Bottom Line Tool, 2013

What constitutes "sustainability" for a sector or organization depends considerably on context and goals. This has resulted in a vast realm of literature and guidance documents on defining sustainability and how to get there. Despite this, the 1987 Brundtland Report's definition remains the most-often quoted and most-widely accepted general definition of sustainability: Sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

Regardless of the definition used, stakeholder involvement in defining and implementing sustainability initiatives is becoming a standard practice in all fields. The importance of this is no different for wastewater solids management. Wastewater solids management may entail a narrow view that only examines the thickening, stabilization, dewatering, and final use or disposal. Or it may explore a larger context that also includes wastewater treatment or green (environmental) infrastructure. The different impacts the choice of scopes has reflects the importance of including stakeholders in the pursuit of “sustainability.”

These are some of the considerations that must be addressed in developing a TBL approach to decision making for wastewater solids management. Therefore, in developing the *WERF TBL Tool for Assessing Biosolids Options*, the researchers began by conducting a literature review that looked at others’ experiences with the following:

- Defining “sustainability” (the scope, degrees, and context).
- Balancing social, environmental, and economic interests in water resources planning.
- Identifying commonly used economic, environmental, and social criteria and reasons for their use.
- Identifying the role of stakeholder participation and its impact on decision making aimed at developing sustainability.
- Understanding the challenge and growing practice of complex decision making (decision making that involves multiple criteria, not just economic numbers – e.g., multi-criteria decision analysis (MCDA)).
- Understanding the use of TBL analysis in reporting an organization’s progress toward sustainability goals.
- Understanding the use of TBL for decision making (including the limited number of examples of applying a TBL approach to wastewater or biosolids management).
- Designing a TBL analysis (including stakeholder involvement, criteria selection, and developing measures for each criterion).

A summary of this literature review is included in Appendix A.

CHAPTER 2.0

TRIPLE BOTTOM LINE EVALUATION

2.1 Background: WERF TBL Tool for Assessing Biosolids Options

TBL evaluations are commonly used as tools for decision-making processes or for reporting organizational progress with regards to economic, environmental, and social criteria. Our focus on TBL is as a tool in the decision-making process. The research team developed a TBL spreadsheet tool and protocol to help WERF, NYSERDA, and other industry research organizations better differentiate and focus biosolids management research on promising sustainability options. The iterative TBL-driven decision-making process can identify the biosolids management option that optimizes possible economic, environmental, and social benefits to a specific community.

The choice of a biosolids management approach has great impact, affecting technology vendors, contractors, other private businesses, neighbors, rate-payers, employees, local politicians, environmental and community groups, the media, and agency management. The scope and scale of that impact render decision making a contentious process at times. A TBL analysis can help because it:

- ♦ Guides and calms the process, directing focus on tangible, measurable differences among options.
- ♦ Helps stakeholders refine their thinking about the importance of different factors or criteria.
- ♦ Breaks down the decision-making process into manageable, individually addressed steps.

The value of a TBL analysis for a specific community or utility in their solids management decision making is directly related to the integrity of the stakeholder involvement process. A TBL analysis includes numerous small assumptions and decisions that, as a whole, add up to a meaningful final decision. If the myriad of small assumptions and decisions are made by only a select few, the outcome will reflect only their biases and the TBL may be a sham exercise. Today, the public expects stakeholder involvement; organizations are advised to involve stakeholders early and often.

The research team developed the TBL tool[*] based on review of the literature and TBL analyses conducted in the water quality sector for biosolids management. Its development included input from experts within the water quality profession. It reflects best current practices in TBL analysis and provides a robust tool, given the following caveats:

- ♦ This TBL tool is useful only when it is understood, adjusted, and applied by a group of engaged and diverse stakeholders in a particular local context.

[*] See Appendix B for the discussion of TBL model tool.

- A TBL analysis does not guarantee answers to any questions: Rather, it helps structure discussions and analysis, ensuring that key economic, environmental, and social impacts are considered.

- Biased adjustment of assumptions and qualitative assessments can undermine the value of a TBL analysis. However, a vigorous stakeholder engagement process minimizes the potential for individual bias to skew the TBL process.

Having stressed the importance of stakeholder involvement when applying the TBL to the decision-making process, it is also important to note that all stakeholders – including biosolids managers, the media, and the public – have the responsibility to understand the proposed options and the TBL tool well enough to generate meaningful and balanced results. One of the goals of this project team has been to honor the various perspectives of biosolids managers, WRRF operators, and public stakeholders during development of the TBL, expanding from a single focus on utility/operational costs, to also include social and environmental costs or benefits. If a project or decision only weighs economic criteria, it is impossible to maximize overall potential benefits.

2.2 General Considerations

TBL analyses can be simple or extremely complex, depending on the number of criteria included. Literature on the TBL identifies several important criteria, however. As a TBL for a particular local decision-making process is developed, it is important to ask stakeholders what they see as the most significant potential impacts of the project.

For the TBL in this report, the research team selected criteria most commonly used in other TBL assessments in the water sector and solids management. However, different stakeholders in different situations may choose other criteria. One TBL analysis cannot fit every need; users of this TBL are encouraged to adapt it to fit their needs.

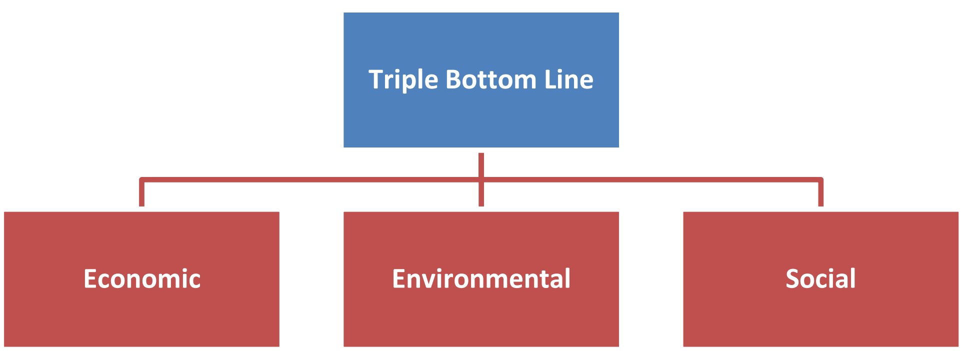


Figure 2-1. Components of the Triple Bottom Line.

2.2.1 Defining the Scope of the TBL Analysis

Determining the scope of a TBL analysis can be challenging. If too narrow, a scope omits key factors. Conversely, an overly wide scope will unnecessarily increase the complexity of a TBL evaluation. The TBL approach in this project defined the scope of solids management to include processes and actions downstream of solids removal from primary and secondary clarifiers. The analysis further includes significant impacts on the liquid treatment processes at WRRFs, as well as social and environmental aspects outside of the WRRF, such as soils, air, water, organisms, neighbors, and communities. This scope is broader than the boundaries in the energy models used in the ENER1C12 study report, which are limited to net-energy use for the solids management processes only (for example, this report includes transportation outside of the plant and land application processes).

2.2.2 Selecting TBL Criteria and Sub-Criteria

The research followed these steps in selecting, defining, and clarifying criteria to be used in this TBL tool:

1. Perform a literature review to identify criteria commonly used in similar TBL evaluations.
2. Review and evaluate the array of potential criteria.
3. Define each potential criterion, including identifying what each criterion addresses.
4. Determine the value of each criterion to the decision-making process and eliminate criteria that result in similar scores among all options.
5. Select the proposed criteria, ensuring that the criteria address all key elements of sustainability.
6. Discard criteria that result in redundancy or "double-counting."
7. Write clear, complete definitions of each criterion.
8. Develop measurements/metrics for each criterion, using measurements that are appropriate and commonly understood by stakeholders (e.g., net present value (NPV), or NOx (nitrous oxide) emissions in Mg/year).
9. Identify existing models that can be leveraged to help calculate specific measurements for specific criteria, such as the BEAModel for greenhouse gases.
10. Develop a clear and simple ranking system for criteria that are not subject to specific measurements (such as many social criteria) and provide the TBL user with a ranking matrix.
11. Determine how the measurements/scores will be normalized, using a similar scale for each criteria (See Section 2.6.3 for several normalization techniques).
12. Weight the scores applied to each category (economic, environmental, and social) and criterion. Categories are often weighted equally (33.3% each).

Qualitative vs. Quantitative

TBLs commonly include criteria that are evaluated with qualitative scores, such as, in the current TBL, scores from 0 to 5. Qualitative scoring is needed when there is no clear measurement of a particular criterion. For example, "regulatory flexibility" or "visual impacts" are hard to quantify, but they are important considerations. In contrast to qualitative scores, quantitative TBL criteria are able to be more objectively estimated. For example, economic criteria are estimated using actual capital and operating costs observed at facilities.

For this TBL tool, the project team agreed upon recommended weights; the rationale for which is included in the discussions of the criteria below. In addition, a survey of project advisors – leading professionals in the field – provided an alternative set of weights used to adjust the TBL tool criterion weighting for this study.

The complexity of a TBL analysis can vary from the very simple (qualitative scores for the three, equally weighted major categories – economic, environmental, and social) to evaluations using calculated quantitative values for criteria within each category (nested formats). The most detailed and involved process for scoring would involve assigning scores to sub-criteria – the lowest level in the nested format – and summing the sub-criteria to obtain a score for the criteria. Use of nested criteria and sub-criteria allows greater detail in the analysis, while maintaining a balance among the major criteria.

The spreadsheet model presented here includes one level of criteria below the major categories and, for some criteria, two levels of sub-criteria. Depending on the needs of the situation and decision-making process, two or three levels of criteria and sub-criteria can be used.

In choosing the criteria for the current TBL for biosolids management options, the research team took into account fundamental principles common to most TBLs, such as ensuring that the approach includes “upstream” and “downstream” impacts of technology choices, and defines criteria to be “directional, concise, complete and clear” (Yoe, 2002):

- **Directional** (it is clear in what direction a positive score is): For example, it is clearly desirable to minimize nuisances, release of pollutants, and costs, and it is clearly desirable to maximize such things as nutrient use, flexibility, and workplace safety.
- **Concise:** It is best to use the smallest number of criteria possible that still allow for discerning differences among alternative biosolids management options/configurations.
- **Complete:** It is important to have the criteria address all aspects of the option; no significant impact is omitted.
- **Clear:** Each criterion can be measured in simple quantitative or qualitative terms.

The criteria chosen for this TBL include many of the criteria common to existing TBLs related to biosolids use, such as those completed by Hampton Roads Sanitation District (HRSD), AlexRenew, Capital Regional District (Victoria BC), Johnson County Wastewater, Melbourne Water, and Metro Vancouver (formerly Greater Vancouver Regional District). However, fewer criteria are used in this TBL to avoid overlapping scopes and to reduce complexity, with the intention of producing a useful TBL analysis and ensuring that that every criterion is helpful in making distinctions between solids management configuration options (as suggested by Pomerol and Barba-Romero, 2000).

2.3 Economic Criteria for This TBL Analysis

The research team's initial review of wastewater utility TBL survey results showed two predominant economic criteria approaches that utilities use for TBL scoring (see Section 4.4 for a discussion of the TBL survey conducted as part of this study). A little more than half of the wastewater utilities responding use a simple scale to score different factors. The other responding utilities (more than 40%) use a more comprehensive lifecycle economic assessment approach, with the most common being use of the NPV, which quantifies life-cycle costs and revenues related to an investment.

Since a cost-benefit analysis cannot determine all economic impacts, a complete TBL analysis should examine qualitative effects of a capital allocation decision in terms of the impact on an entity's operations and risks. The researchers recommend supplementing lifecycle economic assessment approach results with engineering/technical criteria. Such criteria are common in multiple utility approaches, are a composite of several sub-criteria, and include the following:

- Simplicity.
- Flexibility.
- State of technology.

For these engineering/technical sub-criteria, the team developed two scenarios. One scenario focuses on informing research priorities. This scenario does not include the simplicity and state of technology criteria in the economic results, as innovative biosolids management alternatives have not been demonstrated as widely as established practices. These criteria shift the weights of this analysis in favor of the status quo, which is not aligned with research objectives. In a second scenario, focused on utility decision making, the simplicity and state of technology are included in the economic score since several utilities use some form of these criteria in their existing TBL models. Chapter 6.0 includes results for these alternative scenarios and compares the six biosolids management options with both approaches.

Each of the above engineering/technical criteria focuses on a different aspect of the potential economic impact of a biosolids management option and will be scored using the project team's judgment and a pre-defined scoring scale. The research team included the above criteria in addition to the lifecycle NPV cost evaluation because many utilities they surveyed use some form of these criteria in evaluating the economic impact of investments. Maintaining flexibility and options for plant expansion are other factors to consider and score. A detailed discussion of each criterion is provided in the following sections.

Note that there is room for interpretation as to whether some of these criteria can be better included in social or environmental categories. An important point of distinction between economic and social/environmental criteria can be the accrual of the benefits. The economic criteria directly affect a company's or utility's operations, while social and environmental impacts are also borne by customers and society at large.

2.3.1 Lifecycle Economic Assessment

Lifecycle costs and benefits are typically used to understand the direct (cash flow) impact of any capital allocation decision. The following methods were considered for measuring the economic impact of the project:

- Simple payback period.
- NPV.
- Internal rate of return (IRR).
- Equivalent uniform annual net value (NUV).
- Risk analysis.
- Scenario analysis.

Any criterion of economic impact should address the following basic requirements:

1. A typical project has an initial capital outlay, operating costs and benefits and a terminal cash-flow. The assessment method should reflect all costs and benefits over the entire project life. Figure 2-2-1illustrates an example of the life cycle of an investment.
2. Time value of money.

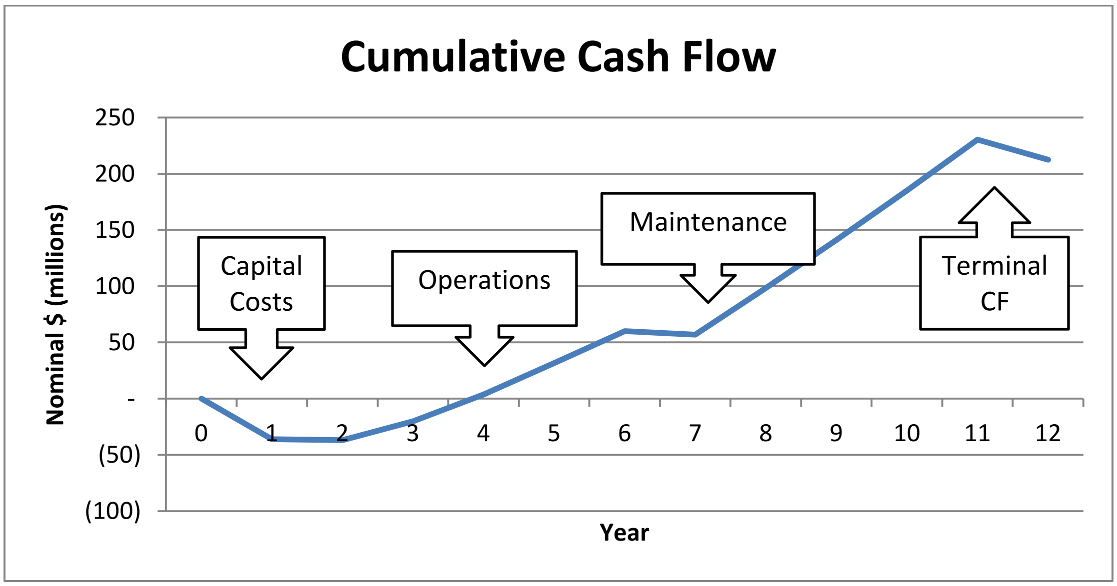


Figure 2-2. Typical Project Cash-Flow Profile.

A simple payback period evaluation does not address full life cycle costs or the time value of money. IRR satisfies the two requirements but IRR calculations can become suspect when cash flows reverse directions more than one time during the project life cycle. NPV and NUV satisfy all requirements. While NUV is a useful criterion to evaluate projects of dissimilar life cycles, the options evaluated in this study have similar life cycles; consequently, NUV does not offer any additional insight beyond NPV.

Using tools such as Monte Carlo simulations to perform risk analyses can provide insight into the key economic assumptions that impact overall project viability. This more rigorous risk analysis approach statistically quantifies the uncertainty associated with various project assumptions. While this report's TBL approach does not explicitly quantify risk using this technique, the TBL approach does evaluate uncertainty through simple sensitivity analysis (which does not incorporate the probability of uncertain assumptions, but does quantify the potential range of impact on the results).

Sensitivity analysis identifies the range of cost estimates expected for each option based on particular cost sensitivity assumptions. This report used this relatively simple method to quantify the potential costs resulting from unknown future conditions, essentially testing the sensitivity of different TBL results.

The research team's recommended approach is to use a simplified NPV model for different biosolids management options. The researchers chose this approach since it incorporates all life cycle costs, is well-accepted and understood by many industries, and incorporates the time value of money (the cost of capital). The WERF factsheet *Reframing the Economics of Combined Heat and Power Projects*, generated as part of the WERF research study *Barriers to Biogas for Renewable Energy* (OWSO11C10) further discusses this approach.

2.3.2 Engineering/Technical Criteria

The research team was careful not to discourage innovation by giving low scores for currently unproven technologies. This decision counteracts a critical institutional bias or inertia against technologies or processes that have great potential benefits but, since their recent emergence, are considered 'unproven.' There are potential disadvantages when implementing new technologies; for example, additional training costs of staff may pose additional financial burdens on a utility. Therefore, it is important to weigh the costs of implementing new technologies against the advantages of the technology through use of a balanced TBL analysis to ensure a comprehensive evaluation.

Engineering/technical criteria can be used to represent qualitative effects of a capital allocation decision on an entity's operations and risks. While utilities' TBL criteria and definitions differed, many utilities' models included criteria that addressed simplicity, flexibility, and state of technology. Consequently, these concepts were included in the TBL model as sub-criteria under Engineering/Technical Criteria, as shown in Figure 2-3. As discussed, the base case evaluated in this report, to inform research priorities, does not include simplicity and state of technology criteria. The research team conducted a sensitivity analysis, including all engineering/technical criteria in order to evaluate the impact of these weighted criteria on the results. Definitions of these sub-criteria are as follows:

Simplicity: Complex technologies add to operational risk for failure. A simple-to-operate and easy-to-understand technology is more likely to be accepted by the workforce. Regular maintenance is also likely to be easier, resulting in lower downtime.

Flexibility: A technology that accommodates a wide range of options for maintenance and capacity expansion is more likely to serve future needs with minimum downtime. The capability to convert or modify a technology to support future needs and processes increases flexibility.

State of Technology: Operational and maintenance costs and performance of a well-established technology are better understood than those associated with an unproven technology, reducing perceived risk. Well-established technologies score higher in this TBL sub-criterion.

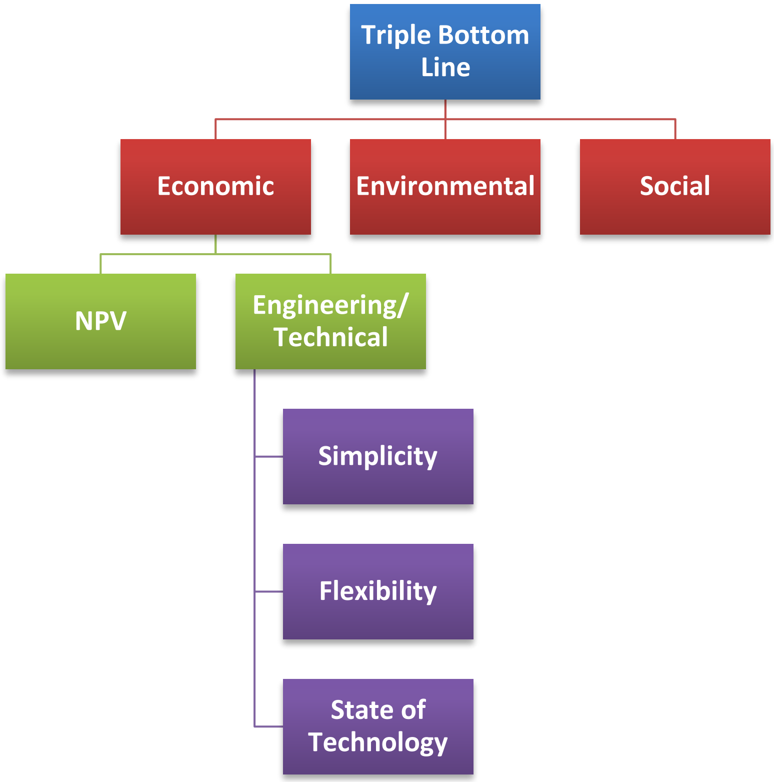


Figure 2-3. Economic Sub-Criteria for This TBL.

2.3.3 Additional Considerations

Some utilities have used other criteria in their capital allocation process, apart from the criteria discussed above. The following partial list of economic criteria not included in this report, but that utilities used in TBL assessments include:

Economic Impact on Stakeholders: Some utilities score or assign dollar amounts to economic impact on other stakeholders such as local community, business owners, etc. However, assigning dollar values may be challenging and may oversimplify the impacts. The social category often addresses impacts on stakeholders more effectively.

Tax Revenue Impact: A proper lifecycle costs analysis would include all tax and revenue impacts. There is no need for this criterion if lifecycle cost (LCC) is used.

Maintenance/Initial Capital Outlay: A proper lifecycle cost analysis would include these considerations. There is no need for this criterion if LCC is used.

Cost to Ratepayers (Rate-Impacts): Regulatory institutions often require utilities to address this criterion, especially when large investment is needed. If it is part of the decision-making process, this criterion can replace NPV as long as it does the following:

- Accounts for the entire project lifecycle.
- Accounts for the time-value of money.

The team prefers using NPV to compare options, as it is less sensitive to utility-specific regulatory and financial mechanisms and assumptions.

2.4 Environmental Criteria for This TBL Analysis

The environmental criteria chosen for the model consist of three major criteria with several nested sub-criteria, based on our review of environmental criteria in earlier water and wastewater-related TBLs and discussions among the project team. The environmental criteria are:

- Conservation/optimization of resources.
- Net impacts on media (soil, water, air).
- Compliance with regulations.

Conservation/Optimization of Resources

Conservation of resources is an environmental criterion found in virtually all of the TBLs reviewed. For this model, conservation of resources refers to maximizing resource recovery of the nutrients, energy, and water found in biosolids. Various technologies may maximize the use of a portion of the resources inherent in biosolids, but a well-structured TBL ultimately results in higher rankings for technologies that capture the greatest sum of these resources.

Conservation of resources is additive. Consequently, biosolids management systems that recover several resources, such as methane from anaerobic digestion and nutrients through land application, rank higher than similar treatment processes without land application.

Energy recovery from biosolids is a criterion that inherently overlaps with economic factors. While the NPV analysis in the economic option includes revenues or avoided costs from energy recovery, energy recovery also falls within the environmental criteria. Maximizing the use of resources is an indicator of sustainability, as well as a stated goal of entities participating in a TBL approach to decision making. As an example, for two technologies with similar costs and revenues for energy recovery, the technology with the higher net energy recovery should rank higher. Additionally, inclusion of an energy recovery criterion in the environmental category allows stakeholders to reflect a goal of energy recovery, independent of its economic benefits.

Water recovery and water conservation associated with biosolids treatment and beneficial use were included as sub-criteria of the conservation/optimization of resources criterion. The increase in water-holding capacity related to the organic matter biosolids added to soil is generally a desirable attribute, but retains location-specific weights. As an example, land application and composting programs that improve the water-holding capability of soils may be more important to utilities in arid climates and consequently receive higher weights than utilities in more temperate locations.

The final sub-criteria for conservation/optimization of resources include the following:

- Nutrients (nitrogen and phosphorus).
- Fixed carbon (consisting of the following 2nd level sub-criteria).
  - Greenhouse gas emissions.
  - Energy recovery.
- Water conservation.

Net Impacts on Media

Biosolids have the potential to both improve and negatively impact soil, water, and air quality depending on the chosen methods for biosolids management. For example, biosolids can improve soil fertility (through the addition of nitrogen, phosphorus, and micro-nutrients), as well as the physical and biological properties of soils, by increasing soil organic matter, soil biology, and the erosion-resistance of soil. Additionally, utilities can use biosolids compost to treat stormwater run-off in the form of bio-retention swales or in other low-impact development management practices. Finally, the remediation of disturbed sites can improve soil characteristics while increasing wildlife habitat for many species. These potential benefits should be considered in measuring the sustainability of biosolids processing technologies.

On the other hand, over-application of the nutrients contained in biosolids can accelerate eutrophication of downstream water bodies. Treatment technologies can also impact the environment, such as VOC emission from composting, NOx and particulates from biosolids combustion. Impacts from some of these criteria, such as air emissions of NOx and particulate matter can be quantified and consequently lend themselves more easily to rankable metrics. For instance, in Metro Vancouver's assessment of biosolids management options, the modelers were able to provide an assessment of the impacts of criteria air contaminants (NOx, SOx, and particulate matter) from the investigated options based on disability-adjusted life-years (DALY).

Metrics for impacts from other criteria that are less quantifiable, such public perceptions of land applied biosolids that meet regulatory requirements, are harder to apply, and must be based on local factors. The final sub-criteria for net impacts on media include the following:

- Impacts to land/soil.
- Impacts to air (consisting of the following 2nd level sub-criteria).
  - NOx.
  - SO2.
  - Particulate matter.
- Impacts to water.

Compliance with Regulations

While all evaluated biosolids options must comply with current regulatory requirements, use of a regulatory criterion allows a differentiation of options based on the ease with which certain biosolids technologies allow compliance with existing regulations and the flexibility for meeting reasonably anticipated future changes.

For example, if a WRRF with relatively high arsenic concentration in their biosolids was considering a land application option, this option may rank lower than non-land application options due to the inherent variability in the material. Such variability may suggest that the biosolids would not consistently and easily meet the arsenic standard. Additionally, any incremental lowering of the arsenic standard would be more likely to have a negative impact on the sustainability of this option.

In terms of flexibility for meeting future changes in regulations, the potential for bans on landfilling organics may rank landfilling lower in the regulatory criterion than it would for incineration or land application/composting. Similarly, the potential for stricter standards for air emissions from sewage solids incinerators may drive a lower ranking for combustion options, even if current emissions control technologies meet existing regulatory requirements.

Consequently, the regulatory criterion used in this TBL analysis is ranked using a qualitative assessment of the flexibility of a biosolids management system to comply with existing regulations and predicted future changes in regulations.

The structure of the environmental criteria and sub-criteria for this TBL analysis is displayed in Figure 2-4.

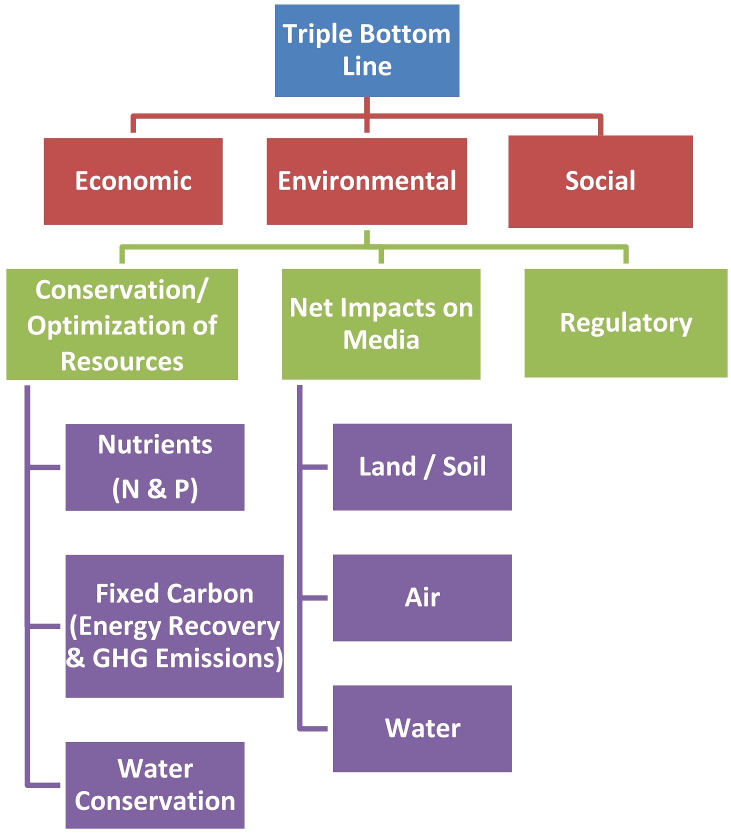


Figure 2-4. Environmental Criteria and Sub-Criteria for This TBL.

2.4.1 Use of LCA Within the Environmental Criteria

Some of the environmental criteria listed here for consideration lend themselves to life cycle analysis (LCA). Thus, using LCAs in a TBL may provide more precise metrics for several of the environmental criteria.

The research team used the Biosolids Emissions Assessment Model (BEAModel) to quantify GHG emissions (an element of the Fixed Carbon sub-criteria) in this TBL. The Canadian Council of the Ministers of the Environment (CCME) developed the BEAModel in order to quantify GHG emissions from various biosolids management options. Several other LCA options exist that may be incorporated into the environmental criteria portion of a biosolids TBL. For instance, Peters and Rowley (2009) used LCA methods to compare water use, total energy consumption, carbon footprint, human toxicity potential, and terrestrial ecosystem toxicity of several different biosolids processing and end-use options. Another example is Metro Vancouver's use of an EPA-developed LCA model called TRACI (Tool for the Reduction and

Assessment of Chemical) to determine environmental burden and human health impacts in their biosolids technology assessment.

One caution in using a LCA within the TBL is to minimize overlapping, or double-counting of criteria. For instance, results from the BEAModel provided metrics for the fixed-carbon sub-criteria of conservation of resources as well as for scoring methane and nitrous oxide emissions. As designed, no overlap of these emissions with the air emissions component of the net-impacts on media criteria exists. However, this is the type of issue that requires review when developing TBL analyses.

2.4.2 Examples of Environmental Criteria Considered, But Not Included

Several criteria used in previous TBLs were either eliminated or nested within proposed criteria in an effort to limit the number of environmental criteria in the TBL model. As an example, solids minimization is a criteria included in Johnson County Wastewater's TBL. Technologies employing solids minimization will rank higher in the NPV process in the economics portion of the TBL (related to lower transport and processing/end use costs) and will influence (lower) the carbon/energy ranking in the environmental criteria. Similarly, the risk of site remediation, an environmental criterion in the Central Regional District's TBL, should be accounted for in the proposed criteria addressing impacts to air, water, and soil and in the regulatory criteria.

Another criterion suggested by a reviewer for inclusion in the environmental category was biosolids product quality (pathogen reduction, vector attraction reduction, etc.) and associated market availability and reliability. However, the intention in this model is to address market availability and reliability aspect of the biosolids product through the economic assessment (this can be done by either scoring this as a separate economic sub-criterion or including price uncertainty in the economic model), and issues related to pathogen reduction and vector attraction reduction are regulatory issues that would be covered in the regulatory flexibility component of the environmental criteria.

2.5 Social Criteria for the TBL Analysis

Though it is possible to use quantitative metrics for social criteria, it is difficult to develop this type of scoring for water utilities. For example, the level of public engagement can be determined by raw counts of communications (emails, phone calls, etc.) an organization receives. But most WRRFs and biosolids management programs are not collecting data on such social criteria. By default, many TBL exercises rely on simple subjective scores for evaluating social criteria.

In the current TBL for biosolids management, the project team selected three social criteria based on a review of literature, experience, and best professional judgment regarding which criteria are most important for distinguishing between competing biosolids management options:

- Nuisance issues.
- Workplace conditions.
- Public engagement.

There is widespread agreement on use of some of these criteria, especially “nuisances.” Other social criteria chosen, such as “workplace conditions,” are found in some, but not all, TBLs applied to biosolids management assessment.

2.5.1 Nuisance Issues

Biosolids management involves particular common issues that are suitable for evaluation through the social criteria lens. Most commonly emphasized are nuisance factors, especially the potential for malodors. Under nuisance issues, the research team included the four most significant sub-criteria: odors, dust, visual, and truck traffic. Grouping these as sub-criteria gives these issues similar levels of importance.

Note that weighting of criteria, a later step in the development of the TBL, allows the user to increase the emphasis on one or more of these sub-criteria, depending on the local situation. However, because they are nested within the criterion of nuisance issues, the impact of any single sub-criterion is limited. Some TBLs might move odor to the criteria level, where it would be equal in importance to workplace conditions and public engagement. The team chose not to do that.

2.5.2 Workplace Conditions

Several inherent qualities associated with biosolids treatment that make for uncomfortable work spaces renders workplace conditions an important criterion for biosolids evaluations. For example, workplace conditions are significantly different between a belt filter press (from which odors can readily migrate) and a screw press or centrifuge (which are enclosed systems that emit little malodor).

2.5.3 Public Engagement

The project team identified “public engagement” as the most important social criterion. This criterion was carefully developed after considerable discussion. Several other TBLs include “public acceptance” of the biosolids management option, but the research team considered that too challenging to measure objectively. In addition, public engagement can be a valuable precursor step to public acceptance. While the required level of day-to-day public engagement varies with the biosolids management option, some degree of engagement is recommended for all options. For example, options that generate a compost product require continuous public engagement through interactions with customers who use that product. Conversely, options without biosolids products and minimal nuisance issues may need less continuous public engagement. Therefore, the idea of public engagement was developed, based on the following:

- This criterion easily and significantly distinguishes among different solids management options.
- This criterion stresses the importance of proactive public involvement (WEF, 2013. Solids Process Design and Management), which is key to successful biosolids management.

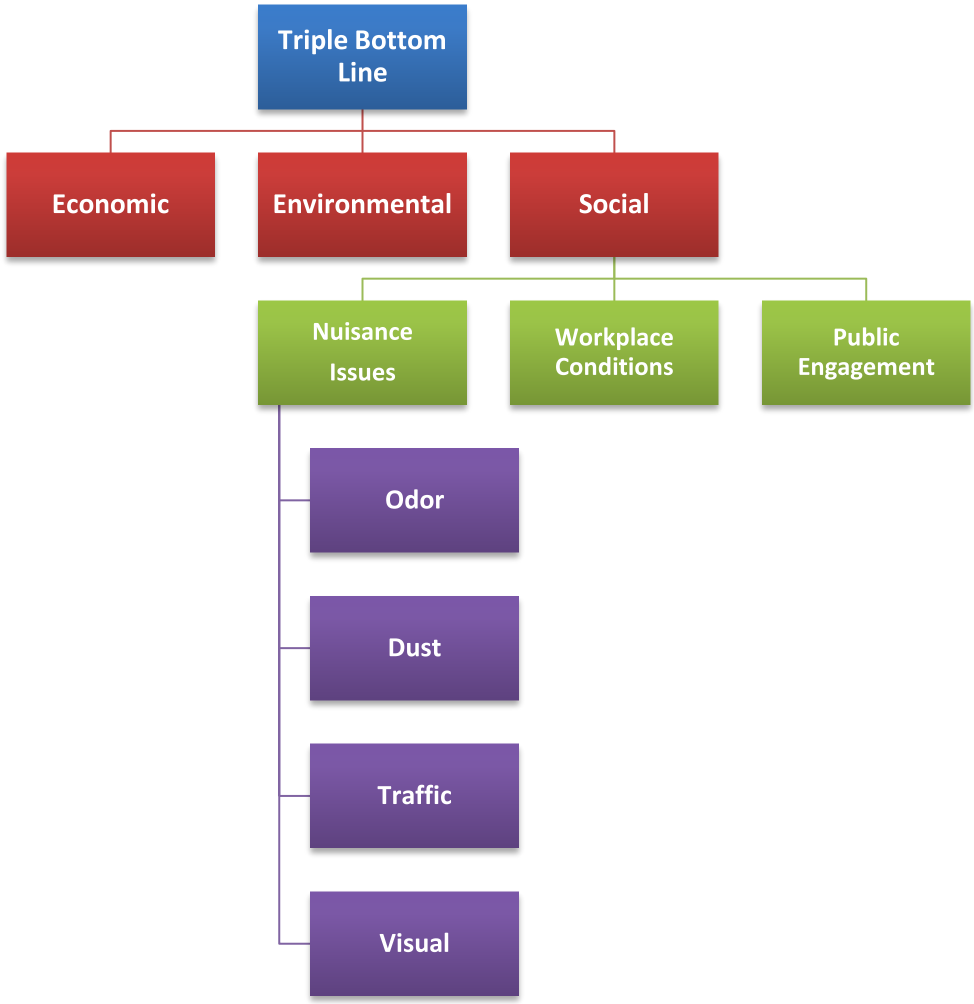


Figure 2-5. Social Criteria and Sub-Criteria for This TBL.

2.5.4 Social Criteria Focus on Inherent Qualities of a Biosolids Management Option

A unique challenge in choosing criteria and measurements in the social category of a TBL is to score technology options based on an "average" rather than an "exceptional" program since operational issues strongly affect whether or not there are social concerns or public acceptance. For example, biosolids management options with the potential to generate more nuisance issues than others will automatically receive lower ratings than options that have lower nuisance potential. However a well-run program can mitigate nuisances, while a poorly run program can exacerbate nuisances. This approach was taken so that the TBL tool could be used in a decision-making process as a way to reduce the risk of negative outcomes around social issues without forcing the TBL user to try to look into the future and determine if a proposed option, once operating, will run well or not. Some current programs, such as DC Water's lime stabilized biosolids program, successfully manage highly malodorous materials, through use of odor specialists at land application sites to minimize application of malodorous loads and strict adherence to application hours to reduce neighbor impacts. In summary, the key question for framing the evaluation of each biosolids management option is whether or not the technology/process/management option presents inherent issues.

2.5.5 Examples of Social Criteria Considered, But Not Included

Several other nuisance issues are found in other TBLs, including noise and aesthetics. Though considered, the team found these to be less of an issue for biosolids management options, as they are not particularly helpful in differentiating between competing options, and are often difficult to score.

Initially, the team considered including safety in the workplace conditions criterion. However, utilities are unlikely to adopt any management option that poses a significant safety threat. Therefore, as a criterion, safety does little to differentiate among different options; all options in serious consideration will be safe.

Many TBLs include some version of a criterion called “jobs.” This was not seen as useful in the current biosolids TBL, because it is unlikely to provide significant differentiation between one biosolids management option and another. Adoption of any new biosolids management option will involve some construction jobs, and the numbers of jobs may vary considerably from one option to another. However, those jobs are short-term. Longer-term impacts on employment during operations are unlikely to differ greatly from one option to the next. For example, land application may involve more field operators, but an incinerator or other technology at the treatment plant requires more maintenance staff time at the facility.

Siting and environmental justice are social criteria commonly used in TBLs that have to do with facility siting. These were not included in the biosolids TBL because the solids management configurations being compared typically assume that the new configuration is added at the existing WRRF site (with the potential exception being the regional incinerator option).

During the development of the biosolids TBL, project reviewers suggested the following additional social sub-criteria:

- Integration.
- Branding/marketing.
- Web presence.
- Availability of product suitable for local use.
- Accessibility of product.
- Use by municipal agency/infrastructure.
- Outreach to local groups – i.e., master gardeners.

These were not included separately in the current biosolids TBL, but most can be seen as part of one or more of the three major social criteria. For example, “branding/marketing,” “outreach to local groups,” and others are incorporated into the public engagement criterion.

2.6 The Criteria: Metrics, Weighting, Normalizing, and Sensitivity Analysis

This section describes the considerations used in developing the criteria.

2.6.1 Choosing Metrics for Criteria

If all measurements related to each criterion or sub-criterion in a TBL are quantitative, cardinal (definite number), and empirical, then subjectivity in the TBL analysis would be limited. But not all criteria lend themselves to such measurements. Therefore, the TBL presented here includes some quantitative metrics (e.g., air emissions, economic assessment) and some that are qualitative (e.g., public engagement, regulatory flexibility) and some that are empirical and some that are subjective. Examples (excerpted from Yoe, 2002) of the types of data to be used include the following

1. Qualitative: Empirical – plan does comply with law.
2. Qualitative: Subjective – plan is equitable.
3. Quantitative: Ordinal – Empirical – big, bigger, biggest.
4. Quantitative: Ordinal – Subjective – good, better, best.
5. Quantitative: Cardinal – Empirical – expected annual benefits of $2,315,000.
6. Quantitative: Cardinal – Subjective – about 5 acres, about 21 acres.

The overall TBL scoring system developed for this project relies on normalizing each score to a range of 0 to 5. Higher values are considered positive. Thus, for example, those biosolids management options that recover a greater amount of the energy inherent in the biosolids are calculated to have a higher (closer to 5) score in the energy recovery sub-criterion. For those criteria in which a higher value is a less desirable outcome, such as costs, GHG emissions, or other air emissions, the values are adjusted (normalized) so that lower values provide higher scores.

Wherever possible, the metrics used to score results from any criterion are the same metrics commonly used in the literature for a specific criterion. For example, for GHG emissions, U.S. tons per year of emitted carbon dioxide equivalents are the chosen metric. For energy recovery, all sources of recovered energy are converted to MJ/day. The economic analysis uses US dollars.

For criteria that require qualitative assessments, such as visual impacts or public engagement, alternatives were simply scored on a 0 to 5 scale, again with the more desirable qualities scoring higher (closer to 5) and the alternatives with the least desirable qualities scoring closer to 0.

2.6.2 Weighting the Criteria

The chosen criteria, sub-criteria, and even the basic three categories of economic, environmental, and social, have varying levels of importance for different groups. For example, respondents of the project survey gave the economic category a range of importance from 30% to 55% (out of a total of 100%). On a sub-criteria level, many biosolids professionals consider odor to be the most significant of the nuisance factors associated with biosolids. Therefore, some would prefer to see more weight given to consideration of potential odors than to visual or other nuisance impacts.

In the current TBL, differences in the importance of various criteria are clearly shown by percentage weights by which each criterion score is multiplied. This is standard practice in TBL analysis. On the TBL spreadsheet for comparing solids management options (which accompanies this report), the weight applied to each criterion appears on the summary scoring tab; each weight can be changed by the TBL user. The weighting determined by the project team was used for the final comparison of the biosolids management alternatives. Additional weighting (including the average weighting from survey respondents) are shown in the model and used for sensitivity analysis.

Weighting is a critical and significant part of a TBL. Weights are reflections of personal bias, and, therefore, every weight should be clearly shown, so it can be discussed and its impacts can be understood. In developing the current TBL, every effort was taken to eliminate hidden weights or biases. For example, the choice of the normalization method, or use of more than one method of normalization, can result in an unintended weighting of some scores relative to other scores.

2.6.3 Normalizing Scores for Comparison

There are several common methods used to normalize a range of values to produce the 0 to 5 criteria numbering range used in the TBL. Since a TBL involves quantitative metrics that have different units, such as grams of air emissions per unit of time, and qualitative metrics, these disparate numbers and units need to be normalized so they can be summed with metrics for other criteria. Several common approaches to the normalization of data include the following (Yoe, 2002):

- Percentage of maximum value.
- Percentage of range.
- Percentage of total.
- Unit vector approach.

As discussed above, when higher values for an alternative represent a less-desirable outcome, normalization is a two-step process, with the first step being to minimize the maximum values, either by changing the sign of the number or by using the reciprocal (inverting the number). Table 2-1 shows the differences in results between four normalization techniques chosen for this TBL tool and using the 0 to 5 scale.

For most criteria where quantitative cardinal data were used as the metric, the normalization was performed using the percentage of maximum technique. This tends to be the most widely used normalization technique and preserves proportionality in the results (Yoe, 2002).

Table 2-1. Differences in Results Among Four Normalization Techniques.

			Score Adjusted to 0 5 Scale			
Alternative	Total NPV	Reciprocal of Total NPV	% of Maximum	% of Range	% of Total	Unit Vector
1	$63,206,645	1.58E-08	3.9	0.5	0.7	1.8
2	$64,985,721	1.54E-08	3.8	0.0	0.7	1.8
3	$55,317,059	1.81E-08	4.5	2.8	0.8	2.1
4	$57,068,765	1.75E-08	4.4	2.2	0.8	2.0
5	$50,241,047	1.99E-08	4.9	4.8	0.9	2.3
6	$49,658,132	2.01E-08	5.0	5.0	0.9	2.3
	maximum	2.01E-08				
	minimum	1.54E-08				
	range	4.75E-09				
	total	1.07E-07				
sq. root of sum of squares		4.38E-08				

Like much of the TBL process, the choice of the normalization technique is an iterative process, based on both judgment and sensitivity analysis. For some metrics, such as net emissions of GHGs, some scores are negative while others are positive. To integrate such scores into the TBL sums, it is necessary to add to each score the amount that is needed to bring the lowest score to zero; that is, the entire set of scores for that metric is slid up the number scale. Then, the usual normalization technique is applied to the set of scores.

2.6.4 Sensitivity Analysis

Sensitivity analyses were conducted on both the weighting and the normalization techniques to determine the impact on TBL output rankings. Such sensitivity analyses improve understanding of the following:

- Those aspects of the TBL tool itself that can significantly affect outcomes.
- Those criteria and metrics in the model that can most significantly affect outcomes.

As part of the testing of the current TBL tool, the project team ran sensitivity analyses of normalization techniques and weights:

- Normalization techniques: It was observed that normalizing quantitative scores to percent of range can result in non-intuitive results. As an example, normalizing three scenarios with NPV cost of $1001, $1000 and $999 using a percent of range technique would allocate scores of 5, 2.5 and 0 respectively on the scale of 0 to 5, even though the NPV results are nearly identical. This would distort the TBL results by placing additional emphasis on NPV.
- Weights were tested using survey weightings vs. project team weightings.

CHAPTER 3.0

OVERVIEW OF SIX SCENARIOS SELECTED FOR TRIPLE BOTTOM LINE ANALYSIS

For this TBL evaluation, the project team evaluated six biosolids management options that have energy recovery and demand implications. These options are generally common to the industry, or there is great interest to advance their use in the industry. They include:

- 1X – Anaerobic digestion, CHP with pretreatment, with land application.
- 1Y – Anaerobic digestion, CHP with pretreatment, with landfill disposal.
- 2X – Anaerobic digestion, CHP with co-digestion, with land application.
- 2Y – Anaerobic digestion, CHP with co-digestion, with landfill disposal.
- 3Y – Incineration with landfill disposal.
- 4Y – Gasification with landfill disposal.

The scenarios have been numbered 1 through 4 to designate the base configuration. “X” and “Y” designate the use of the biosolids cake or ash:

X – The scenario uses land application.

Y – The scenario uses landfill disposal.

Variances of a typical cogeneration configuration were chosen as the basis for four of the six scenarios: combined heat and power (CHP), using anaerobic digestion. These four were developed using combinations of pretreatment (thermal hydrolysis) or co-digestion and landfill disposal or land application for the stabilized cake solids.

The other two of the six scenarios have their own energy recovery configurations. Option 3Y is a fluidized-bed incinerator that sends waste heat to a boiler that drives a steam turbine. Option 4Y is a gasification plant that uses resultant syngas to dry biosolids in a thermal dryer in preparation for gasification. Each configuration was modeled as part of the Task 1 energy modeling in this project (see report ENER1C12). Results from that modeling effort were leveraged for the economic and environmental TBL modeling described in this report.

This combination of energy recovery options encompasses the typical energy recovery approaches in the industry and includes some promising pioneering technologies, such as gasification. Using their prior experience, the team selected these scenarios to highlight options that utilities commonly evaluate when looking at constructing a WRRF. The pioneering technologies evaluated will further assist WERF in identifying future research priorities.

The e-Sankey diagrams in Figures 3-1 through 3-4 provide a summary of energy flows in the six scenarios used in this TBL analysis. Areas shaded in red represent the boundaries of the processes within the WRRFs included in the TBL analysis. Because land application and landfill disposal occur outside a WRRF’s boundary, the 1X and 1Y scenarios and the 2X and 2Y scenarios are represented by a single e-Sankey diagram, respectively. In the diagrams, flow volumes are listed in MJ/d and energy is listed in either MJ/d or kWh/d. These data points are used in the economic and environmental TBL modeling.

3.1 1X/1Y – Anaerobic Digestion, CHP with Pretreatment

Figure 3-1 illustrates the configuration for 1X and 1Y. Each of these scenarios includes BNR liquid stream treatment, WAS mechanical thickening, pretreatment (thermal hydrolysis), anaerobic digestion, dewatering, and CHP. The anaerobic digester produces 67,680 MJ/d of biogas for use in the generator. The generator has been appropriately sized to accept this level of biogas and produces 6,940 kWh/d of electricity for use in the plant. Since this scenario produces a sufficient amount of biogas, supplemental natural gas is not required as fuel for the generator. In the “X” version of this scenario, the 4.7 dry tons per day (here represented as 40,069 mJ/d) of cake that is produced is used for land application as a fertilizer, while the “Y” version of the scenario sends this cake to a landfill for disposal.

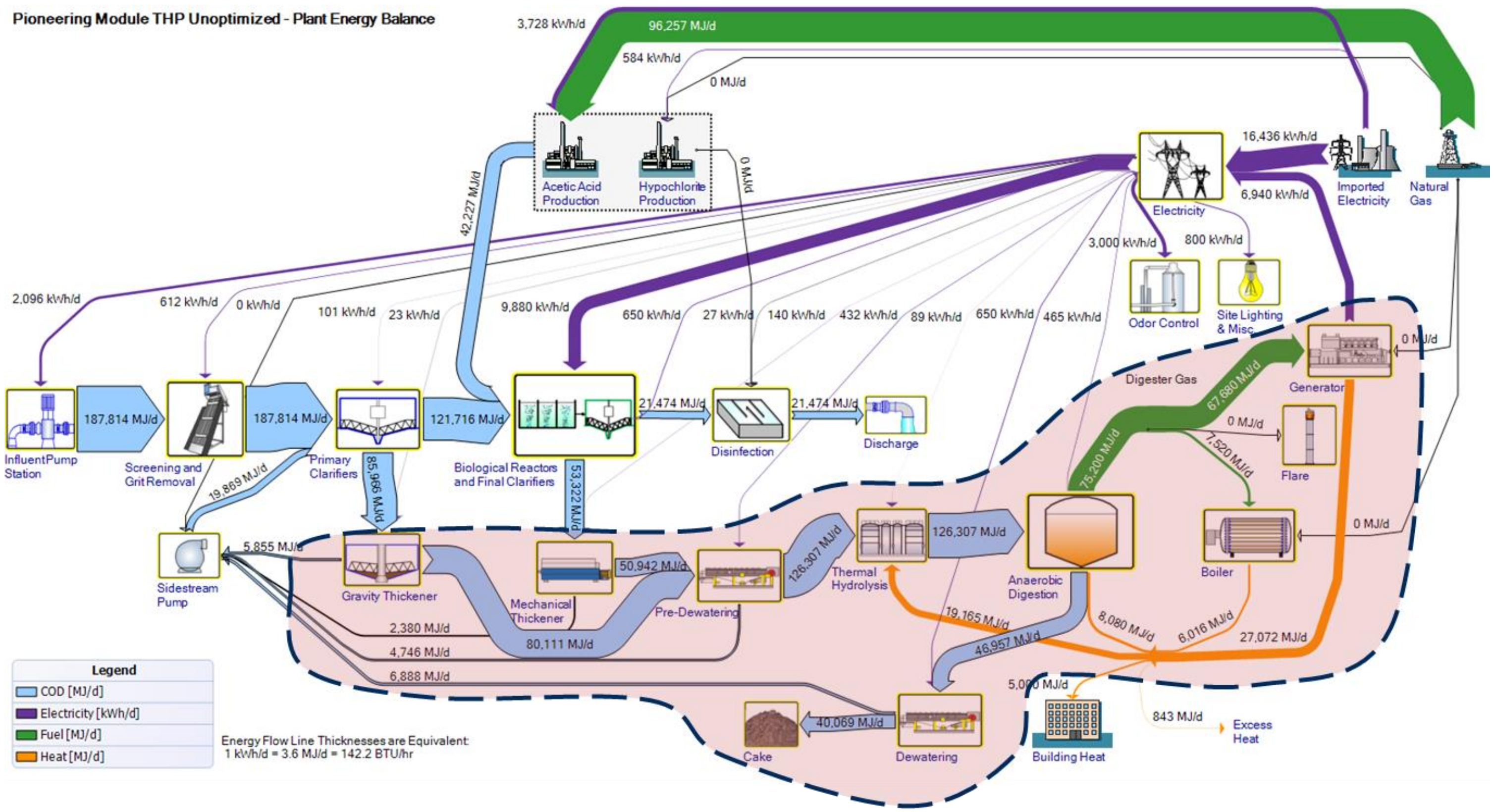


Figure 3-1. Sankey Diagram for Configuration 1X/1Y, Scenarios with Activated Solids with BNR, Pretreatment (thermal hydrolysis), WAS Mechanical Thickening, Anaerobic Digestion, Dewatering, and CHP.

3.2 2X/2Y – Anaerobic Digestion, CHP with Codigestion

Figure 3-2 illustrates the configuration for 2X and 2Y. Each of these scenarios includes BNR liquid stream treatment; WAS mechanical thickening; anaerobic digestion with fats, oils, and grease (FOG) co-digestion; dewatering; and CHP. The anaerobic digester produces 74,200 MJ/d of biogas for use in the generator. Appropriately sized to accept this level of biogas, the generator in turn produces approximately 6,860 kWh/d of electricity for use in the plant. Since this scenario produces a sufficient amount of biogas, supplemental natural gas is not required to fuel the generator. In the "X" version of this scenario, the 6.3 dry tons/day (represented here as 61,206 MJ/d) of cake that is produced is used for land application as a fertilizer, while the "Y" version of the scenario sends this cake to a landfill for disposal.

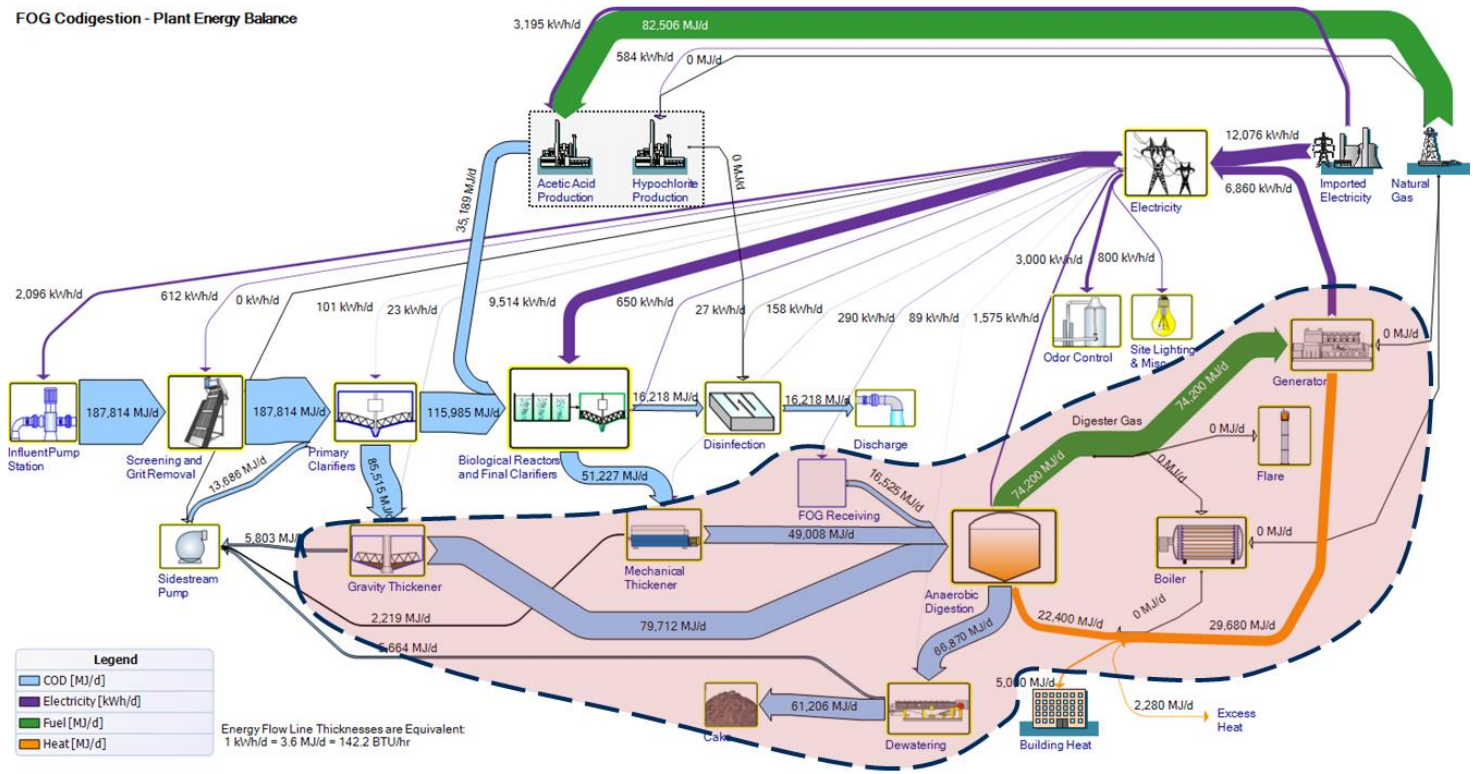


Figure 3-2. Sankey Diagram for Configuration 2X/2Y, Scenarios with Activated Solids with BNR, WAS Mechanical Thickening, Anaerobic Digestion with FOG Co-Digestion, Dewatering, and CHP.

3.3 3Y – Incineration with Landfill Disposal

Figure 3-3 illustrates the configuration for 3Y. The scenario uses conventional activated solids with primary treatment, co-thickening in the gravity thickener, dewatering, fluidized-bed incineration, and a steam turbine. The incinerator provides about 142,000 MJ/d of waste heat to a boiler and steam turbine and provides about 1,760 kWh/d of electricity for use in the plant. Modeling of incineration costs and impacts assumes compliance with new EPA SSI emissions control standards, requiring emissions controls.

For the baseline case with Fluid Bed incineration, the dewatered solid content was assumed to be 25% DS. For Fluid Bed incinerations systems to be auto-thermal, meaning that no supplemental fuel is required, the dewatered solid content must typically be greater than 27-30% DS.

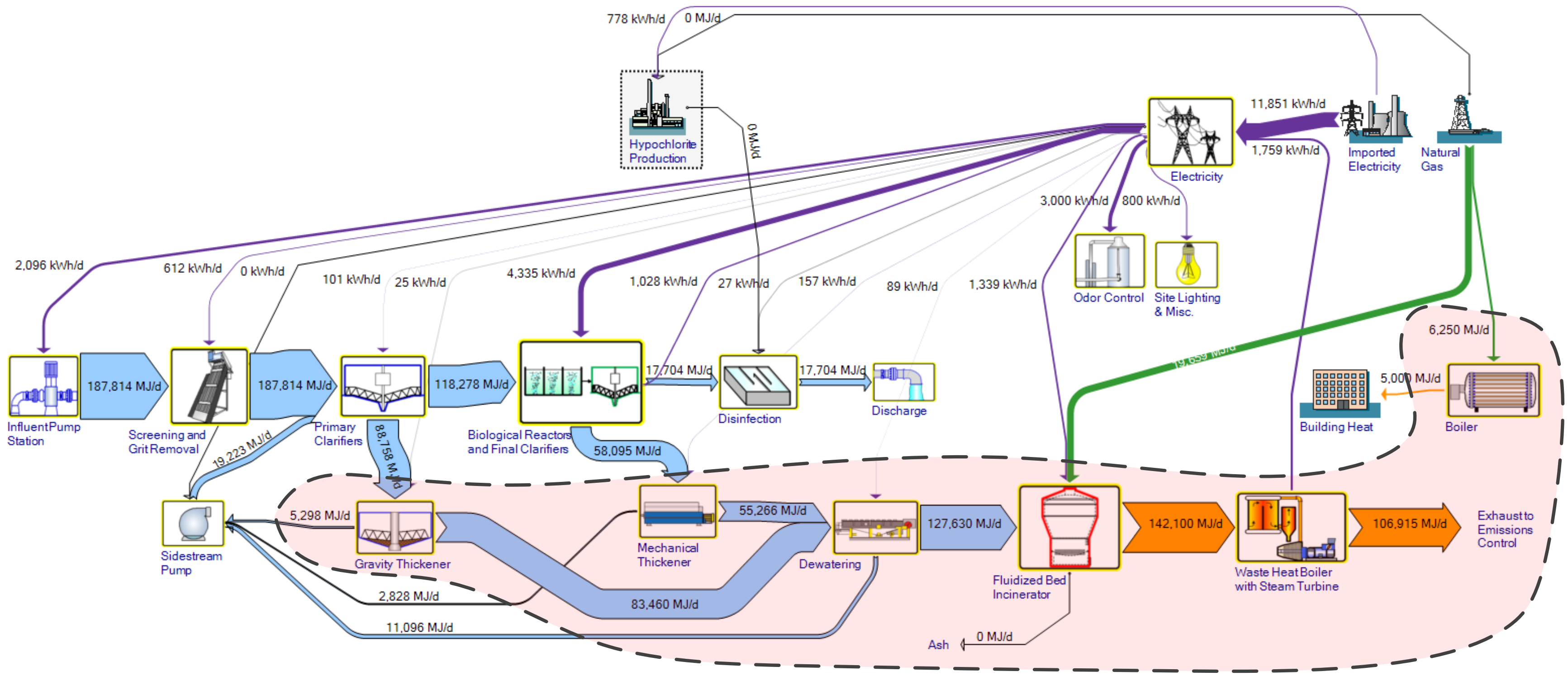


Figure 3-3. Sankey Diagram for Configuration 3Y, Scenarios with Conventional Activated Solids with Primary Treatment, Co-Thickening in the Gravity Thickener, Dewatering, Fluidized-Bed Incineration and a Steam Turbine.

3.4 4Y – Gasification with Landfill Disposal

Figure 3-4 illustrates the configuration for 4Y. The scenario uses conventional activated solids with primary treatment, co-thickening in the gravity thickener, dewatering, followed by thermal drying and gasification in a fluidized bed gasifier. Approximately 67,000 MJ/d of heat generated during the gasification process is used to run the thermal dryer, which also requires an additional 2,100 MJ/d from natural gas.

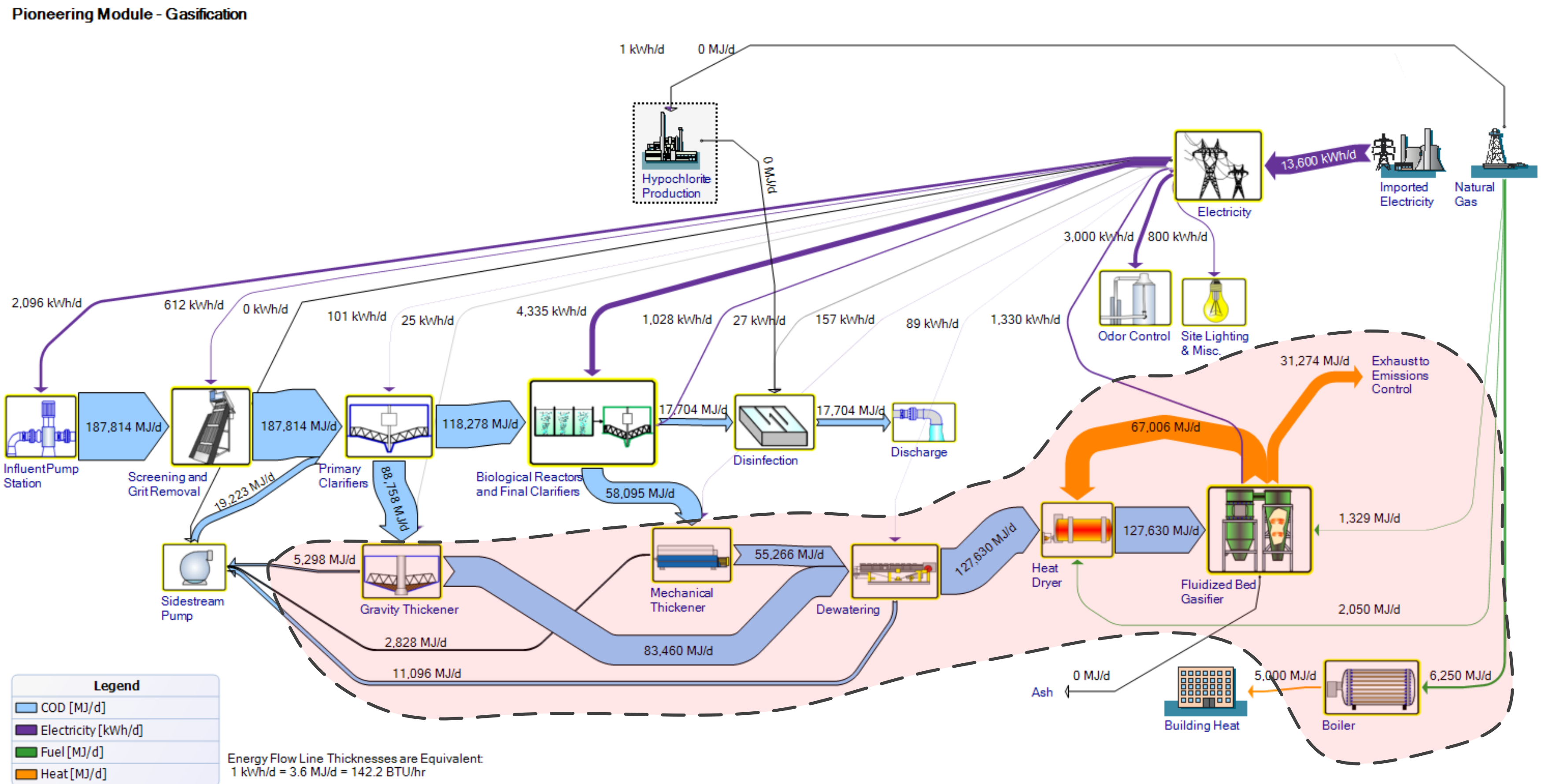


Figure 3-4. Sankey Diagram for Configuration 4Y, Scenarios with Primary Treatment, Co-Thickening in the Gravity Thickener, Dewatering, Followed by Thermal Drying and Gasification in a Fluidized Bed Gasifier.

CHAPTER 4.0

DISCUSSION OF SCORING

Each of the following sub-sections lists the TBL criteria and inputs used in the economic, environmental, and social criteria, respectively.

4.1 Economic Scoring

Table 4-1 lists the economic scoring criteria and inputs used in the TBL evaluation.

Table 4-1. Economic Scoring Criteria and Scoring Methods.

Criterion	Sub criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Life-cycle cost NPV		Quantitative, Dollar costs	Percentage of maximum value, Inverted	NPV Lifecycle Cost Build-ups	Inverted Normalization means least cost alternative received the highest score of 5 while other alternatives received a score proportional to the least cost.
Engineering and technical criteria		Weighted average of three scores below		Based on collective input of the TBL team familiar with technologies.	
	Simplicity	Quantitative, Ordinal, Empirical Points based score	None	The scoring considers: • Logistics and ease of material handling, • Ability of plant professionals to control the process, • Complexity factors that add to likely breakdowns and unscheduled outages of the facility.	All alternatives started with a score of 5. Points were deducted for specific engineering/technical reasons. The simplest technology, received the highest score while the most complex ended up with the lowest score. In general, landfill disposal achieved a higher score than land application.
	Flexibility	Quantitative: Cardinal, Points based score	None	The scoring considers: • Can the process accommodate the changes to flow profiles and quantities easily? • Can the process accommodate the changes to biomass specifications? • Would the process lock down the solids process or are further changes feasible in the future?	All alternatives started with a score of 5. Points were deducted for specific engineering/technical reasons. The most flexible technology, received the highest score while the most inflexible ended up with the lowest score.

Criterion	Sub criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
	State of technology	Quantitative, Ordinal, Empirical Points based score	None	The scoring considers: • Has technology been applied commercially or demonstrated on a pilot scale? • Are the components commercially available or need to be custom built? • Can the operations and maintenance be predicted reliably?	All alternatives started with a score of 5. Points were deducted for specific engineering/technical reasons. The most demonstrated technology, received the highest score while the newest ended up with the lowest score.

4.2 Environmental Scoring

The team derived much of the environmental data from the GPS-X modeling results for the six biosolids management scenarios analyzed. Table 4-2 lists the environmental scoring criteria and inputs used in the TBL evaluation.

Table 4-2. Environmental Scoring Criteria and Scoring Methods.

Criterion	Sub Criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Conservation/ Optimization of Resources			Weighted average of scores below		
	Nutrients	Quantitative, N & P (lb/day) to soil	Percentage of maximum value,	• Based on mass balance calculations of de-watered biosolids from GPS-X output. • Did not include secondary macro-nutrients (Ca and S), nor micro-nutrients (Cu, Fe, Mn, Zn, etc.)	Use of nutrients from biosolids may be based on: • Direct land application of biosolids in agricultural land. • Composted biosolids, or, • Solids incinerator ash (SIA) may be used in fertilizer and/or topsoil blends • Harvested within the WRRF and then applied as chemical fertilizers.
	Fixed carbon: greenhouse gas emissions	Quantitative, short tons of CO_2e/yr.	Percentage of maximum value, Range adjusted, Inverted	GPS-X outputs were used as inputs to the Biosolids Emissions Assessment Model (BEAModel) for each scenario.[2]	General Assumptions Used in BEAModel: • GHG emissions for the generation of electricity: 589 g/kWh (Source: US average from eGrid 2010 Version 1.1) • Landfills accepting biosolids install methane recovery systems and the captured methane is flared • methane production in landfills is based on the Clean Development Mechanism algorithm assuming that the landfill was in a “cold, wet” climate • Transportation distance to land application sites and landfills :50 km

[2] BEAModel was developed by Sylvis for the Canadian Council of the Ministers of the Environment in 2009 (http://www.ccme.ca/ourwork/waste.html?category_id=137).
BEAModel was designed specifically to calculate GHG emissions from different biosolids management options and includes CO^2, CH_4, and N_2O Scope 1, 2, and 3 emissions.

Criterion	Sub Criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
	Fixed carbon: Energy recovery	Quantitative, Net energy (electricity and heat) recovered from solids (MJ/day)	Percentage of maximum value, Range adjusted	e-Sankey diagrams and GPS-X outputs	Net energy recovered considers the energy required to harness the energy inherent in the solids. For example, the electricity and heat recovered from anaerobically digesting the biosolids minus the electricity and heat (from internal or external sources) used to run the anaerobic digestion process provides the net-energy recovered.
	Water conservation	Quantitative, Total Water Conserved (gallons per year)	Percentage of maximum value	Water conservation was calculated based on following data: • Agricultural land application based on 1,500 gallons of water savings per dry ton of biosolids applied • Biosolids compost based on 5,200 gallons of water savings per dry ton applied (Recycled Organics Unit 2006, Brown and Cotton 2011, Brown et al. 2011)	Based on the increase in water-holding capacity in soil provided by the organic matter in biosolids added to soil.

Criterion	Sub Criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Net Impact on Media			Weighted average of scores below		
	Impacts to land/soil quality	Qualitative	Ranking system from 0-5	Scoring based on potential positive and negative impacts to land from biosolids mgt. options including • improvement to disturbed land by reclamation with biosolids • loss of open space for construction of new facilities • restrictions on future use of land due to soil contamination	• Activities likely to increase risk or limit future use of land results in a low score • Activities likely to provide no change in risk result in a mid-range score • Activities likely to decrease risks for future use, or create additional habitat or agricultural land result in a high score Among the six scenarios investigated in this study there were no differences found with a score of 2.5 for each scenario
	Impacts to air quality	Quantitative, Amount of NO_x, SO_2, and PM emissions (Mg/yr)	Percentage of maximum value, Inverted	GPS-X outputs provided flow rates and biogas generation data which were used as inputs to NO_x, SO_2, and particulate matter emissions calculations based on EPA guidance documents. Gasification emissions data came from reports on MaxWest biosolids gasification facility in Sanford, FL	Assumed that incinerator in scenario 3Y meets the emissions requirements of the new EPA SSI rules, but that the CHP engines running off of biogas in scenarios 1X, 1Y, 2X and 2Y did not include emissions controls for NO_x, SO_2 or PM. Team-derived weightings of 70%, 15% and 15% were used for NO_x, SO_2 and PM emissions, respectively.
	Impacts to water quality	Qualitative	Ranking system from 0-5	Scoring based on potential positive and negative impacts to water quality from biosolids mgt. options including: • reducing soil erosion (land application) • increasing soil phosphorus levels in phosphorus sensitive watersheds (land application) • negatively impacting groundwater (landfill sites)	• Activities likely to negatively impact water quality result in a low score • Activities likely to provide no change in water quality result in a mid-range score • Activities likely to improve water quality in a substantive manner results in a high score Among the six scenarios investigated in this study there were no differences found with a score of 2.5 for each scenario

Criterion	Sub Criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Meeting future regulatory requirements		Qualitative	Ranking system from 0-5	Scoring based on the impact of the biosolids management activity to provide flexibility for potential future changes to regulations	Examples include: • Dewatering options that may encourage pathogen regrowth results in a low score • NOx emissions unlikely to meet future ratcheting down of limits results in a low score • Class A technologies where only Class B technologies are currently required results in a higher score

4.3 Social Scoring

The social criteria in this biosolids TBL predominantly use qualitative scores, with the exception of the nuisance issue truck traffic. Understanding that it is important to focus the scoring exercise on each option's inherent expected potential for social issues and concerns, biosolids management options that have the inherent potential for greater nuisance issues will receive lower ratings than options with lower nuisance potential. Consequently, the key question is whether or not the evaluated technology/process/management option presents inherent issues.

Table 4-3 lists the social scoring criteria and inputs used in the TBL evaluation.

Table 4-3. Social Scoring Criteria and Scoring Methods.

Criterion	Sub criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Nuisance Issues			Weighted average of scores below		
	Odor	Qualitative	Ranking system from 0-5	Scoring is based on the expected, inherent intensity and duration of malodor related to the biosolids process or product.	Odor is cited as the most common and impactful of the nuisances from biosolids management. A score of 0 being highly likely to generate intense and lasting malodor and 5 being very unlikely to generate any malodor.
	Dust	Qualitative	Ranking system from 0-5	Scoring is based on the expected intensity and duration of dust related to the biosolids process or product.	Dust from biosolids or a biosolids management practice is a concern for neighbors of treatment facilities and/or final use sites. A score of 0 being highly likely to generate intense and lasting dustiness and 5 being very unlikely to generate any dust at all.
	Visual	Qualitative	Ranking system from 0-5	Scoring is based on the expected of visual impact related to the biosolids process or product.	Visual: A score of 0 being likely to create a significant negative visual impact for many people and 5.0 being very unlikely to generate a significant negative visual impact or to create a positive visual impact (for example, reclamation of a barren landscape with land applied biosolids is a positive visual impact that would be scored high).
	Truck traffic	Quantitative, expected number of truck trips required to transport biosolids/ byproducts	Percentage of maximum value, Inverted	Truckloads per year are derived from the BEAModel (Brown et al., 2011). It uses the number of truckloads estimated from the expected total solids output from the solids processing system from GPS-X modeling for each configuration. Assume an average of 25 wet metric tons of solids per truckload.	Truck traffic (and other traffic) is also a concern for people living near WRRFs, processing facilities, landfills, and/or land application and other beneficial use sites. The expected number of truckloads per year is corrected to provide the highest score for the least number of truckloads.

Table 4-3. Social Scoring Criteria and Scoring Methods.

Criterion	Sub criterion	Type of Score	Normalization Method	Inputs	Criterion/Discussion
Workplace Conditions		Qualitative	Ranking system from 0-5	Scoring is based on the expected variety and intensity of malodors, dust, noise, and other nuisances that would affect operator comfort in the biosolids treatment and management operations environment.	A score of 5 would be assigned to a process and/or technology that does not create difficult working conditions or even makes for comfortable working conditions. For example, the open operations of most belt filter presses create more odors and other nuisances for operators and would be scored low. A screw press, with less noise and odor would score high. In contrast, centrifuge dewatering may lie somewhere in between, as it is an enclosed process but can be noisy.
Public Engagement		Qualitative	Ranking system from 0-5	Considerations when scoring this criterion: • Does the final material lend itself to being a product? If yes, then a higher scoring is required. • Does the management configuration encourage staff to see the final material as a product? If yes, then a higher scoring is required. • Is there a structural aspect about the biosolids management scenario that will require public interaction? Yes, for use of biosolids in parks. No for incineration, where biosolids management can be completely hidden away.	This criterion considers whether or not the biosolids management option inherently forces interaction with the public. Such required interaction is considered a benefit for ensuring public understanding of biosolids management.

4.3.1 Public Engagement

The “Public Engagement” criterion is unusual and deserves additional explanation. Public knowledge of wastewater treatment – and especially solids management – is limited. Yet wastewater treatment and biosolids management are critical to public health and the environment. Decisions regarding solids management processes and technologies should include consideration of their impacts on public perception, knowledge, and understanding of this profession and the people and organizations involved in it.

For example: A widely marketed biosolids compost product intended for general consumer use is inherently more likely to force opportunities for engaging the public in discussions about the benefits of recycling nutrients and organic matter in comparison to a Class B biosolids applied in bulk on an isolated site, kept hidden from notice. Of course, if the Class B biosolids generates malodors, it may inherently force interactions with the farm field’s neighbors.

In general, programs that recycle biosolids to soils present – and even require – more opportunities for interactions with the public in comparison to programs that treat and/or use the biosolids all within the confines of the treatment plant (e.g., incineration or anaerobic digestion and biogas use). Recycling biosolids requires public outreach, which, while sometimes challenging, is a good thing, as it drives public education and knowledge about wastewater treatment and solids management. Incineration, energy recovery, and even landfill disposal programs may choose to conduct public outreach and education effectively, but they are not pushed to do so as much as when biosolids are beneficially used.

For this criterion to be most effective in differentiating between one biosolids management configuration and another, it is important to evaluate structural aspects of the biosolids management program that either force or do not force public engagement. For example, a wastewater facility and biosolids management option that can easily operate “below the radar” can do so because there is nothing that forces public interaction – no odor or other nuisance concerns, minimal off-site transport of materials, and no public interaction with materials transported off-site. Managers of such operations are not forced by the inherent structure of the program to engage the public; if they do so, it is a voluntary effort. It is a good and recommended practice in all biosolids management programs to engage the public, but there are programs that are not structured around public engagement. Such programs score low on this TBL analysis.

This approach to applying the public interaction/engagement criterion to biosolids management configurations is somewhat antithetical to traditional planning and engineering practice; the profession tends to keep its operations unnoticed. However, best practice today is to have public knowledge and understanding for biosolids programs to be noticed – but without creating nuisances and concerns. Therefore, in this scoring process, those biosolids management configurations that structurally force public engagement are given a higher score.

Examples to guide scoring:

- Score of 0: There is no structural aspect of the biosolids management configuration that forces public involvement or awareness.
- Score of 1: There are few structural aspects of the biosolids management configuration that force public awareness of the facility. For instance, a combustion facility that accepts external material resulting in increased truck traffic and a larger footprint that can be seen,

heard, and smelled by neighbors. Another example might be a program that disposes of biosolids at an isolated landfill, where the associated noise, dust, and odors with truck traffic forces public awareness.

- Score of 3: There are structural aspects of the biosolids management configuration that force a moderate amount of public interaction.
- Score of 4: Structural aspects of the biosolids management configuration force a considerable amount of public interaction. An example: biosolids processed to Class A are marketed to only one or two landscapers or farmers.
- Score of 5: Structural aspects of the biosolids management configuration force a great amount of public interaction. Whether the biosolids managers like it or not, the structural aspects of the program mean the public will inevitably be engaged.

It is important to note that water quality professional stakeholders engaged in developing this TBL stated that nuisance issues and public engagement are closely related: the former forces the latter. In defining the scoring of the public interaction/engagement criterion as the researchers have done here, it suggests that increasing the potential to have nuisances increases the score on this criterion. Ironically, this is true. If a program has a greater potential for creating public nuisances, it is forced to engage the public, which is seen as a positive thing under this criterion but as a negative under the nuisance criterion, meaning the scores will cancel each other out. That could happen, but the combination of scores on these two criteria will separate out those programs that are configured in such a way as to both reduce the potential of nuisances and force public engagement. An example might be a composting program that produces a fine, low-odor, easily handled product that must be widely marketed and distributed.

4.4 Stakeholder Involvement in Criteria Weightings

The team performed a survey of wastewater utilities to identify trends in the use of TBL for decision making and to identify common TBL criteria used in the sector. Of the responding utilities, many reported that they use TBL or a similar multi-criteria decision-making process in their budgeting process or asset management program. The research team sent out a follow-up survey to individuals from these utilities that use TBL or a similar approach in order to gather category and criteria weight inputs.

Weightings for economic, environmental, and social criteria are shown in Figures 4-1, 4-2, and 4-3, respectively. From the follow-up respondents, 60% said that they would place more than one-third (or greater than 33%) weight to the economic category.

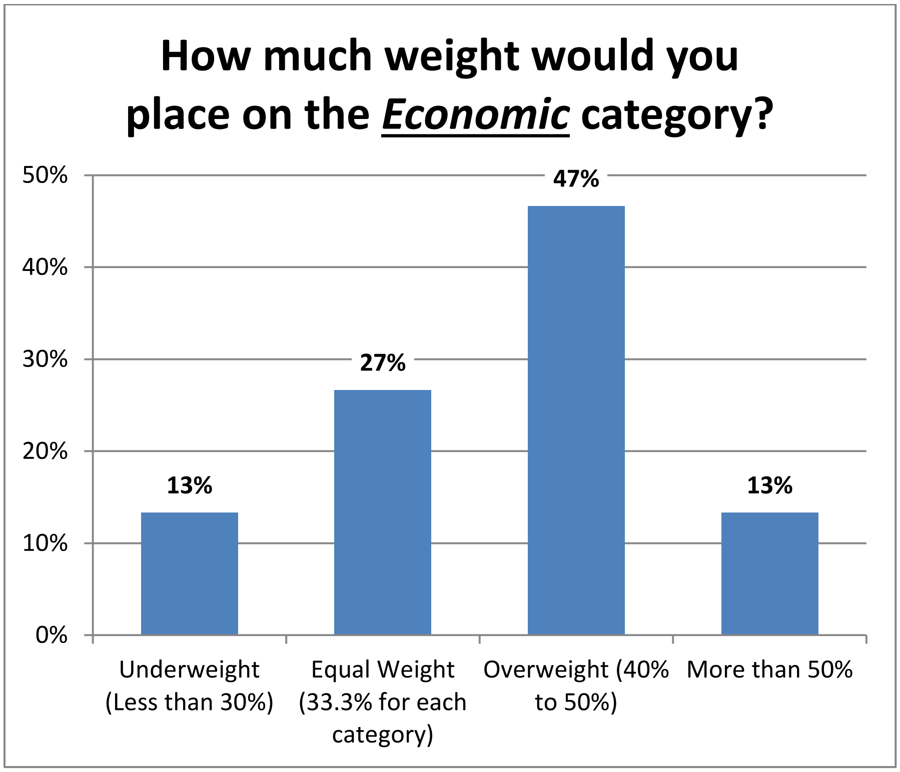


Figure 4-1. Survey Results Showing How WRRFs Weight Economic Criteria.

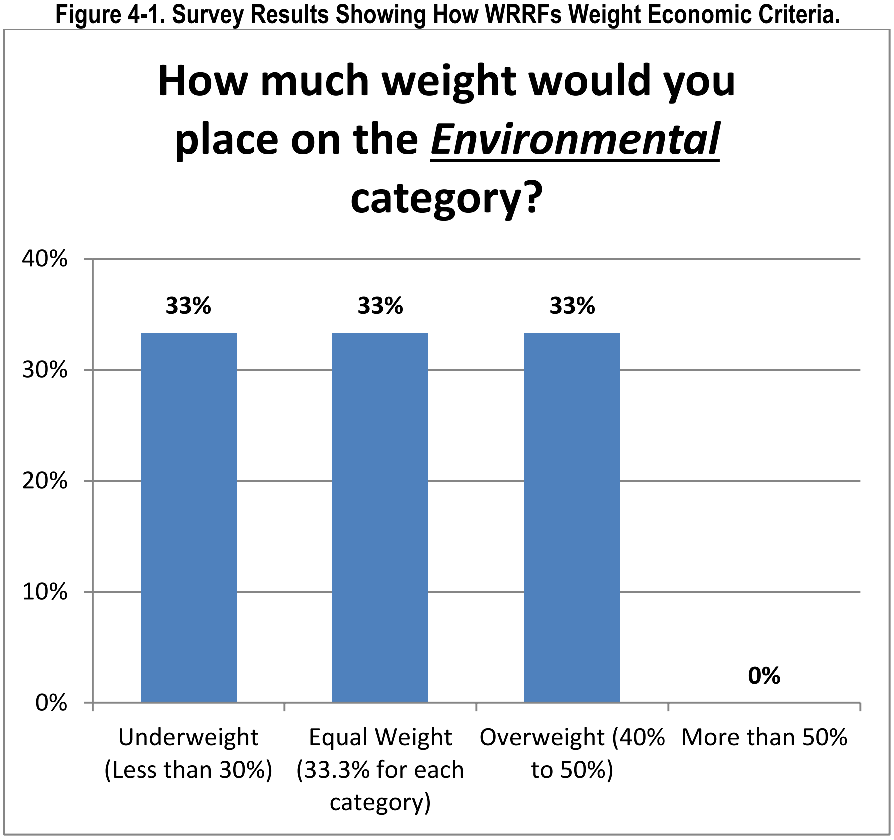


Figure 4-2. Survey Results Showing How WRRFs Weight Environmental Criteria.

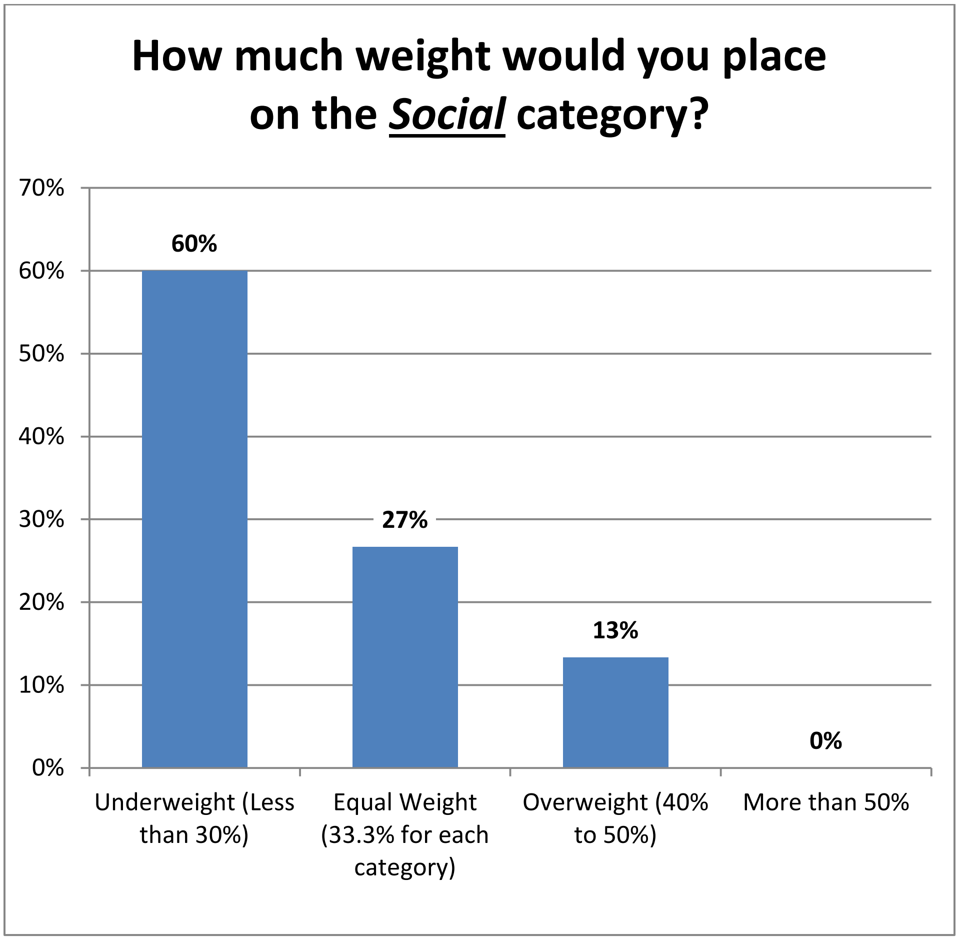
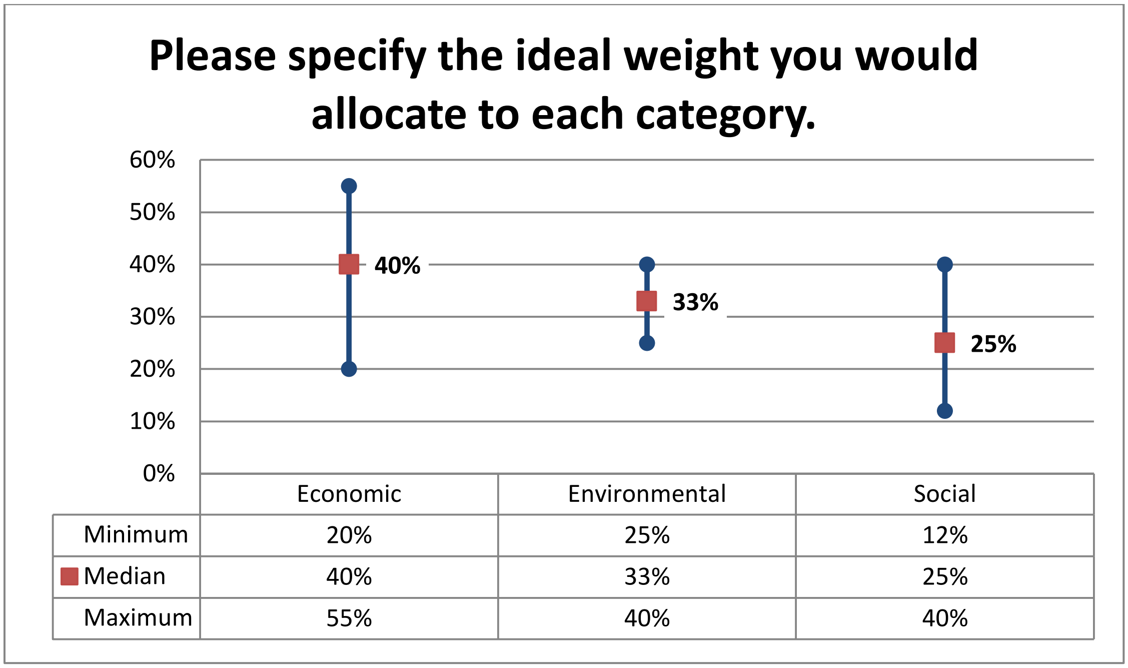


Figure 4-3. Survey Results Showing How WRRFs Weight Social Criteria.

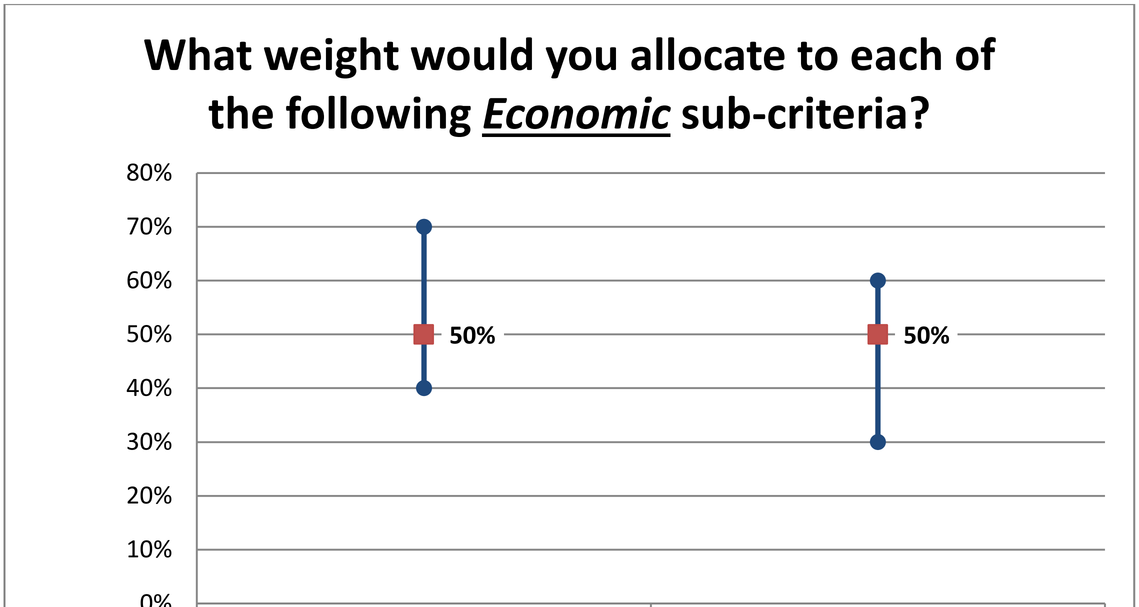
When asked to specify the ideal weight they would place on the economic, environmental, and social categories, the median responses were 40%, 33%, and 25% respectively. The responses were least varied in the environmental category. Respondents were more divided over economic and social categories. However, respondents had a tendency to overweight the economic category at the expense of the social category. Figure 4-4 shows the results and ranges of responses received.



	Economic	Environmental	Social
Minimum	20%	25%	12%
Median	40%	33%	25%
Maximum	55%	40%	40%

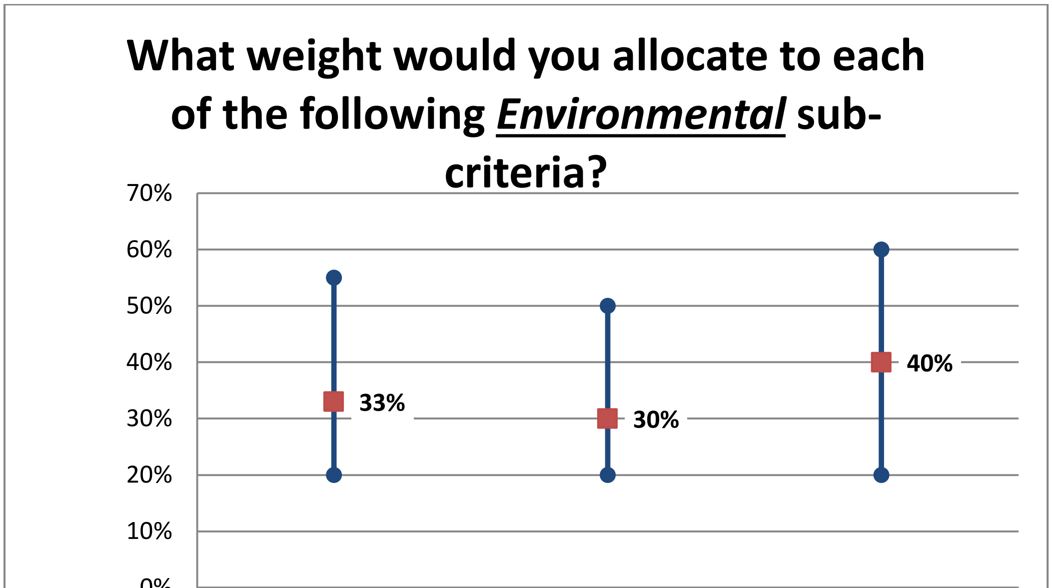
Figure 4-4. Survey Results Showing How WRRFs Assign Ideal Weight to Three TBL Criteria.

For economic sub-criteria, the central tendency was to allocate equal weights to both NPV and engineering/technical criteria, as shown in Figure 4-5. Environmental and social sub-criteria survey responses are shown in Figures 4-6 and 4-7, respectively.



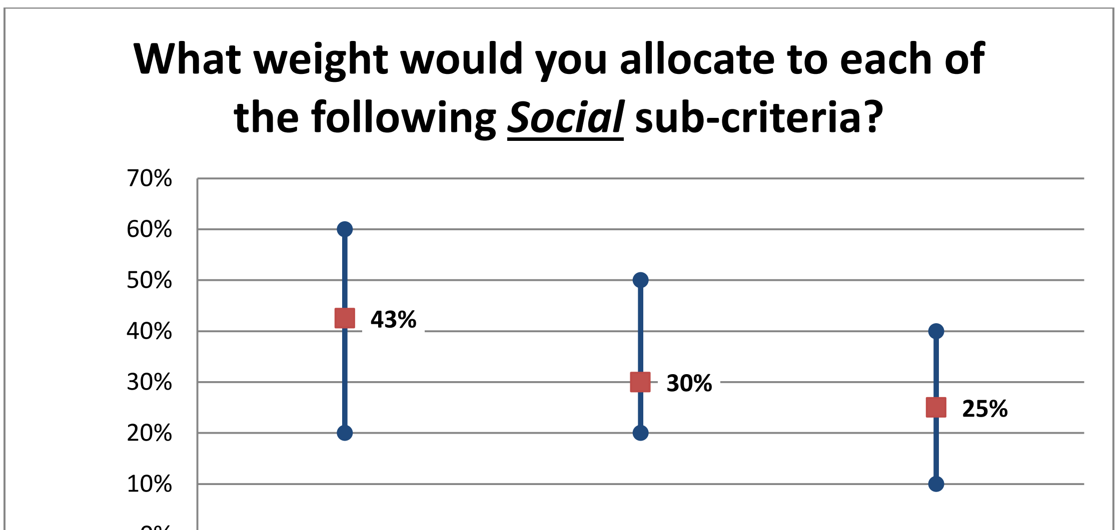
	Net Present Value (NPV)	Engineering/Technical
Minimum	40%	30%
Median	50%	50%
Maximum	70%	60%

Figure 4-5. Survey Results Showing How WRRFs Weight Economic Sub-Criteria.



	Conservation/Optimization of Resources	Net Impacts on Media	Regulatory
Minimum	20%	20%	20%
Median	33%	30%	40%
Maximum	55%	50%	60%

Figure 4-6. Survey Results Showing How WRRFs Weight Environmental Sub-Criteria.



	Nuisance Issues (Odor, Dust, Traffic, and Visual)	Workplace Conditions	Public Engagement
Minimum	20%	20%	10%
Median	43%	30%	25%
Maximum	60%	50%	40%

Figure 4-7. Survey Results Showing How WRRFs Weight Social Sub-Criteria.

CHAPTER 5.0

TRIPLE BOTTOM LINE RESULTS FOR RESEARCH GUIDANCE

Thus chapter discusses the TBL model results for the research guidance 'base case' and compares the TBL results from the different biosolids management options.

5.1 Economic Results

Figure 5-1 shows cumulative capital cash outflows from each of the configurations analyzed. All configurations have an initial capital outflow. Configurations 1X and 1Y were found the most capital-intensive while configuration 3Y is the least capital-intensive. Note that in its current format, configuration 3Y assumes installation of an offsite 100 dtpd incineration facility. The costs included in the analysis are the 10 mgd plant's share of the total capital costs for a 100 dtpd FBI at the regional facility. The team recognizes that such an option may not be available to all wastewater treatment facilities. In absence of such an option, it would not be practical to consider the FBI alternative. Configuration 4Y (gasification followed by landfill) can be considered the least capital-intensive process. However, note that the cost estimates have a high degree of uncertainty given they are based on only one facility.

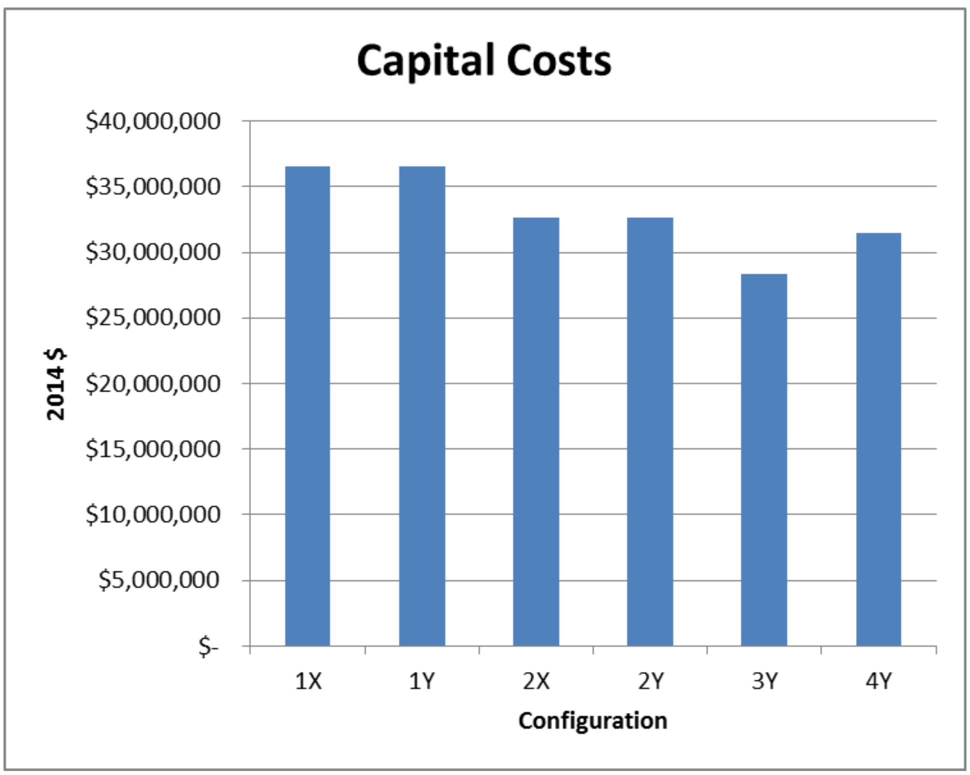


Figure 5-1. Cumulative Capital Cash Outflows from Analyzed TBL Configurations.

In Figure 5-2, Option 1Y is most expensive configuration to operate and maintain. Gasification followed by landfill (4Y) is the lowest-cost option to operate and maintain. Labor was the largest component of O&M costs across the options (between 38 and 60%).

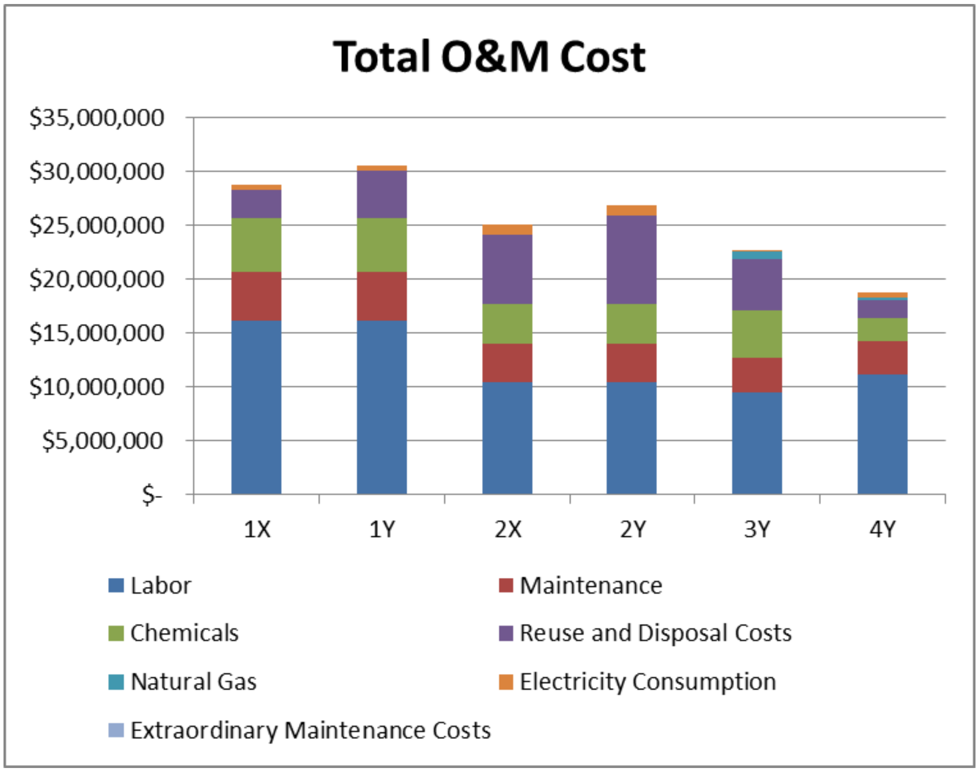


Figure 5-2. Lifecycle O&M Costs (NPV) from Analyzed TBL Configurations.

When capital and O&M costs are considered along with benefits on an NPV basis, configuration 1Y remains the highest-cost option while 3Y and 4Y are the lowest cost options.

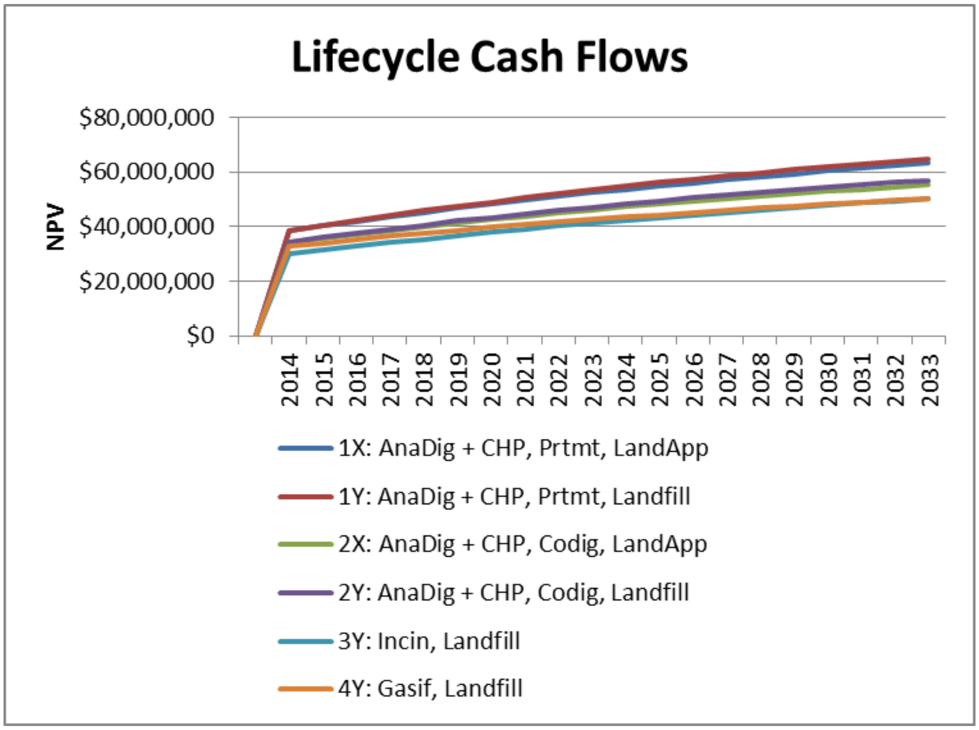


Figure 5-3. Lifecycle Cash-flows from Analyzed TBL Configurations.

The researchers' TBL economic evaluation includes engineering and technical criteria in addition to the NPV results. Table 5-1 shows the team's scoring for engineering and technical criteria. Team scoring workpapers provide a brief discussion along with reasoning for the ratings.

Table 5-1. Engineering and Technical Criteria Scores.

Scenario	Simplicity	Flexibility	State of Technology
1X: Anaerobic digestion + CHP, pretreatment, land application	Not Used	3.5	Not Used
1Y: Anaerobic digestion + CHP, pretreatment, landfill	Not Used	3	Not Used
2X: Anaerobic digestion + CHP, co-digestion, land application	Not Used	4.5	Not Used
2Y: Anaerobic digestion + CHP, co-digestion, landfill	Not Used	4	Not Used
3Y: Incineration, landfill	Not Used	1.5	Not Used
4Y: Gasification, landfill	Not Used	3	Not Used

Figure 5-4 shows the economic analysis results after normalization of NPV. The gasification (4Y) and incineration (3Y) have the lowest NPV cost results of the six options evaluated with the NPV model. As noted previously, the incineration option life-cycle costs assume that a large incineration facility is feasible and that the WRRF would only be responsible for a portion of the capital and operating costs commensurate with the percentage of solids that it is adding to the facility. This results in improved economies-of-scale, and is consistent with the size of regional incinerators currently being planned in North America.

When engineering/technical scoring is also incorporated into the economic results, the gasification option still has the highest economic score. Of note, option 2X (AD, co-digestion, CHP with land application) results in a higher economic score than option 3Y (incineration). All other options do not change in economic rank. Anaerobic digestion with co-digestion, options 2X and 2Y, have lower NPV costs than their counterpart options that include solids pretreatment (thermal hydrolysis) instead of co-digestion.

	1X	1Y	2X	2Y	3Y	4Y
NPV	3.42	3.32	3.90	3.78	4.30	4.30
Engineering/Technical	0.49	0.42	0.63	0.56	0.21	0.42

Figure 5-4. Weighted Economic Scores for Categories.

5.2 Environmental Results

The environmental category scores and resulting rankings for the six biosolids management scenarios are listed in Table 5-2.

Table 5-2. Environmental Category Scores.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.86	1
1Y: Anaerobic digestion + CHP, pretreatment, landfill	2.03	3
2X: Anaerobic digestion + CHP, co-digestion, land application	3.62	2
2Y: Anaerobic digestion + CHP, co-digestion, landfill	1.53	6
3Y: Incineration, landfill	1.62	5
4Y: Gasification, landfill	1.94	4

The two configurations that included anaerobic digestion followed by land application of the biosolids (1X and 2X) scored the highest in the environmental category. The following sections present discussion of the scoring results for the environmental criteria and sub-criteria.

5.2.1 Results for Conservation/Optimization of Resources

The sub-criterion for conservation and optimization of resources is weighted as 50% of the environmental criteria. Within this sub-criterion, anaerobic digestion followed by land application scores higher than the remaining four alternatives (each of which involves landfilling the final product) in all three of the components of this criteria. Options 1Y, 2Y, 3Y, and 4Y received a score of 0 for nutrient recovery resulting from landfill disposal. The combination of total nitrogen and orthophosphate available from biosolids cake was slightly higher in 2X than in 1X (809 v. 688 pounds per day, respectively). Normalizing these scores using the percent of maximum value method results in scores of 4.3 for 1X and 5.0 for 2X.

Energy recovery (a sub-criterion of fixed carbon) was scored based on the net energy recovered from the energy inherent in the wastewater solids. The results of the energy recovery scoring are shown in Figure 5-5. In the four configurations that included anaerobic digestion, significant energy was recovered through biogas utilization, generating electricity and heat in CHP engines. Based on the e-Sankey diagrams developed for each configuration, net energy (the energy produced minus the energy expended in its production) of the anaerobic digestion configurations ranged from 24,094 MJ/day for 1X and 1Y to 22,662 MJ/day for 2X and 2Y.

Option 3Y, with FBI for biosolids management, recovered approximately 25% of the heat evolved during the incineration process through a waste-heat boiler that in turn drives a steam turbine to generate electricity. The amount of electricity generated (1,759 kWh/day) is greater than the 1,300 kWh/day used in the incineration process, but approximately 19,700 MJ/day of natural gas is needed for the incineration process with the final net-energy balance being 18,147MJ/day. For configuration 4Y (gasification), syngas generated during the gasification process is used in the thermal drying process required prior to gasification. However, the syngas does not meet all of the needs for the thermal dryer and is supplemented with about 2,000 MJ/day of natural gas. There is some recoverable energy (2557 MJ/day) from gasification that can be used to supplement building heat. The net result for energy recovery in this configuration is -5,610 MJ/day.

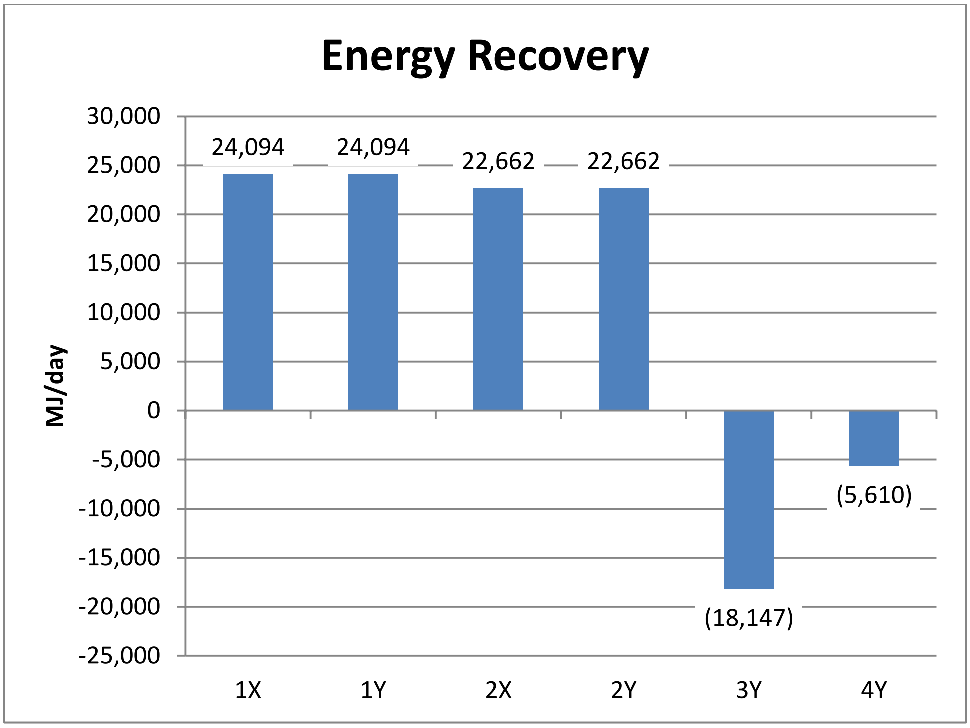


Figure 5-5. Net Energy Recovery Results.

Figure 5-6 shows the GHG emissions for the evaluated options calculated using the BEAModel. The calculations indicate the greatest emissions result from methane emissions from landfilling dewatered cake and nitrous oxide emissions from incineration. The research team did not have data on nitrous oxide emissions from gasification and assumed for this exercise that nitrous oxide emissions from gasification are minimal due to the controlled system of the gasification process and the vendor's claims.

Although the landfills accepting the biosolids in options 1Y and 2Y are assumed to have methane collection systems in place, some fugitive methane emissions are expected both prior and subsequent to cell closure. Methane emissions, and consequently overall GHG emissions, are higher in configuration 2Y than in 1Y because the thermal hydrolysis pretreatment step in 1Y minimizes the mass and volatile solids content of the biosolids generated, providing less potential for methane generation from the landfilled biosolids.

GHG emissions credits from the biosolids management configurations come from several sources, including carbon sequestered in landfills and agricultural soils in configurations 1X, 1Y, 2X, and 2Y, avoided nitrogen and phosphorus fertilizer production in the land application configurations, and energy production from the biosolids from anaerobic digestion, incineration and gasification.

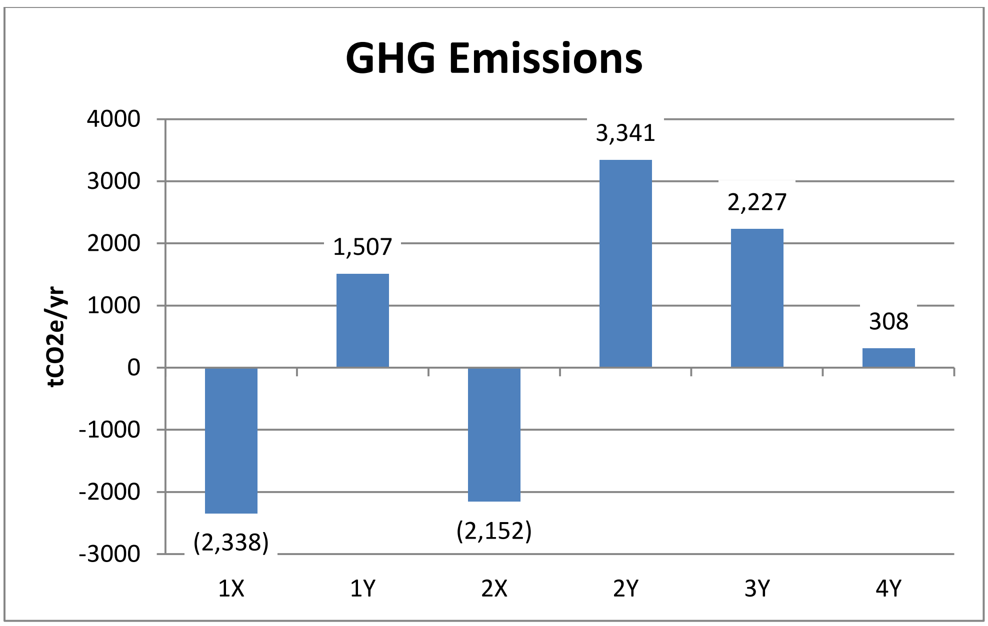


Figure 5-6. GHG Emission Results.

As is the case with nutrients, landfilling biosolids cake or ash does not provide any opportunity for water conservation attributed to the biosolids beneficial use. All four of the configurations with landfilling scored 0 for water conservation. Land application options 1X and 2X assume a factor of 1,500 gallons of water conserved per dry ton of biosolids applied. Because the thermal hydrolysis pretreatment in 1X results in a reduction in the mass of biosolids generated, 2X provides a greater potential conservation of water (about 2,850,000 gallons per year for 2X versus 2,140,000 gallons per year for 1X).

5.2.2 Results for Net Impacts to Media

The potential impacts to land and water quality described here are largely site- and region-specific impacts or impacts that are characteristic of particular programs. For instance, the potential positive impact to land reclamation through the use of biosolids is a characteristic that would be specific to a WRRF only with available disturbed land sites nearby.

Impacts on water quality would be based on the specific characteristics of watersheds in which biosolids are being applied. For instance, in regions with a high density of chicken, hog, or dairy operation, eutrophication from high soil phosphorus levels may create circumstances under which the land application of biosolids may exacerbate a water quality problem. For this TBL exercise, the biosolids management configurations were generic relative to U.S. region; the configurations could be applied to WRRFs in any part of the country and not characteristic of a specific region.

Impacts of land disturbance for new facilities for biosolids management options were based on the assumption that new construction would be built within existing footprints of developed areas of the WRRF (with the exception of regional incineration). Consequently, no new acreage would be converted from agricultural or wooded land to developed/industrial areas. As a result, there were no measurable differences between the six configurations relative to impacts on land or water quality. Each of these sub-criteria scored 2.5.

Differences in impacts to air quality are evident among the six biosolids management configurations despite that potential impacts are not region-specific. Based on the scoring technique chosen for this TBL (see Table 4-2), NOx emissions from CHP engines constituted the largest air emissions impacts (resulting in the lowest overall scores) among the six configurations. NOx emissions from the CHP engines were predicted to be 10 and 9.8 Mg/year for 1X/1Y and 2X/2Y, respectively. Note that these emissions assumptions assume that CHP options (1X, 1Y, 2X, 2Y) do not require additional emissions control technologies Conversely, required incineration emissions are included for 3Y, contributing to its lower NOx emissions assumption, with expected emissions of 4.0 Mg/year. Gasification NOx emissions (4Y) are based on data from the MaxWest biosolids gasifier in Sanford, FL (scaled to the size of the WRRF in the model) and predicted to be 1.5 Mg/year.

In all four anaerobic digestion configurations, the predicted emissions are 0.10 Mg/year in SO_2 from the CHP engines. Predictions for the FBI were also 0.10 Mg/year. Based on MaxWest data, the gasifier has no associated SO_2 emissions. The CHP engines were not predicted to be a source of particulate matter, but both the FBI and the gasifier were predicted to emit 0.4 Mg/year of filterable particulate matter. Table 5-3 includes the final air quality impact scores. These scores further include the results of the three individual air emissions parameters normalized to the percent of maximum and then weighted according to the team-assigned weights. Based on the scores, configuration 4Y (with the gasifier) received the highest rating (indicating the lowest emissions) followed by 3Y (FBI). Due to the higher NOx emissions from the CHP engines, the four anaerobic digestion configurations rated the lowest.

Table 5-3. Air Impact Sub-Criteria Scores.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	1.45	5 (tied)
1Y: Anaerobic digestion + CHP, pretreatment, landfill	1.45	5 (tied)
2X: Anaerobic digestion + CHP, co-digestion, land application	1.50	3 (tied)
2Y: Anaerobic digestion + CHP, co-digestion, landfill	1.50	3 (tied)
3Y: Incineration, landfill	2.78	2
4Y: Gasification, landfill	3.72	1

5.2.3 Results for Regulatory Flexibility

The maximum score for regulatory flexibility represents configurations extremely likely to meet future regulatory requirements. The minimum score represents configurations for which it is almost certain that future regulatory changes would rule out the biosolids management option.

Clearly none of the six configurations represents these extremes. Instead, all the configurations are closer to the median, with slight variation among them.

Anaerobic digestion of biosolids is unlikely to become restricted by future regulations. On the other hand, regulations regarding land application of biosolids have already become more restrictive in some regions of the country, despite the steady amount of land applied biosolids nationwide since the U.S. EPA implemented the 40CFR 503 regulations in 1993. While Class B biosolids have a long track record of being acceptable within most regulatory frameworks in the US, local ordinances sometimes restrict or even ban the practice. Moving to a higher quality Class A technology clearly provides greater protection against future regulatory changes. Consequently, option 1X (which generates a Class A material) does not score a 5, but still ranks higher than option 2X (which generates a Class B material). While pathogen criteria has little effect on landfill disposal, Class A material offers more flexibility in use as an alternative daily cover at a landfill than Class B material. Consequently, 1Y, which landfills a Class A cake, scores slightly higher than 2Y, which landfills a Class B cake.

Landfilling biosolids is a time-tested management strategy that is likely to continue. Landfills have limited volume, and consequently, long-term use of landfilling as an option may be dependent upon successful permitting for landfill expansions. This inevitably involves some regulatory risk. Additionally, some states in the U.S., such as Massachusetts and Vermont, are implementing bans on landfilling organics. At the time of this report, these bans had not been focused on landfilling of biosolids, but it remains a possibility. Given historical trends, however, this option seems relatively secure with regard to future regulatory changes. Nevertheless, it involves some risk of future restriction due to emerging regulations.

Incineration of biosolids (3Y) has a long track record of use for biosolids management in the U.S. Disposal of biosolids incineration ash generally produces a non-hazardous solid waste that is non-pathogenic, meaning that regulatory limitations on landfilling the ash are minimal. Incineration reduces volume and mass, reducing landfill capacity requirements and destroying volatile solids, which essentially eliminates methane production potential and odors. From a regulatory perspective, landfilling incinerator ash likely provides more flexibility to meet future disposal requirements than landfilling biosolids cake. Consequently, this configuration scores higher than configurations 1Y and 2Y. Note that the current TBL model does not include emissions control technology costs.

Gasification of biosolids (4Y) is a new technology for biosolids treatment. At the time of this report, a single biosolids gasification facility – MaxWest in Sanford, FL – was in operation in the U.S. Emissions data for gasification were based on performance at this plant. The limited existing data from this technology has uncertainty and risk in its ability to meet regulatory requirements. Gasifier ash is expected to be fairly similar to incineration ash, although it will contain a small organic component. Consequently, there should be little difference in regulatory risk from the 3Y configuration. Since gasification is a new technology, the regulatory flexibility score is slightly below average. Scores from the regulatory flexibility assessment are provided in Table 5-4.

Table 5-4. Scenario Scores for Regulatory Flexibility.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	4	1
1Y: Anaerobic digestion + CHP, pretreatment, landfill	3	2 (tied)
2X: Anaerobic digestion + CHP, co-digestion, land application	2.5	4 (tied)
2Y: Anaerobic digestion + CHP, co-digestion, landfill	2.5	4 (tied)
*3Y: Incineration, landfill	3	2 (tied)
4Y: Gasification, landfill	2	6

The environmental results in Figure 5-7 show significantly higher environmental scores for options 1X and 2X. These are the options that model anaerobic digestion, CHP, and land application with either solids pretreatment (1X) or co-digestion (2X). The primary reason for these significantly higher results is from the higher levels of conservation/optimization of resources achieved in the environmental score category.

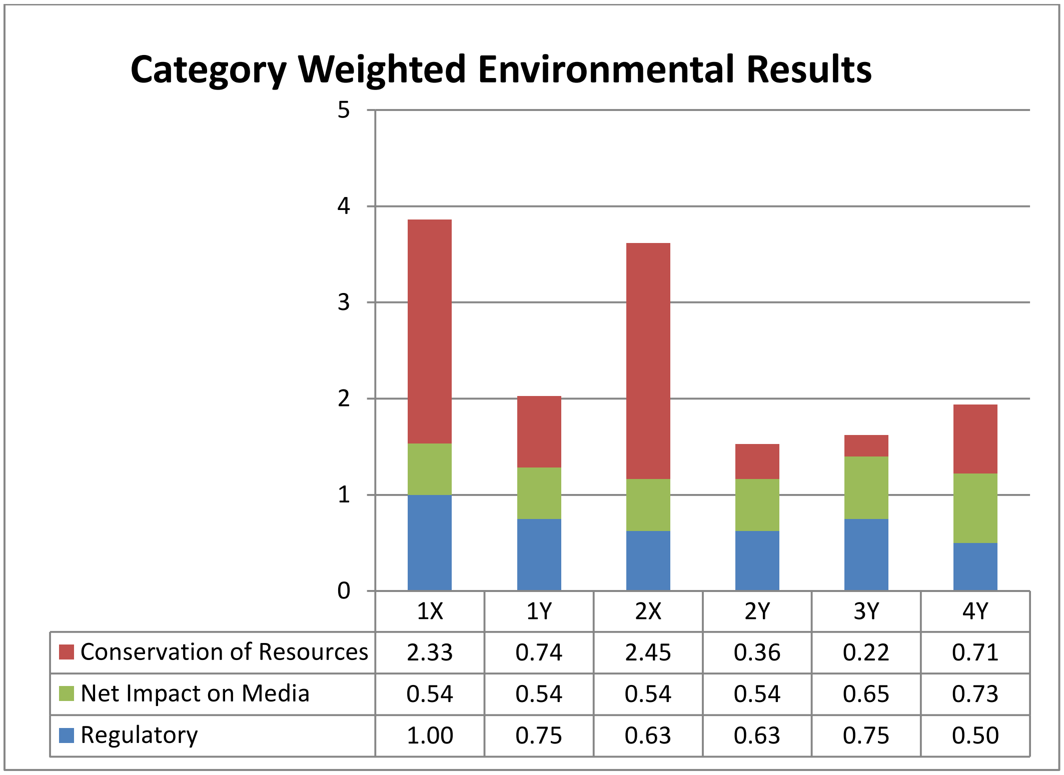


Figure 5-7. Weighted Environmental Scores for Categories.

5.3 Social Results

The social category scores for the six biosolids management configurations assessed with the biosolids TBL tool are listed in Table 5-5:

Table 5-5. Scenario Scores on Social Criteria.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.21	2
1Y: Anaerobic digestion + CHP, pretreatment, landfill	2.69	4
2X: Anaerobic digestion + CHP, co-digestion, land application	3.36	1
2Y: Anaerobic digestion + CHP, co-digestion, landfill	3.09	3
3Y: Incineration, landfill	2.34	5 (tied)
4Y: Gasification, landfill	2.34	5 (tied)

Scoring social criteria will vary significantly based on site specific issues. A biosolids program manager participating in this study emphasized this point: “Odor and related nuisance issues are extremely important to my circumstance, but this is likely to vary with the site and situation and local ‘climate’.”

The two configurations that included anaerobic digestion followed by land application of the biosolids (1X/2X) scored the highest in the social category. A discussion of the social criteria scores is presented in the following sections. The social scoring results shown in Figure 5-9 indicate that option 2X has a slightly higher overall social score than options 1X and 2Y. Options 1Y and then 3Y and 4Y follow these three.

The top contributor to these results is significantly higher public interaction/engagement scores (from a social standpoint) for the top three options. This highlights an important finding, as proactive communication and engagement of the public with sustainable investments and programs is a key focus of the industry and energy neutrality research.

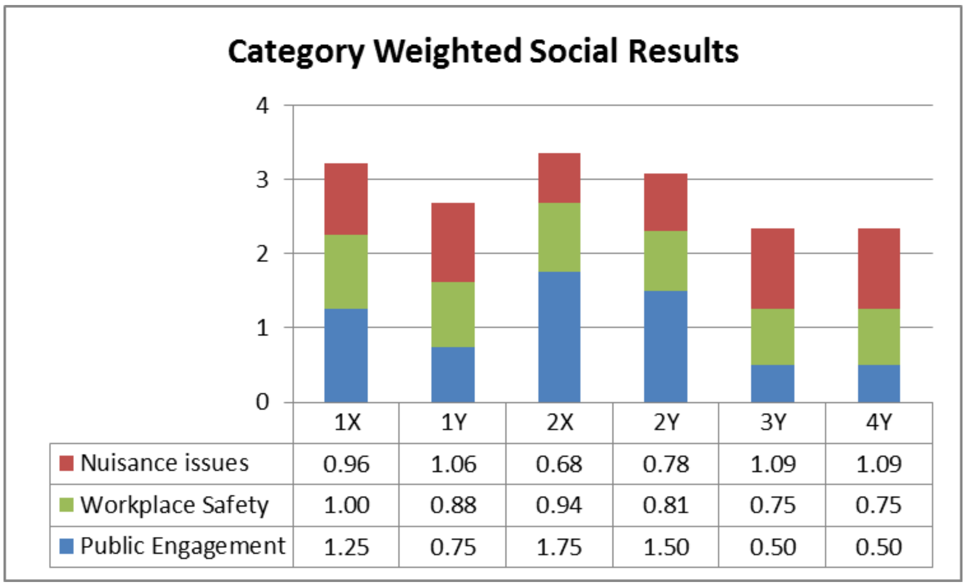


Figure 5-9. Weighted Social Scores for Categories.

5.3.1 Results for Nuisance Issues

Nuisance issues were scored based on impacts to the general public rather than to the treatment plant or biosolids professionals. Table 5-6 lists the scores for Nuisance Issues. Determining scores is challenging because the duration of exposure is not clear or consistent for each case modeled. Thus, putting a high value on this criterion is not appropriate.

A discussion of the “dust” sub-criteria clarifies this point. Dust will be a consideration for land application sites, but dusting potential is greatest during application when soils are dry. During times of the year when soils are moist, there is a very limited potential for dust. In addition, studies have shown that biosolids-amended soils have improved aggregation or soil structure (Brown et al., 2011; Wallace et al., 2009). Over the long term, biosolids application will reduce the potential for dust from soils with a history of dust emissions.

A similar process applies for the other nuisance considerations. While there may be a point where odor, traffic, and visual reminders of biosolids land application can be considered a nuisance, use at agronomic application rates means that only a finite amount of material can be applied to any particular site in one year. This suggests that, while odor, dust, and traffic can be nuisance issues, they will only be nuisance issues at a particular site for a short time. If properly managed, biosolids land application is likely to be seen as a normal farming operation of limited duration. Exceptions include areas used as storage or staging facilities, biosolids applications at high rates at reclamation sites, and traffic in close proximity to the treatment plant or along a fixed route when there are many truckloads involved.

Odor, dust, and visual impacts are considered less likely when solids are landfilled, incinerated, or gasified. At landfills, biosolids disposal is a small part of the total landfill operation. At thermal processing facilities, it is standard practice for engineered controls to control odors and dust, and the visual impacts will be no greater than those associated with the larger WRRF.

Truck traffic is the one nuisance issue that is measured with a quantitative, cardinal, empirical score: the number of truckloads needed to move the solids from the WRRF to the end-use or disposal site. In all configurations, truck traffic will have the greatest density and impacts on the neighborhood immediately near the WRRF. With landfill disposal of solids or ash (in the incineration or gasification scenarios), a similar density of truck traffic will impact those along the full length of the route to the landfill. In the land application scenarios, the truck traffic likely will be dispersed to several different locations over the course of a year.

In scoring nuisance issues involving anaerobic digestion, the team scored the anaerobic digester facility's impacts separately from the end use or disposal impacts and averaged the two scores. The highest score of 5 was given to anaerobic digestion facilities, because they are typically enclosed and generate no significant dust or odor. Visual impacts scored a 4, slightly below the most positive score, because anaerobic digestion facilities are large and obvious.

Anaerobic digestion with co-digestion (with hauled foreign waste) earned a lower score of 4 for odors because of the greater odor potential at the receiving station and some potential for increased odor and mess in operations. The increased truck traffic associated with hauled waste also negatively impacted the score for co-digestion. On the positive side, there is a potential for beneficial side effects due to co-digestion such as improvements in dewaterability and a decrease in residual odors (Rajagopalan et. al., 2014).

The researchers applied nuisance issue scores for end use or disposal as follows:

Class B land application: Class B land application generally received moderate ratings for nuisance issues. The assumption was made that this scenario involved a schedule and location of the application that was average – not too close to neighbors and of only a few days' duration (corresponding to the 10 mgd WRRF being modeled in this project). Therefore, odor scored 3. Dust was given a 4, both because of the potential for biosolids to mitigate soil dust and because the Class B material has high moisture. Visual scored a 3.

Class B landfill disposal: Landfill disposal received lower scores for odor (2) and traffic (1) than land application. The lower scores were based on the fixed location of the landfill whereby the same people are subjected to odors and truck traffic on a year-round basis. Dust rated a 5 because landfill regulations minimize the potential for fugitive dust.

Incineration and gasification were both ranked highly (4.3) on nuisance issues because odor and dust impacting stakeholders and the public are expected to be minimal. The visual impact of these facilities was scored a 2 because of the larger facility footprint and the required landfill disposal. Incineration or gasification facilities will have the largest volume reduction, minimizing truck traffic. Consequently, these options are scored very highly (4.6).

There is potential to manage issues that cause a technology to have a low score. For example, King County, WA, land-applies biosolids to a number of sites that all require transport along the I-90 corridor. Colorful biosolids branding messages on each of the long-haul vehicles somewhat mitigates the nuisance potential of truck traffic and creates an opportunity for public engagement (http://www.loopforyoursoil.com/).

Table 5-6. Scenario Scores on Odor, Noise and Truck Traffic: Scores for Nuisance Issues.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.85	4
1Y: Anaerobic digestion + CHP, pretreatment, landfill	4.25	3
2X: Anaerobic digestion + CHP, co-digestion, land application	2.70	6
2Y: Anaerobic digestion + CHP, co-digestion, landfill	3.10	5
3Y: Incineration, landfill	4.35	1 (tied)
4Y: Gasification, landfill	4.35	1 (tied)

5.3.2 Results for Workplace Conditions

Workplace condition scores are shown in Table 5-7. The scores shown in the table reflect a combination of scores for the treatment technology and final use.

Options that include anaerobic digestion earned a score of 4 because of the unpleasant nature of necessary occasional digester cleanings. The addition of foreign waste results in somewhat less-pleasant workplace conditions because of increased potential for odors and mess, so these configurations were scored 3.5.

Class B **land application** earned a score of 4. Drivers will spend time in agricultural or forest settings during this application, and are likely to visit different end-use sites. There will be Potential interactions with farmers along with a diverse route which is considered a positive.

Class B **landfill** disposal earned a score of 3. While workers are able to work outside, the environment in a landfill is not pleasant and does not have the association with natural environments such as farms or forests. In addition, there is no variety in the site.

Incineration and gasification were given a score of 3 for workplace conditions, because they are typically places with some odors, dust, and noise – less pleasant work conditions than, for example, a land application site.

Table 5-7. Results for Workplace Conditions.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	4.00	1
1Y: Anaerobic digestion + CHP, pretreatment, landfill	3.50	3
2X: Anaerobic digestion + CHP, co-digestion, land application	3.75	2
2Y: Anaerobic digestion + CHP, co-digestion, landfill	3.25	4
3Y: Incineration, landfill	3.00	5 (tied)
4Y: Gasification, landfill	3.00	5 (tied)

5.3.3 Results for Public Engagement

The project team developed scores for the public engagement criterion based on the assumption that public knowledge of the wastewater treatment process is beneficial and desirable. People who are aware of the wastewater treatment process are more likely to respect recommendations on what is appropriate material to flush or put down the drain (McIvor, 2010; Miller, 2012; Palme et al., 2005; Penninsi, 2012), resulting in lower contaminant concentrations and reduced maintenance requirements in the collection system and at the treatment facilities. Increased understanding of biosolids also reduces concerns about biosolids management, allowing increased resource recovery including water, nutrients and fixed carbon.

As with the other sub-criteria, the project team scored treatment and final use separately. Scores for Public Engagement are listed in Table 5-8.

Anaerobic digestion, which is embedded at a WRRF, does not require any significant public engagement, and, therefore earned a low score of 2. However, **AD with CHP** has the potential to provide an excellent opportunity to engage the public in the merits of green energy increasing the rating. From a public engagement perspective, AD with co-digestion received a higher rating than AD alone, because of the need to communicate with more stakeholders and the additional benefits for waste reduction and energy production.

Class B **land application**, earned a score of 3 for public engagement because although End-use customers and regulators will have to be familiar with the product, there is no indication or requirement for outreach beyond this. Class B land application tends to be less public, with less involvement, than what is involved with a Class A product, for example.

The project team gave low scores to **landfill** disposal, because it does not require public engagement and there are few potential beneficial messages associated with landfilling for public engagement.

Low scores were given for public engagement associated with **incineration and gasification** because there is nothing inherent in the facility and its operations that drive such interactions.

Table 5-8. Scenario Scores for Public Engagement8: Results for Public Engagement.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	2.5	3
1Y: Anaerobic digestion + CHP, pretreatment, landfill	1.5	4
2X: Anaerobic digestion + CHP, co-digestion, land application	3.5	1
2Y: Anaerobic digestion + CHP, co-digestion, landfill	3.0	2
3Y: Incineration, landfill	1.0	5 (tied)
4Y: Gasification, landfill	1.0	5 (tied)

5.4 Research Guidance Case Results

Table 5-9 lists the team-applied weighting for the categories, criteria and sub-criteria for all of the parameters considered in this TBL. The table provides an “at-a-glance” understanding of the impact of any single parameter on the outcome of the final TBL score. For instance, any differences in net present value (at 28% of the total TBL score) will result in a much greater difference between two biosolids management strategies than differences in particulate matter emissions (0.4% of the total TBL score).

Table 5-9. Applied Weighting for Categories, Criteria, and Sub-Criteria for All TBL Parameters.

Level of Category, Criteria or Sub Criteria	1	2		3		4	
		% within category	% of TBL	% within criteria	% of TBL	% within sub criteria	% of TBL
Economic	**33.3%**						
Net Present Value		84%	28%				
Engineering/Technical		14%	4.67%				
Simplicity				0%	0%		
Flexibility				100%	4.67%		
State of Technology				0%	0%		
Environmental	**33.3%**						
Conservation of Resources		50%	16.7%				
Nutrients				30%	5.0%		
Fixed Carbon				60%	10.0%		
Energy Recovery						25%	2.5%
GHG						75%	7.5%
Water Conservation				10%	1.7%		
Net Impacts on Media		25%	8.3%				
Land/Soil Impact				33%	2.8%		
Air Quality Impact				33%	2.8%		
NOx						75%	2.1%
SO2						15%	0.4%
Particulate Matter						15%	0.4%
Water Quality Impact				33%	2.8%		
Regulatory Flexibility		25%	8.3%				
Social	**33.3%**						
Nuisance Issues		25%	8.3%				
Odor				40%	3.3%		
Dust				20%	1.7%		
Traffic				20%	1.7%		
Visual				20%	1.7%		
Workplace Conditions		25%	8.3%				
Public Interaction		50%	16.7%				

Figure 5-10 illustrates the combined economic, environmental, and social scores. The overall TBL scores for the six biosolids management options that include weighted economic, environmental, and social scores highlight the following findings:

- Due to higher environmental and social scores for options 1X and 2X (which both include anaerobic digestion, combined heat and power (CHP) and land application), they are the highest scoring overall options evaluated. Co-digestion (2X) has a slightly higher overall TBL score, driven by both lower life-cycle NPV costs (economic) and slightly higher social scores.
  - As discussed in earlier sections, these results highlight research priorities and show how investing in biosolids management options brings a combination of economic, environmental, and social value.
  - The results show that all else being equal, land application (options 1X and 2X) has superior triple bottom line value when compared to landfill disposal (options 1Y and 2Y). The two land application options also score higher than the incineration (3Y) and gasification (4Y) options.

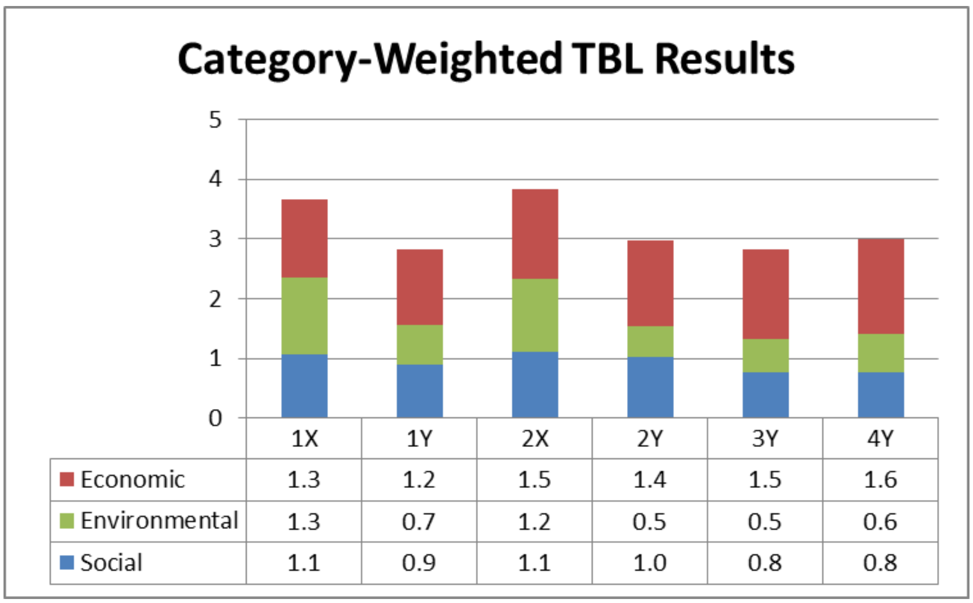


Figure 5-10. TBL Results for Research Guidance.

Table 5-10. TBL Results for Research Guidance.

Scenario	Score	Rank
1X:AnaDig+CHP,Prtmt,LandApp	3.66	2
1Y:AnaDig+CHP,Prtmt,Landfill	2.82	6
2X:AnaDig+CHP,Codig,LandApp	3.84	1
2Y:AnaDig+CHP,Codig,Landfill	2.99	4
3Y:Incin,Landfill	2.82	5
4Y:Gasif,Landfill	3.00	3

CHAPTER 6.0

TRIPLE BOTTOM LINE RESULTS FOR UTILITY DECISION MAKING

6.1 Utility Decision Making

Utilities are using TBL analysis more and more frequently to assist in decision making for large projects such as the investment in biosolids management options. The TBL research team also scored each of the six biosolids management options against metrics that included economic sub-criteria for simplicity and state of technology. These are two TBL economic criteria that utilities use in their internal TBL decision making and capital prioritization models. When they are included, options that have greater operational simplicity and use technology that has been proven to a greater level will score higher using the TBL model. Table 6-1 shows the team's scoring for the two additional engineering and technical criteria.

Table 6-1. Engineering and Technical Criteria Scores.

Scenario	Simplicity	State of Technology
1X: Anaerobic digestion + CHP, pretreatment, land application	2	3
1Y: Anaerobic digestion + CHP, pretreatment, landfill	3	3
2X: Anaerobic digestion + CHP, co-digestion, land application	3	4
2Y: Anaerobic digestion + CHP, co-digestion, landfill	4	4
3Y: Incineration, landfill	4	4.5
4Y: Gasification, landfill	3	1

When these criteria are included, the gasification configuration (4Y) moves lower to fifth place, while 2Y and 3Y climb one place each, as shown in Figure 6-2 and Table 6-2 (note that configurations 4Y and 3Y have nearly identical overall TBL scores).

Figure 6-1 shows the economic scoring at a more granular level. This shows how the addition of criterion for simplicity and state of technology change the economic TBL rankings. Option 4Y (gasification) moves down from being ranked No. 1 for overall economic score to being the fourth highest-ranked option, behind 2X, 2Y, and 3Y. Note that the difference in economic score for these four options is not significant – all four options score at or just above a 4.0 economic score (out of a maximum possible score of 5.0).

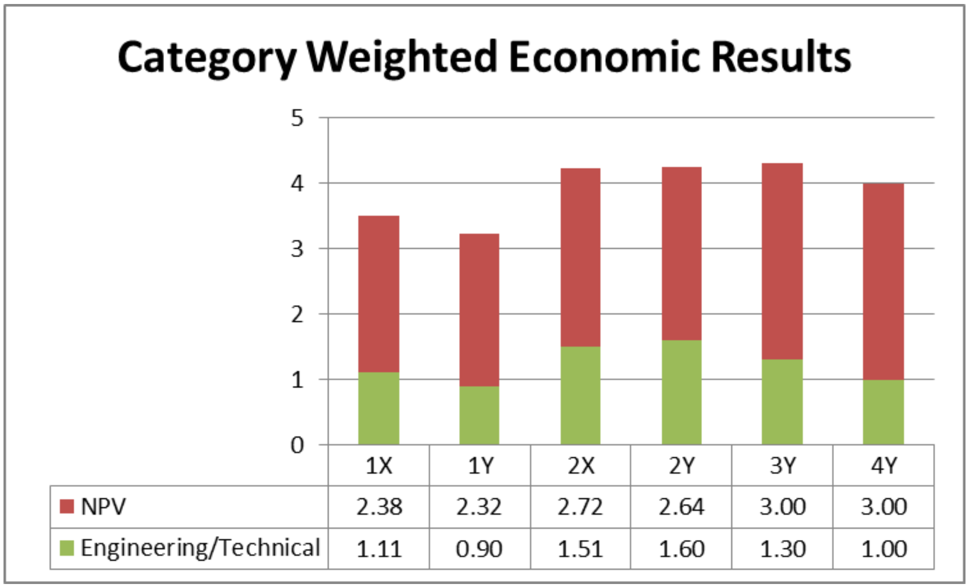


Figure 6-1. Weighted Economic Scores for Categories.

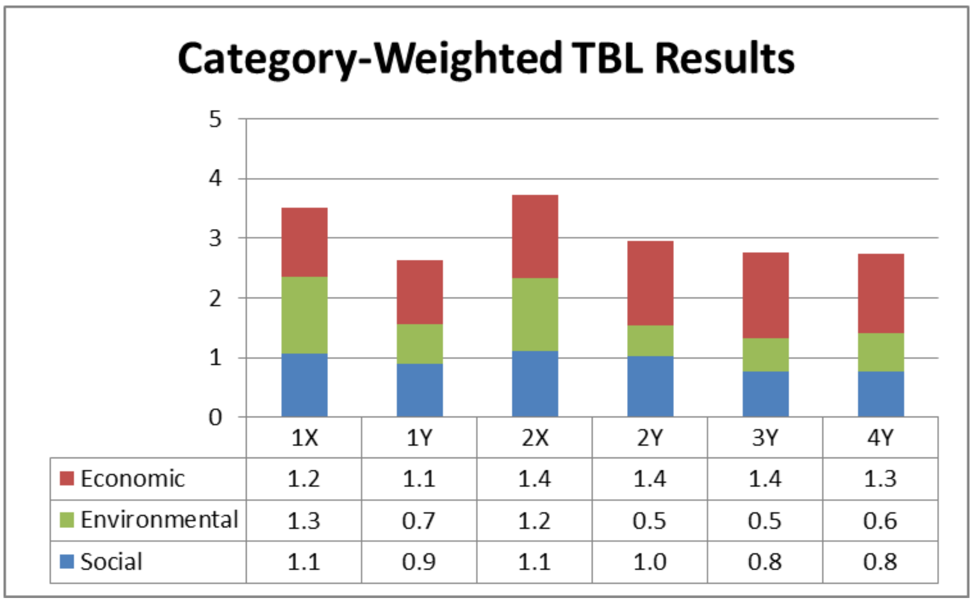


Figure 6-2. TBL Results for Utility Decision Making.

Table 6-2. TBL Results for Utility Decision Making.

Scenario	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.52	2
1Y: Anaerobic digestion + CHP, pretreatment, landfill	2.64	6
2X: Anaerobic digestion + CHP, co-digestion, land application	3.74	1
2Y: Anaerobic digestion + CHP, co-digestion, landfill	2.95	3
3Y: Incineration, landfill	2.75	5
4Y: Gasification, landfill	2.76	4

6.2 Sensitivity Analysis and Discussion

The researchers evaluated four different sensitivities to test how the TBL results differ when significantly altering key input assumptions, weighting criteria amounts, and sub-criteria. The sensitivities evaluated include:

- Low electric/gas costs sensitivity.
- High electric/gas costs sensitivity.
- Carbon Cap sensitivity.
- Alternative criteria weightings sensitivity.

6.2.1 Assumptions Used for Sensitivities

This section describes all sensitivities (except the reference case, detailed in the preceding chapter) along with their evaluation results. Table 6-3 below lists each sensitivity, as well as the relevant assumptions and how they differ across each sensitivity. The carbon cap sensitivity and assumption is discussed further in Section 6.2.4.

Table 6-3. Assumptions Used for Sensitivity Analysis.

Sensitivity	Electric & Gas Costs	GHG Emission Criteria	GHG Cost Use	Criteria Weightings
Low electric/gas costs	EIA High Resource Case[2]	Yes	None	Base
High electric/gas	EIA GHG25 Case[3]	Yes	None	Base
Carbon Cap Sensitivity	EIA Reference Case	No	\$25 per ton CO_2	Base
Alternative Wtgs Sensitivity	EIA Reference Case[1]	Yes	None	Survey Wtgs

1 EIA Annual Energy Outlook 2013, reference case scenario
2 EIA Annual Energy Outlook 2013, high resource scenario
3 EIA Annual Energy Outlook 2013, GHG25 with low gas price scenario

Figure 6-3 displays the natural-gas price forecast used in the TBL economic model to estimate natural gas fuel costs. Figure 6-4 shows a similar forecast of electricity costs. Both sets of forecasts are from EIA's 2013 *Annual Energy Outlook*.

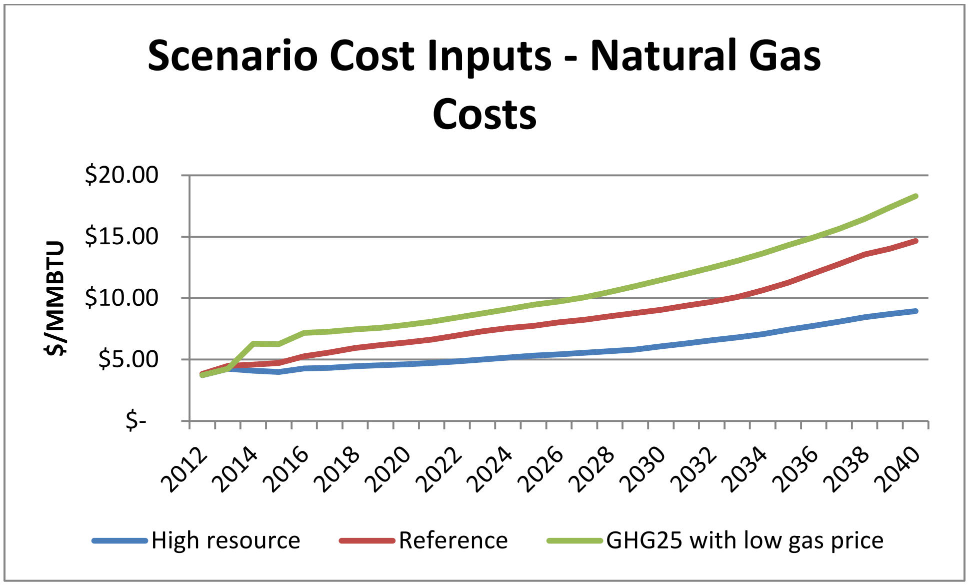


Figure 6-3. Natural Gas Price Inputs for TBL Economic Model.

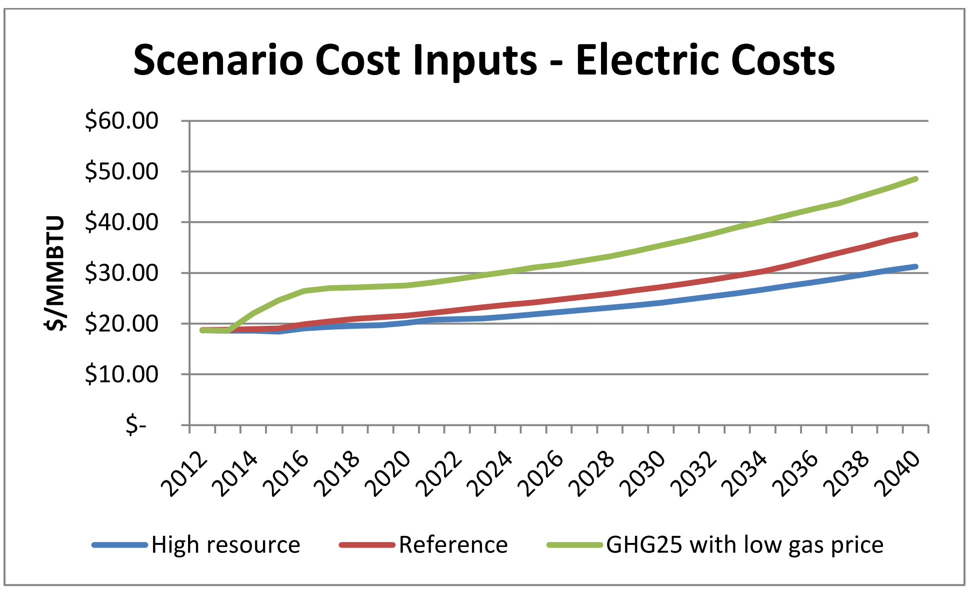


Figure 6-4. Electrical Cost Inputs for TBL Economic Model.

Figure 6-5 illustrates the criteria weighting percentages used for the weighting discussed in this report. Note that only utility decision making and research guidance weightings are discussed in this report. Survey results are for reference only. The TBL tool allows a user to choose among a number of weighting schemes.

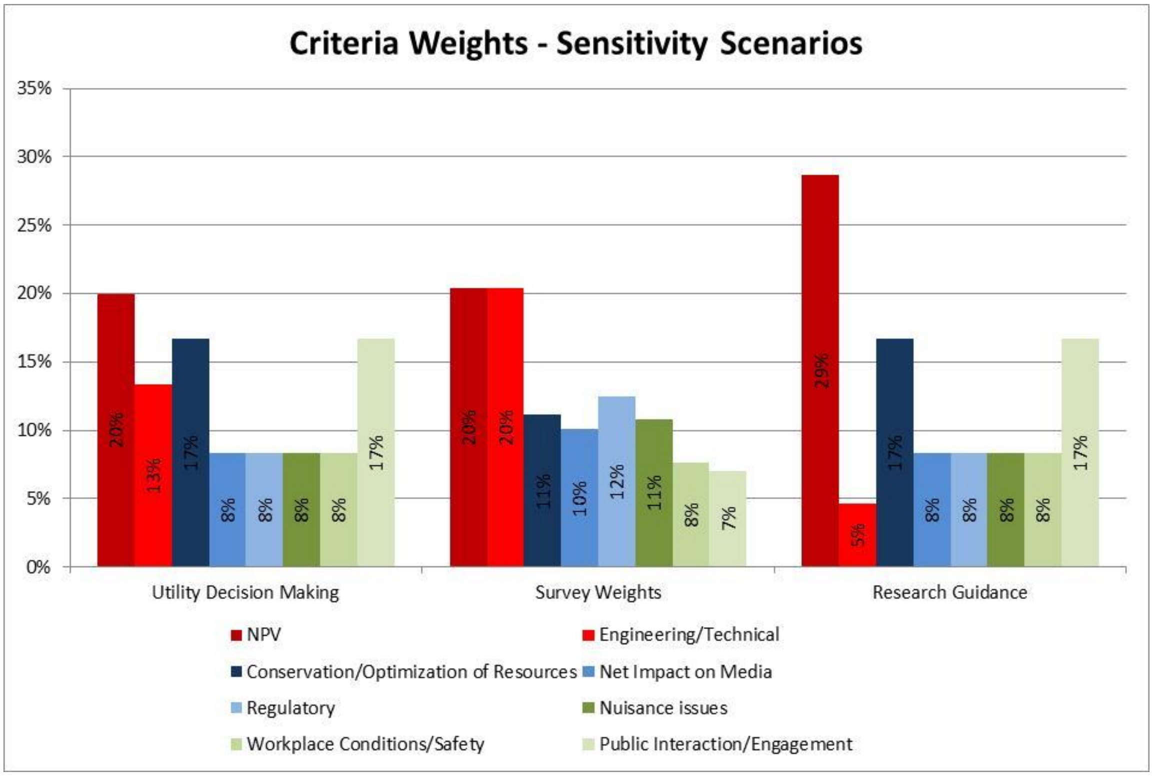


Figure 6-5. Sensitivity Weightings.

6.2.2 Low Electric and Gas Cost Sensitivity

Electric and natural gas costs have variable effects on the lifecycle costs for different configurations, depending on whether the option is a consumer or producer of energy. Table 6-4 summarizes the impacts of lower energy costs. Lower electric and gas costs make incineration and gasification configurations marginally more attractive and make the CHP options slightly less attractive. However, the effects were limited to 0.4 to 2.5% of lifecycle operations and maintenance (O&M) costs and did not make an impact that would change the overall TBL results significantly. Figure 6-6 and in Table 6-4 show the revised scores for the lower energy cost sensitivity.

Table 6-4. Cost Impacts of Lower Energy Costs ($ Thousands).

	1X	1Y	2X	2Y	3Y	4Y
Reference Case	$63,207	$64,986	$55,317	$57,069	$50,233	$50,233
Low Electric and Gas Cost Sensitivity	$63,335	$65,114	$55,419	$57,171	$50,088	$50,142
Difference	-$128	-$128	-$102	-$102	$145	$90

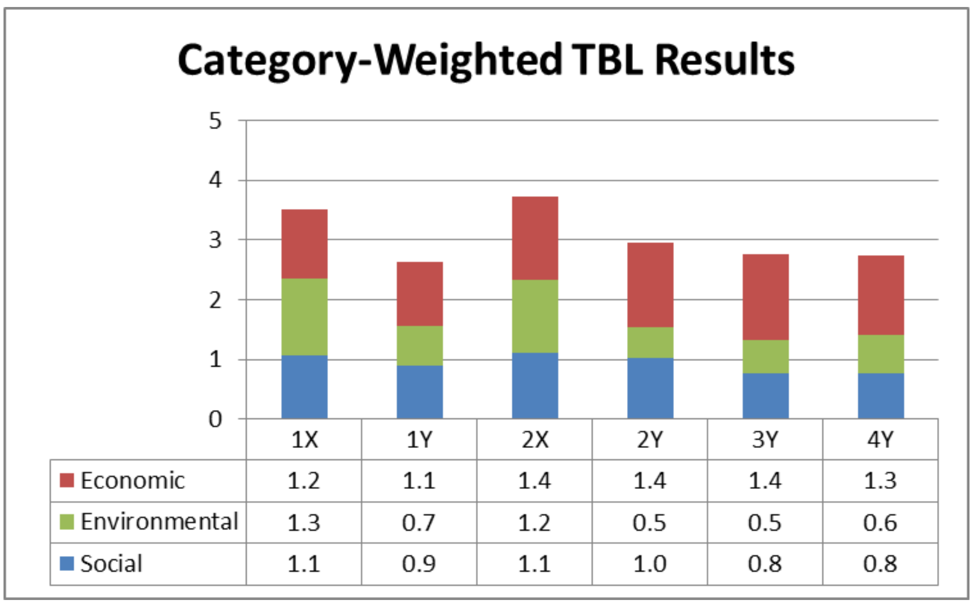


Figure 6-6. TBL Analysis Results – Low Electric and Gas Costs.

Table 6-5. TBL Revised Scores for the Lower Energy Cost Sensitivity.

Sensitivity	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.52	2
1Y: Anaerobic digestion + CHP, pretreatment, landfill	2.64	6
2X: Anaerobic digestion + CHP, co-digestion, land application	3.73	1
2Y: Anaerobic digestion + CHP, co-digestion, landfill	2.95	3
3Y: Incineration, landfill	2.75	4
4Y: Gasification, landfill	2.76	5

6.2.3 High Electric and Gas Cost Sensitivity

Higher electric and gas costs make incineration and gasification configurations marginally less attractive and the CHP options a little more attractive. Again, the change in costs is not large enough to change the overall TBL results significantly. The cost impact for the higher energy costs is shown in Table 6-6. Figure 6-7 and Table 6-7 show the revised TBL scoring.

Table 6-6. Cost Impacts of Higher Energy Costs ($ Thousands).

	1X	1Y	2X	2Y	3Y	4Y
Reference Case	$63,207	$64,986	$55,317	$57,069	$50,233	$50,233
High Electric and Gas Cost Sensitivity	$62,736	$64,515	$54,941	$56,693	$50,236	$50,426
Difference	$471	$471	$376	$376	-$3	-$194

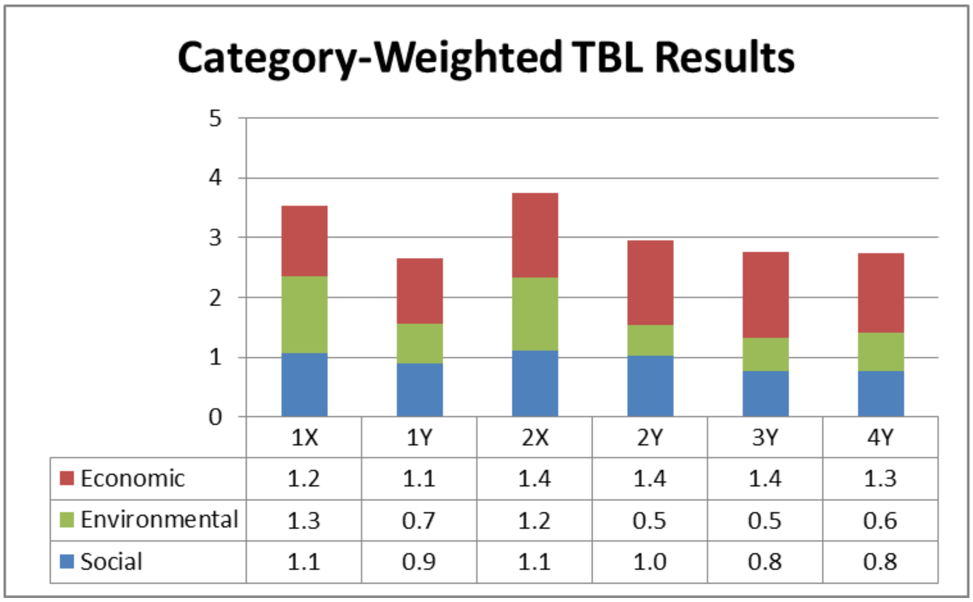


Figure 6-7. TBL Analysis Results – High Electric and Gas Costs.

Table 6-7. TBL Revised Scores for the Higher Energy Cost Sensitivity.

Sensitivity	Score	Rank
1X: Anaerobic digestion + CHP, pretreatment, land application	3.53	2
1Y: Anaerobic digestion + CHP, pretreatment, landfill	2.65	6
2X: Anaerobic digestion + CHP, co-digestion, land application	3.74	1
2Y: Anaerobic digestion + CHP, co-digestion, landfill	2.96	3
3Y: Incineration, landfill	2.75	4
4Y: Gasification, landfill	2.75	5

6.2.4 Carbon Cap Sensitivity

A carbon cap sensitivity criterion was used to investigate the potential impacts of a future carbon cap and trade program. This sensitivity criterion was based on the assumption that plants would either 1) deploy equipment to reduce/capture GHG emissions, or 2) buy carbon credits on market. Hence, the sensitivity analysis treats GHG emissions as an additional cost, or credit, for each ton of CO_2. Using this, the research team determined that the cost per ton of CO_2 on the market would need to be around $1500 (an unreasonably high amount) before it would change the rankings among the six configurations. In general, adding the price for carbon credits increased the difference in scores between those two configurations (1X and 2X) that generated carbon credits compared to the other four that were net emitters of CO_2.

6.2.5 Applying Different Criteria Weights Sensitivity

As part of the sensitivity analysis for the use of the TBL tool in analyzing the six biosolids management configurations of particular interest, the research team ran the model to compare the impacts of using different weights:

- The average of the weights recommended by stakeholders in the stakeholder survey.
- Those initially proposed by the project team based on its best recommendation.

The resulting difference in final TBL score for each biosolids management configuration is shown in Figure 6-8.

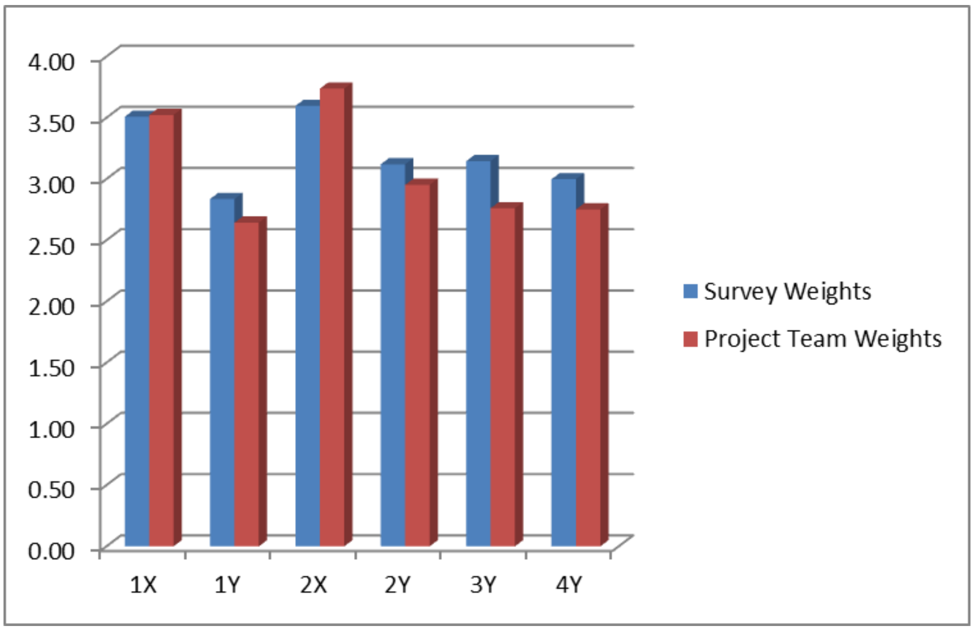


Figure 6-8. Difference in Final TBL Score for Each Biosolids Management Configuration.

CHAPTER 7.0

CONCLUSIONS AND FINDINGS

The TBL model and results presented in this report are useful for decision makers in order to prioritize different utility and industry investment options for biosolids management with potential for energy recovery and efficiency. Researchers developed the TBL model with the objective of setting research priorities. This report highlights how TBL results can differentiate between investment options for biosolids management and prioritizes them for their long-term sustainability. Individual utility decision-making processes, however, can also use the TBL model by tailoring input assumptions to utility-specific conditions such as energy costs. This section discusses findings, conclusions, and next steps to leverage this research.

7.1 Research Guidance TBL Model Findings

The overall TBL scores for the six biosolids management options that include weighted economic, environmental, and social scores highlight the following findings:

- ***Anaerobic digestion, CHP, and land application options score the highest overall.*** This is primarily due to higher environmental and social scores for these options. Co-digestion adds a slightly higher overall TBL score, driven by both lower life-cycle NPV costs (economic) and slightly higher social scores.
  - These results show how investing in biosolids management options brings a combination of economic, environmental, and social value.
  - All else being equal, options with land application have superior triple bottom line value when compared to landfill disposal options. The two land application options also score higher than the incineration and gasification options.

Economic Results

- ***Gasification and incineration have the lowest NPV cost results*** of the six options evaluated. As noted in the economic assumptions section, the incineration option's life-cycle costs assume that a regional incineration facility is feasible and that the WRRF would only be responsible for a portion of the capital and operating costs commensurate with the percentage of solids that it is adding to the facility. This results in improved economies-of-scale, and is consistent with the size of regional incinerators currently being planned in North America.
- Anaerobic digestion with co-digestion, have lower NPV costs than their counterpart options that include solids pretreatment (thermal hydrolysis) instead of co-digestion.

Environmental Results

- ***Anaerobic digestion, CHP, and land application with either solids pretreatment or co-digestion have significantly higher environmental results*** of the six options evaluated. The primary reason for these significantly better results is from the conservation/optimization of resources environmental score category. Anaerobic digestion, CHP, and land application options have a much higher resource conservation score and thus higher overall environmental score than all other biosolids management options evaluated.

Social Results

- ***Anaerobic digestion, CHP with co-digestion, with land application option, has a slightly higher overall social score*** than options for anaerobic digestion, CHP with pretreatment, with land application and anaerobic digestion, CHP with co-digestion, with landfilling. Anaerobic digestion, CHP with pretreatment, with landfilling, then incineration with landfill disposal and gasification with landfill disposal follow these options in social score rankings.
- The main contribution to the social results is from the significantly higher public interaction/engagement scores for the three top-scoring options. This highlights an important finding: proactive communication and public engagement in sustainable investments and energy programs need to be a key focus.

7.2 Utility Decision-Making Results Findings

The research team also scored each of the six options as if they were evaluating a specific option for a utility location. The utility decision making evaluation included economic sub-criteria for simplicity of operations and on the developmental state of the technology. These are two TBL economic criteria that several utilities already use in their internal TBL decision making and capital prioritization models. When included, options that have greater operational simplicity and use technology that has been proven to a greater level will score higher using the TBL model.

- The option ranking based on utility decision-making criteria on overall TBL scoring for the top two configurations does not change from the research-guidance results.
    - This is because the engineering/technical weightings are less than the NPV-cost criterion, and because environmental and social scoring remains unchanged in these results from the research guidance results.
- At a more granular level, the addition of simplicity of operations and state of the technology changes the economic TBL rankings. Gasification drops from being ranked No. 1 in the economic category to being the fourth highest-ranked option. The innovative nature of gasification and unfamiliarity of its operation present hurdles to utilities which have a preference for established technologies, even though the economic benefits are attractive. The difference in economic score for the top four options is not large – all four options score at or just above a 4.0 economic score (out of a maximum possible score of 5.0).

7.3 Guidance When Using Triple Bottom Line for Decision Making

The following considerations should be made when applying TBL in the decision-making process.

7.3.1 Using a Life-Cycle Approach

Incorporating a life-cycle economic assessment is a critical step in evaluating capital investments. The research team used net present value (NPV) as the primary economic metric, but several other metrics that take into account the time value of money can also evaluate the life-cycle of cash-flows from different investments. Utility infrastructure has long lives, often measured in decades, not just years. This is why taking into account the full life-cycle of the investments and the time value of money is critical to a sustainable, long-term utility. In addition to life-cycle economic assessments, evaluating the life-cycle of environmental impacts and valuing those impacts through the TBL approach helps utilities align investment decisions with how those investments will bring value to customers and stakeholders over multiple decades that those investments bring value.

While taking into account short-term financial impacts is something to be considered when making investment decisions, basing capital investment decisions entirely on short-term financial metrics (such as simple payback) is not appropriate since it can lead to flawed economic decisions over the long term. By using a life-cycle approach that incorporates the time value of money, decision making that focuses too much on short-term financial impacts can be avoided. This is because the metrics used to evaluate the decision include future years when those investments provide value.

7.3.2 Stakeholder Involvement

Stakeholder involvement is an important component of a thorough TBL decision-making process. TBL criteria weightings can be adjusted to reflect what different stakeholders value in order to align investments with those values. Where the values and opinions of one stakeholder group diverge significantly, the TBL process is flexible, allowing for differences in criteria weighting and scoring. This can help show that the cost – economic, social, and environmental – reflects local values.

7.3.3 Risk Analysis Tests Alternatives

Thorough decision analysis uses some form of risk analysis to test how sensitive results are to different input assumptions. A robust risk analysis approach can add tremendous value, particularly where large long-term capital investments are being prioritized and optimized. Sensitivity analysis can show how the uncertainty inherent in different input assumptions can drive a significantly different long term result than the base case shows.

An effective first step is a simple sensitivity analysis to change individual or groups of assumptions to see how they impact long term value. However, more sophisticated risk analysis techniques are increasingly easier to model. These include development of decision trees, as well as the Monte Carlo simulation. Both of these statistical modeling approaches are progressively more user-friendly and robust software packages that integrate with Microsoft Excel™. Using statistical modeling approaches allows for incorporating the probability of a future event or forecast into the decision analysis approach. Instead of needing to model many different individual cases to test the impact of, natural gas price levels, for example, a probability distribution of those values can be modeled quickly through Monte Carlo simulation. Or the impact of multiple input assumptions and their probabilities can be modeled simultaneously. This evaluation of the impact of multiple assumptions can quantify the impact to decision variables on a one-off basis, as well as show the probability of those variables and the range of their impact on decision variables such as the overall TBL score. This yields a more complete picture of the range of uncertainty in long term value of alternatives.

7.3.4 Manage the Decision-Making Process to Be Objective

Study in the field of decision theory in recent decades has begun to more clearly show how a variety of cognitive biases impact decision making. The late Amos Tversky and his colleague, Daniel Kahneman, are two leading (and Nobel prize-winning) researchers in this growing field. In their landmark paper *Judgment Under Uncertainty: Heuristics and Biases* and a related article "Choices, Values, and Frames" by the same authors, Kahneman and Tversky share their research into many ways cognitive bias can enter into decisions. While this report does not focus on or detail their research, it briefly discusses the guidance that emerges from the research with respect to managing against different cognitive biases in decision making. Utilities are investing very large sums of capital into technologies that will bring value to their communities for many decades. Many utilities use multi-criteria decision analysis approaches such as the TBL approach outlined in this report to assess the potential value of such investments. Thus, understanding and incorporating guidelines that account for some of the biases decision makers have is an important consideration.

Kahneman, in his book *Thinking, Fast and Slow*, describes how a number of cognitive biases can lead to counterintuitive decision making. For instance, how individuals often neglect the duration of an event and provide more weight towards what they remember at both the peak and the end of the event. Helping manage against this bias is one reason why our research team recommends framing the evaluation using a life-cycle NPV cost analysis and environmental assessment when making long-term capital decisions in biosolids management. By framing the investment over its full life, duration neglect and the peak-end rule are at least partially mitigated through the evaluation process. This helps give an equal footing to investments that may require a large capital investment yet also result in greater long-term savings and thus a more financially sustainable utility in the long run.

Other ways to frame the decision-making process to avoid bias include:

- Take time to educate decision makers on long-term tradeoffs (economic, environmental, and social) and the value of investments.
- Solicit diverse opinions on assumptions and options early in the decision making process. Do not use the TBL approach in a vacuum.
- Use direct quantification using proven fundamental models of plant processes/energy use to help minimize subjectivity.
  - An example of this is the process and technology energy modeling used in this study to quantify energy usage, environmental impact, resulting costs and TBL impacts.
- Define scoring scales for more qualitative TBL criteria to help minimize subjectivity and enforce a consistent scoring approach across the options.
- Have individual team members score qualitative criteria independently, without consulting each other to test for consistency or inconsistency.

- Following this, review the scoring results as a team to explain differences in scores and the perspectives used to score the qualitative criteria.

- ♦ Frame options to test range of alternatives and assumptions.
  - Assumptions are important – e.g., incineration has a huge amount of heat loss; if this is improved energy recovery, the TBL scoring outcome will be different. Risk analysis techniques are a useful way to test these assumptions.

7.4 Next Steps to Leverage TBL Research

Use the results of this report and its partner report on energy neutrality to guide research priorities using TBL results. This could include adjusting the criteria selection or weightings that the research team uses to score the different options to further align results with changing values and new priorities.

Along with the report, the TBL model used to score each of the six biosolids management options is included as an appendix. Ways to improve and evolve this TBL model include:

- ♦ Customize the TBL model for regional differences such as:
  - Regional energy markets differ widely across North America and the world. The model could incorporate regional-specific energy market price forecasts depending on the region.
- ♦ Use the Monte Carlo simulation capability for risk analysis. Adding this capability to the model would add probability distributions to different uncertain assumptions (such as capital cost, energy prices, even environmental impacts) that drive project TBL score results and option value.
  - Incorporate scoring criteria for facility/system resiliency by scoring investment options in a way similar to how vulnerability assessments score security risk. Options that are more resilient and less vulnerable to outages due to events or threats (such as severe weather events, for example) would score higher than options that are less resilient.
- ♦ Apply the TBL model for further research in areas such as:
  - Other pioneering technologies/options beyond the six options evaluated in this report to further understand/inform tradeoffs between technologies.
  - To utilities as a case study to show how the model would score investments to an existing facility.

APPENDIX A

TBL LITERATURE REVIEW SUMMARY FOR TBL CHAPTER

A Triple Bottom Line (TBL) analysis is a method for evaluating the impacts of a project or program on not just economic, but also environmental and social outcomes. The reasons for applying Triple Bottom Line (TBL) analysis to decision making around the management of wastewater solids are:

- To help managers of wastewater solids choose the option(s) best suited to their local circumstances.
- To provide the broader wastewater management profession with improved understanding of the costs and benefits of various common solids management scenarios.
- To provide the Water Environment Research Foundation (WERF) with guidance on which solids management scenarios are worth further research.

The strong commitment from leading wastewater management organizations, including WERF, to advance the sustainability of wastewater treatment operations (water resource recovery) provides an important context for this study. As WERF noted in a recent report, the goal of assessing a new technology or process is to "realistically answer the simple question: is this a good long-term investment?" (WERF, 2012). And how is be defined? What makes for a good long-term investment? Inevitably, most answers to these questions include some discussion of the term "sustainability."

Defining Sustainability for Decision Making

The 1987 Brundtland Report provides the most-often quoted definition of "sustainability." Sustainable development is, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). But what does this mean to the manager of wastewater solids? And does it mean the same thing for his or her manager, the manager of the entire urban water system, or the ratepayer that uses the system?

There are dozens of published papers and guidance documents that address definitions of sustainability in the context of making decisions, planning, and reporting on progress. Corporations and local municipalities (City of Grand Rapids, MI, 2012; San Francisco Public Utilities Commission, 2013) provide annual updates on their progress on specific Sustainable Development Indicators (SDIs) goals. Many authors advocate use of SDIs as a more robust assessment of water systems than economic analysis or life cycle assessments alone (Amajironwu et al., 2008; Balkema et al., 2002; Lundin and Morrison, 2002; Roeleveld et al., 1997; Sahely et al., 2005). SDIs also include consideration of social and cultural factors. An early definition of sustainable development includes balancing concerns with the protection of environmental systems, enriching the quality of life for current and future generations, and simultaneously advancing economic development (Sahely et al., 2005).

But it is challenging to create SDIs and/or criteria used in making decisions on how best to manage wastewater solids. What is “sustainable”? Who decides what counts? The facility manager? The solids program operator? The design engineers? And what should the decision makers consider to be the scope of their analysis?

The management of wastewater solids can be viewed narrowly, looking only at the thickening, treatment, dewatering, and final use or disposal. Or, it can be seen within the larger context of wastewater treatment. The latter makes sense, as solids management has direct impacts on the larger wastewater treatment processes, such as side streams from anaerobic digestion. But solids management is actually set in an even broader context of the urban water system. Considering the role of municipal solids in the water cycle and water treatment processes generally, rather than treating solids in isolation, is key to a fuller understanding of sustainability criteria (Lundin and Morrison, 2002). “Looking at the whole system, one can find integrated solutions that may not be visible when looking at smaller parts of the system. Similarly, optimizing in one dimension, for instance, the environmental dimension, will improve this aspect of the system but may have unwanted effects in other dimensions” (Balkema et al., 2002). A narrow scope can result in missing impacts, connections, or opportunities that would result in previously unconsidered ways to increase sustainability.

As wastewater and solids management professionals shift their paradigm to recognize wastewater treatment facilities as “water resource recovery facilities,” (Water Environment Federation, 2012(b)) the scope of what constitutes “sustainability” is changing in other ways as well. For example, over the past decade, the Capital Regional District in Victoria, BC has been developing its initial water resource recovery facilities with a deliberate vision of “waste” water as a *resource*: “wastewater is a key component of urban resource management” (*Innovations*, Nov/Dec 2008. p. 26).

For an individual solids management program, defining “sustainability” is not a simple task. Addressing economic, environmental, and social criteria together requires far more work than just looking at a simple economic bottom line.

Lundin and Morrison (2002) set up a system to evaluate various urban water infrastructures. They quantified the performance of an urban water system by its scores on SDIs or benchmarks. The authors recognize four levels of “sustainability:”

- ♦ At a minimal level, the system meets the demand for water and protects public health – basic functioning.
- ♦ A more advanced, more sustainable system also meets minimum standards for environmental protection and health.
- ♦ The third level of sustainability is characterized by the system also meeting regulatory standards, with a basic focus on compliance. This level is typical of most wastewater treatment facilities in the U.S. today and includes monitoring of potable water, storm water, and effluent and may pay attention to energy recovery.
- ♦ The highest level of sustainability would be an urban water system that is classified as clean technology. Besides doing all of the above, this kind of system ensures maximum use of

resources and waste minimization, accompanied by source separation technologies. Recycling of nutrients, organic matter, and water is practiced.

While there are widely accepted, general criteria that define sustainability, it is important to recognize that the local context will also play a significant role in defining sustainability for any particular water, wastewater, or solids management program. For example, Roeleveld et al. (1997) conducted a narrow evaluation of sustainability for a wastewater treatment facility in the Netherlands, where there is an overabundance of nutrients available for farmland and an existing large investment in incineration capacity, which makes sludge minimization a high priority. This local assessment concludes that continued incineration with energy recovery is more sustainable than land application of biosolids.

Local and regional factors inform the ranking and performance of a system. Lundin and Morrison (2002) evaluated two systems, one in S. Africa and one in Sweden. In S. Africa, water conservation is the most important factor, and the operators focus on reducing leakage within the system. In Sweden, water is abundant, as are nutrients. Concerns regarding heavy metal concentrations in the biosolids restrict beneficial reuse of water and the recycling of biosolids nutrients.

In defining what is sustainable, it is important to consider local concerns such as water conservation, energy balance, carbon intensity, nutrients, the health of soils, and/or myriad other criteria.

Stakeholder Participation is Critical

Because local circumstances are critical to defining sustainability, informed stakeholders are critical to the decision-making process. The only way to define “sustainability” for use in evaluating solids management options is by involving those who will use the definition, applying it as they develop their understanding of a solids management program. Those people are employees, managers, engineers, consultants, boards, politicians, community groups, the agricultural/landscaping/ horticultural community, neighbors to the treatment facilities and solids management operations, the media, the public, etc. “The stakeholder approach is recognition that no effective indicator set can be developed without the input of stakeholders…. Active public participation is a prerequisite for achieving sustainable development” (Amajirionwu et al., 2008; Goven and Langer, 2009). Labeling something “sustainable” is worthless without agreement between the speaker and the listener about what “sustainable” means.

In summary, those wastewater solids managers who decide to utilize a multi-criteria decision-making process, by using, for example, a TBL, must first determine the scope and context of their analysis and how they will define “sustainability.” To do this successfully, they must engage diverse stakeholders. Once this is done, they, as a group, can move on to defining the particular challenges in the particular decisions they face together.

The Challenge of Complex Decision Making

Much literature on decision making aims at developing understanding of the pitfalls inherent in making decisions and on approaches to reduce bias and incorporate multiple criteria and perspectives.

Linkov et al. (2006) note that "decision making in environmental projects is typically a complex and confusing exercise, characterized by trade-offs between socio-political, environmental, and economic impacts."

The U.S. Army Corps of Engineers (USACE) has conducted considerable research and developed considerable expertise in the area of complex decision-making processes. Their work addressing natural risks and protecting human health while striving to maintain ecological balances involves many decisions involving complex trade-offs.

The decision makers available to USACE and other project developers and analysts, such as wastewater solids managers, have limited capabilities. Kiker and MacNair (2004) point out that "'humans are quite bad at making complex, unaided decisions,' and 'there is a temptation to think that honesty and common sense will suffice...' Individuals respond to complex challenges by using intuition and/or personal experience to find the easiest solution. Groups can devolve into entrenched positions resistant to compromise."

There has been progress, but there is no sure solution as to how to make rational, thoughtful, and appropriate decisions about complex systems. "A systematic method of combining quantitative and qualitative inputs from scientific studies of risk, cost and cost benefit analyses, and stakeholder views has yet to be fully developed for environmental decision making. As a result, decision makers often do not optimally use all available and useful information in choosing between identified project alternatives" (Linkov et al., 2006).

Developing Systems for Complex Decision Making

There is a considerable body of literature that has strived to develop systems for rational, structured decision making. Multi-criteria analysis (MCA) and multi-criteria decision analysis or decision making (MCDA or MCDM) are established paradigms for addressing complex decisions. Striving for sustainability requires multi-criteria analysis. Thus, as interest in sustainability has increased, MCA and MCDA have gained greater attention (Yoe, 2002). A triple bottom line analysis is a tool used for MCDA.

Yoe (2002) emphasizes that MCDA cannot subjectively provide "the correct answer" in choosing between different alternatives, but that it is a tool that structures the decision-making process and associated discussions. The goal of this kind of structured process is to ensure proper and balanced evaluation of all of the important concerns.

Experience in applying MCDA has led to the idea that *successful* decision making is *iterative*, with many feedback loops. Instead of the old linear process driven by a small, like-minded group of project proponents, today's paradigm includes multiple perspectives moving forward and back from problem definition to identification of alternatives to determination of performance and back to redefinition of the problem, as needed (Yoe, 2002).

Further refinement of this iterative concept has led to what is called "adaptive management." Linkov et al. (2006) state that "adaptive management acknowledges that uncertainty is inherent in any natural system, and it seeks to minimize this uncertainty by learning about the system being managed. Its basic process is straightforward: when managing any system, one chooses a management action, monitors the effects of the action, and adjusts the action based on the monitoring results.

"Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a "trial and error" process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders" (National Research Council, 2004).

There are several examples of the use of multi-criteria decision analysis (or decision making) in the wastewater management field. Palme et al. (2004) used multi-criteria analysis to cooperatively develop a set of SDIs for the Stockholm Water Company in Sweden. They recognized the importance of having users of the SDIs involved in their formulation. The process was informed by formal assessments of risk, life cycle, uncertainty, and economics.

MCDA aims to make decisions based on diverse criteria and in the face of uncertainty. Adaptive management aims to reduce key uncertainties by treating management as experimentation.

Triple Bottom Line (TBL) – A Tool for MCDA

A Triple Bottom Line (TBL or 3BL) analysis is a form of multi-criteria decision analysis (MCDA). However, a TBL is generally defined as limited to three categories of criteria: economic, environmental, and social – but within each category there can be many different criteria. TBL has become a widely known and cited form of MCDA. It has proven to be relatively simple to grasp and is used widely by corporations and government entities worldwide. The concept is also summarized in such phrases as "profits, people, planet" (*The Economist,* 2009*)* and "natural ecology, economics, social equity (Fowler, 2012).

*"*The term "Triple Bottom Line" dates back to the mid-1990s, when management think-tank AccountAbility coined and began using the term in its work. The term found public currency with the 1997 publication of the British edition of John Elkington's *Cannibals with Forks: The Triple Bottom Line of 21st Century Business.* There are in fact very few references to the term before this date, and many (including the man himself) claim that Elkington coined it" (Norman and MacDonald, 2003).

Elkington (1998) specifically stated: "The triple bottom line focuses corporations not just on the economic value they add, but also on the environmental and social value they add – and destroy. At its narrowest, the term 'triple bottom line' is used as a framework for measuring and reporting corporate performance against economic, social and environmental parameters."

Research and experience in utilizing TBLs has resulted in some general, agreed-upon characteristics (Suggett and Goodsir, 2000, as cited by Potts, 2004):

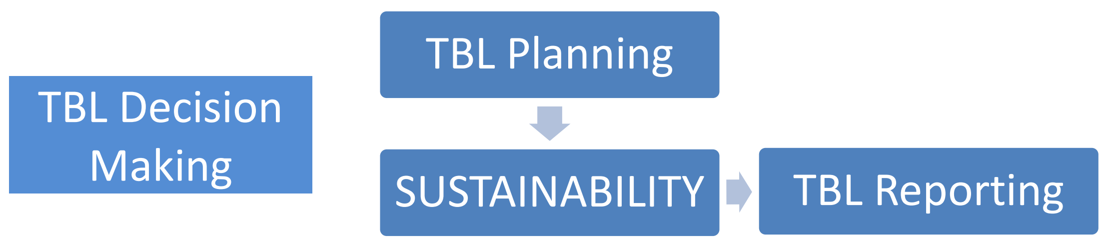
- Accountability.
- Transparency.
- Integrated planning and management.
- Commitment to stakeholder engagement.
- Multi-dimensional measuring and reporting.

Some have greatly emphasized the social engagement aspect, noting that using a TBL approach can play an important role in addressing critical social and community issues, including advancing

- Social inclusion.
- A holistic 'community health' approach.
- A more open and democratic process that drives increased accountability.

In late 2012, a "Triple Bottom Line Tool" was released online, intended to "be used to design for better outcomes, decide between projects, or describe project impacts" (TBL Tool, 2013).

ICLEI, the international organization promoting greenhouse gas reduction and sustainability at the municipal level, has embraced TBL. "At its broadest TBL is about values, issues and processes that companies must address to create economic, social, and environmental value" (iclei.org). ICLEI makes clear that TBL analysis can be used in three major ways, all related to sustainability:



ICLEI's U.S. division has developed a "sustainability planning toolkit. "Recognizing that local governments around the United States are vastly different, this toolkit presents a straightforward yet flexible process for developing a sustainability plan."

Wastewater agencies, as parts of local governments, are part of ICLEI's target audience, and TBL analyses can be an integral part of an agency working toward and evaluating progress on sustainability.

How TBLs Are Used

As noted by ICLEI, TBLs are used for planning, decision making, and reporting. Most prevalent is the use of TBLs in reporting. More and more organizations are providing annual reports on their performance relative to economic, environmental, and social criteria (Grand Rapids, MI, 2012; San Francisco Public Utilities Commission, 2013). Extensive protocols and standards have been and are being developed for using a TBL approach for reporting an organization's progress on sustainability. For example, the Sustainability Accounting Standards Board (SASB), a U.S. based non-profit incorporated in July, 2011, is establishing industry-based sustainability standards for the recognition and disclosure of material environmental, social and governance impacts by companies traded on U.S. exchanges (Sustainability Accounting Standards Board, 2013).

Kenway et al. (2007) point out that, in the water sector in the U. S., "There is a lack of public TBL information in U.S. utilities when compared with other U.S. sectors (e.g., electricity), as well as with the water industry globally. Therefore, there is a need for a number of implementation measures by individual utilities and the industry as a whole."

But while use of TBL for reporting progress toward sustainability is important, of greatest interest for the development of the TBL for assessing wastewater solids management options is the use of TBL analysis in *decision making*, specifically local decisions around what technologies and scenarios to employ in managing wastewater solids. Like other forms of MCDA, a TBL creates a structure for bringing together diverse stakeholders in an effort to make decisions to address complex problems.

There are a growing number of wastewater treatment operations using TBL for planning and decision making regarding solids management. For example, the Capital Regional District, Victoria, BC developed a TBL tool for its full Core Area Wastewater Treatment Program, and this tool was adapted for their biosolids TBL program.

Other wastewater agencies that have used TBL for wastewater and/or solids management decisions include:

- Metro Vancouver (British Columbia).
- Hampton Roads Sanitation District (Virginia).
- Alex Renew (Alexandria, VA).
- Washington (DC) Suburban Sanitation District.
- Melbourne Water (Australia).
- Johnson County Wastewater (Kansas).

The TBL approach in complex decision making "allows decision makers to vary or weigh criteria to discover those criteria that have the greatest influence on differentiating alternatives. It can suggest potential mitigation measures to reduce the impacts of an alternative" (Capital Regional District, 2007).

The TBL model for making decisions regarding biosolids management that was developed in 2013 for the Water Environment Research Foundation (WERF) and is detailed below builds on these pioneering applications of TBL in decision making around water and wastewater programs.

Designing and Conducting a TBL

There are several critical steps to designing and conducting an effective TBL:

1. For a TBL to serve its stated purpose, the designers of the process must strive to balance their inherent bias with that of other diverse stakeholders.
2. Once stakeholder involvement is established, criteria – and the metrics used to measure progress on them – must be selected and agreed-upon.
3. Then the criteria are weighted with stakeholder input.
4. Finally, when the TBL model is agreed upon, data from options that are being compared are fed into it, resulting in scores that can be compared, contrasted, and discussed.

Throughout this process, adaptive management can be employed, allowing for changes in the TBL model, criteria, and weightings, if stakeholders agree on the need for such changes. A TBL process should stimulate discussion and understanding of underlying issues.

TBL analysis adds a social component to economic and environmental analysis. This component has been added as a result of the recognition that technologies or process changes have to be socially acceptable as well as scientifically sound in order to facilitate widespread adoption and acceptance.

While it is a laudable goal to involve the public in the decision-making process, it is particularly challenging for the wastewater treatment industry. People have a deeply rooted aversion and mistrust for fecal matter (Miller, 2012). As a result there is a general "flush it and forget it" mentality towards wastewater treatment and its byproducts (Miller, 2012). This mentality has led to public mistrust and poor acceptance of a range of beneficial reuse projects including use of reclaimed water (Cutler and Miller, 2004; Beecher et al., 2004; Miller, 2012).

In cases where sufficient outreach and education efforts have been made, public awareness of the wastewater treatment process, as well as acceptance and support of land application of biosolids, is high. But attempting to integrate the public in the wastewater decision-making process without significant prior efforts for public outreach and education are likely to result in poor or antagonistic results (Amajirionwu et al., 2008). Organizations interested in conducting a robust, defensible TBL or other MCDA process around solids management need to recognize that their diverse stakeholders may need to learn a lot more of the basics before they can be constructive, informed participants.

Ensuring informed stakeholder involvement in designing and refining the decision-making protocol and the TBL is the first critical step in an effective process.

The next step involves defining criteria. Roy (1985) and Yoe (2002) define effective criteria as:

- ♦ Directional (there is a clear preference for the direction in which the outcome is to be driven, i.e., minimized, maximized or otherwise optimized).
- ♦ Concise (using the smallest number of possible measures while ensuring all significant impacts are assessed).

- Complete or exhaustive (no significant impact or consideration is left out).
- Consistent (there are no secret preferences).
- Non-redundant (there is no double counting of any parameter).
- Clear (understandable to others, with definitions of how measurements are to be made and whether in quantitative or qualitative terms).

Yoe (2002) stresses that, "when discriminating among plans, the decision maker should not have to resort to any test, principle, rule, canon or standard that is not explicitly included among the criteria."

Several TBL practitioners emphasize that criteria are not static. Draft criteria should be discussed and created, and then they should be tested – and revised, if necessary – throughout the decision-making process (Kiker and MacNair, 2004).

"Because human cognition is limited, it becomes difficult to make meaningful comparisons with too many criteria. Some research has suggested that six or seven criteria are good numbers. This is enough to make meaningful distinctions without overloading the brain. Good visual information can extend the ideal set by a few criteria. No serious analysis can be performed with more than around twenty decision criteria (Pomerol and Barba-Romero 2000). Large numbers of criteria should be rearranged into smaller sets. This may be done by aggregating or grouping related criteria or by dividing the criteria into a hierarchical structure with no more than seven or so criteria at each level" (Yoe, 2002).

By definition, the criteria chosen for a TBL must focus on the three categories: economics, the environment, and social concerns. The literature regarding sustainability in the water and wastewater sector and TBLs developed by various organizations have begun to generate a list of commonly used criteria (Sahely et al., 2005; Balkema et al. (2002); Epstein et al., 2003; Marr, 2005; Poulsen et al., 2004; Liner et al., 2012; Miller, 2012; Capital Regional District, 2007; Goven and Langer, 2009).

The third step in developing a TBL is to develop the metrics – the measurements – that will be used to determine to what extent each criterion is met by any particular option (Amajirionwu et al., 2008; Yoe, 2002). Ideally, these measurements are quantitative, are easy to make and/or involve available data, and are easy for stakeholders to understand. In reality, some criteria are hard to assess with concise data. For these, a qualitative scoring system must be defined (Yoe, 2002).

A critically important part of developing the metrics for criteria is figuring out how the various metrics will be integrated into a unified score. Not all social and environmental aspects of an option can be easily described in dollars and cents. Therefore, most TBLs use a simple numeric scoring system, commonly from 0 to 1 or 0 to 100 (percent scale), and every metric is "normalized" – converted with consistent simple math – into a comparable number (Yoe, 2002). Then, all of the measurements can be summed to create a total score for each option under consideration.

Another fourth critical step widely discussed in the literature and applied in specific TBLs is the assigning of weights to the various criteria (Kiker and McNair, 2004; Yoe, 2002). This step is needed because different people will naturally place greater or lesser emphasis on different criteria. Rather than have this individual bias hidden in the structure of the TBL or in scores, applying weights to each criterion makes bias explicit. For example, for many TBLs, the three major categories of criteria – economic, environmental, and social – are given equal weight, 33.33%. But some TBLs will overweight one of the categories; for example emphasizing the economic aspect by giving it a weight of 50%, while assigning 25% to each of the other two categories.

Once these steps have been completed and an agreed-upon TBL framework and process is established, it can then be put to use. This involves deciding on which options – for example which wastewater solids management technologies and processes – are to be considered and scored. Data and scores about each criterion as it relates to each option are compiled and fed into the TBL model or structure. The calculations needed to combine the scores are completed. And then the TBL provides a total numeric score for each option.

But the simple winner – the best score – from a TBL does not result in a decision. The TBL is a process of stakeholder engagement and discussion that provides some focus and clarity regarding what is important. The TBL may help narrow options: one or more options may have significantly higher scores, and others may have significantly lower scores, and this aids the decision making. But further iterations of the TBL process may be necessary to single out "the best" option.

This kind of iterative process was used in developing a TBL for comparing options for the management of wastewater solids. The resulting TBL spreadsheet model, and a demonstration of how it is used, is the subject of this report.

APPENDIX B

BIOSOLIDS MANAGEMENT TRIPLE BOTTOM LINE TOOL

This TBL tool – and the team's recommendations for its use – is intended to encourage those leading biosolids-related decision-making exercises that truly integrate environmental and social considerations into the process. The spreadsheet tool and protocol include a default structure and calculations that can be adjusted, as needed, by the user. The tool includes data developed in the analysis of the TBL sustainability of six specific, detailed biosolids management configurations.

When applying this general model to a specific facility or utility, practitioners should follow these steps:

- Select the desired biosolids management configurations.
- Replace titles and text in the selected spreadsheets (as needed), to reflect local information.
- Collect local data relating to the selected configurations.
- Input the specific local data into the model.
- Review weights for categories, criteria, and sub-criteria and modify (as needed).
- Review model results for quality control.
- Facilitate stakeholder involvement and understanding, so the TBL focuses on productive discussion geared toward making a decision about biosolids management.

The spreadsheet is transparent and flexible and allows the user to modify, add, or delete criteria and change weights, calculations, and metrics, resulting in a TBL approach tailored to the needs of the specific user group.

The team's TBL modeling effort is illustrated in Figure B-1. The team relied on energy and process modeling developed describe in WERF's Net-Zero report (ENER1C12) to help determine operating costs and some of the environmental criteria. Brainstorming sessions, group discussions and scenario analysis were used to finalize qualitative criteria scores (e.g., regulatory criteria, workplace conditions, etc.).

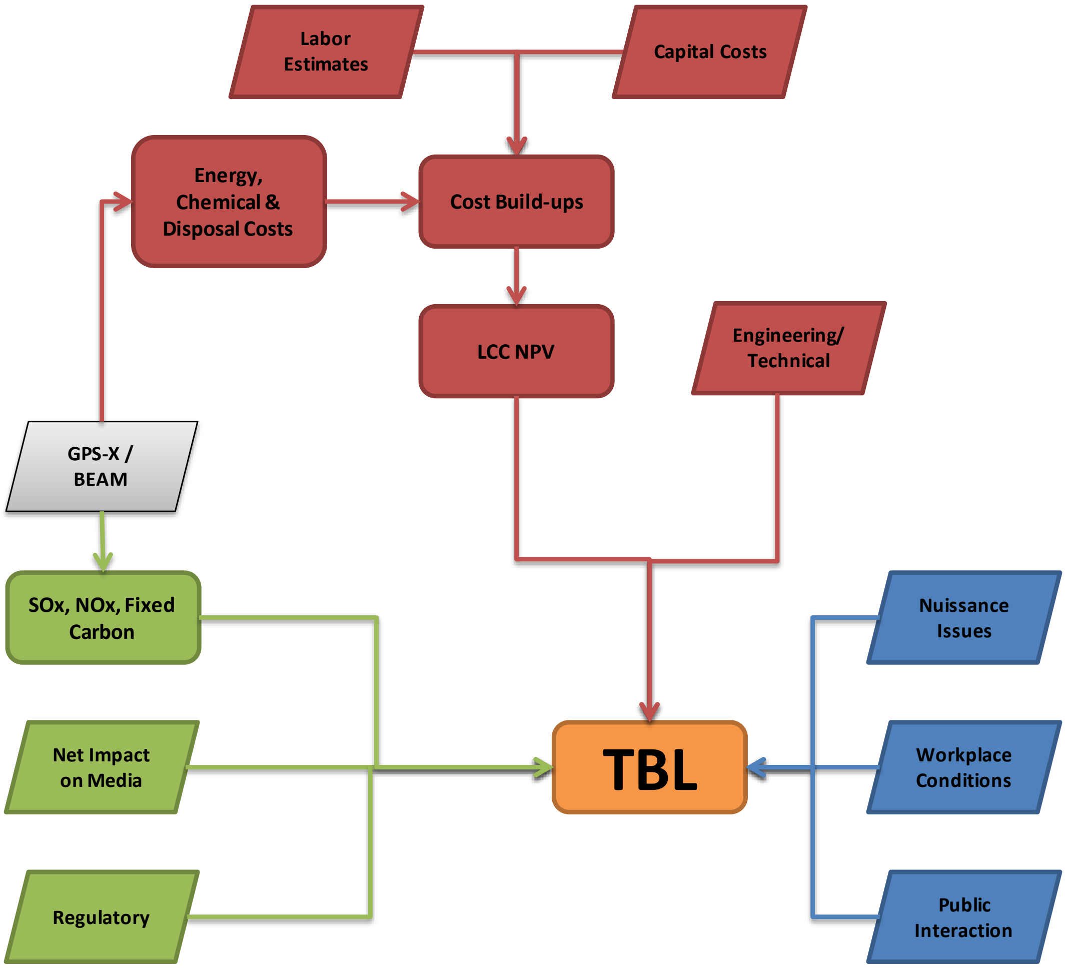


Figure B-1. TBL Tool Flowchart.

B.1 Triple Bottom Line

Following is a high-level overview and summary of the TBL model and consists of:

- Home and table of contents.
- Organization chart.
- TBL scoring summary.

The WERF TBL scoring summary sheet follows the team's TBL approach and enables the user to score three TBL categories (economic, environmental and social). Each criterion can further be broken down into four sub-criteria. This arrangement lets the user customize the criteria and sub-criteria selection. It is not necessary to use all criteria or sub-criteria. The ones that the user does not wish to use can be simply left blank. There are two sets of inputs that feed into the TBL template:

1. Weights: The weights can be modified at category, criteria and sub-criteria level. The weights add up to 100% at all category, criteria, and sub-criteria level.
2. Scoring: Each sub-criterion is scored on a range of 0 to 5. The other two components of the TBL tool (NPV LCC build-up sheets and team scoring workpapers) feed into the scoring.

B.2 Team Scoring Work Papers

The team scoring work papers feed into Section 1. They serve as back-up documentation and rationale for scores assigned to different criteria and sub-criteria by the team. The user may choose to modify these sheets to customize TBL analysis or develop similar documentation of their process. In any case, developing documentation provides a more detailed analysis and a greater insight into the process during review and modifications.

B.3 NPV Life-Cycle Cost Build-Ups

Since NPV often constitutes the single largest sub-criteria by weight (28% of the total score in this TBL tool), the team has provided a detailed build-up of lifecycle costs. The team used a bottom-up approach to identify the following costs and benefits. For a detailed analysis, the configurations were broken up into the following smaller modules/processes:

1. Anaerobic digestion.
2. Ash conveyance and storage.
3. Belt filter press dewatering.
4. Cake storage/load out.
5. Cake storage.
6. CHP.
7. Dewatering.
8. Drying/gasification/energy recovery.
9. Energy recovery.
10. Fluid bed incineration.
11. Fog receiving.
12. Gas cleaning.
13. Gravity belt thickener.
14. Gravity thickener.
15. Pre-dewatering.
16. Pre-treatment (Cambi).
17. Landfill application.
18. Landfill disposal.

For each module, capital, labor, and maintenance costs were developed based on the team's review of operational or demonstrative projects. Energy and chemical costs were derived based on outputs of GPS-X modeling. The GPS-X tool is a wastewater process simulator produced by Hydromantis, and is one of the standard modeling programs used in the municipal wastewater industry. Table B-1 summarizes the major cost categories and relevant inputs.

Table B-1. Lifecycle Cost Inputs Used in GPS-X Modeling.

Cost Category	Inputs
Capital Costs	
O&M costs	Comparable projects, vendor data
Labor	Comparable projects, team estimates
Maintenance	Comparable projects, team estimates
Chemicals	GPS-X
Reuse and disposal costs	GPS-X
Natural gas	GPS-X
Electricity consumption	GPS-X
Extraordinary maintenance costs	Comparable projects, team estimates
Benefits	
Electricity production	GPS-X
Tipping fees	GPS-X

The team developed lifecycle costs for each of the six configurations evaluated. The TBL model user can retain the costs developed by the team or overwrite these estimates at both modular and configuration (summary) level. If a user desires to make changes to assumptions or options, the team recommends that changes be made first at modular level and then at configuration (summary) level. In addition, a custom sheet lets the user pick and choose modules in order to build a custom configuration for comparison purposes. However, it should be noted that a custom analysis may lack the level of detailed analysis performed by the team for the other configurations.

The research team used the estimates and analysis listed in the table above to calculate a 20-year NPV lifecycle cost. The analysis was performed from the viewpoint of a municipal utility and did not include tax effects. However, tax effects could make projects more attractive for an investor owned utility (IOU). The WERF TBL Tool for Assessing Biosolids Options lists all assumptions used in the NPV analysis.

B.4 Methodology for Applying the TBL Tool to Selected Biosolids Management Scenarios

As part the TBL tool development for biosolids management options, the project team applied the model to six biosolids management configurations of particular interest. This involved taking data from the operations and energy modeling completed for other parts of this research study. For example, for each of the six configurations, the energy modeling team created the e-Sankey diagrams and output tables described in Chapter 4.0. The data from these and from the GPS-X model were some of the inputs into the TBL tool. Additional data for each configuration evaluated using the TBL tool were compiled from the literature, and, in a few instances, recent project team experience.

B.5 Selection of Energy Recovery Options for Biosolids Management Scenarios

The project team evaluated six biosolids management scenarios. The goal was to highlight different options common to the industry and include:

- 1X – Anaerobic digestion, CHP with pretreatment, with land application.
- 1Y – Anaerobic digestion, CHP with pretreatment, with landfill disposal.
- 2X – Anaerobic digestion, CHP with co-digestion, with land application.
- 2Y – Anaerobic digestion, CHP with co-digestion, with landfill disposal.
- 3Y – Incineration with landfill disposal.
- 4Y – Gasification with landfill disposal.

The scenarios have been numbered 1 through 4 to designate the base configuration. “X” and “Y” designate the use of the biosolids cake or ash:

X – The scenario uses land application.

Y – The scenario uses landfill disposal.

Variances of a typical cogeneration configuration were chosen as the basis for four of the six scenarios: combined heat and power (CHP), using anaerobic digestion. These four were developed using combinations of pretreatment (thermal hydrolysis) or co-digestion and landfill disposal or land application for the stabilized cake solids.

The other two of the six scenarios have their own energy recovery configurations. Option 3Y is a fluidized-bed incinerator that sends waste heat to a boiler that drives a steam turbine. Option 4Y is a gasification plant that uses syngas from the gasification process to dry biosolids in a thermal dryer in preparation for gasification. Each configuration was modeled as part of the Task 1 energy modeling in this project. Results from that modeling were leveraged for the economic and environmental TBL modeling reported in this section of the study.

This combination of energy recovery options encompasses the typical energy recovery approaches in the industry and includes some promising pioneering technologies, such as gasification. These scenarios were selected to highlight options that utilities commonly evaluate when looking at constructing a water resource recovery facility, based on the project team and WERF experience. The pioneering technologies evaluated will also assist WERF with research priorities in the future.

One important consideration in choosing the scenarios was whether to model facilities that have been optimized and are already highly energy efficient and produce renewable energy. Unoptimized facilities are more typical and will be more in line with the performance of existing WRRFs. As such, and to focus the TBL analysis on model facilities that would most closely resonate with the industry, the TBL analyses were conducted for unoptimized configurations.

For this TBL tool, the researchers assumed that land application and landfilling for biosolids management were in line with the most common practices in North America. Land application was based on bulk application for large agricultural operations. Landfilling was based on co-disposal of biosolids with other municipal solid waste in landfills incorporating methane recovery (but not beneficial use) after cell closure.

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