Assessment and Evaluation of Advanced Solid Waste Management Technologies for Improved Recycling Rates

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WORK ACCOMPLISHED DURING THIS REPORTING PERIOD

In the first phase of this study, the work has focused on the collection of data exploiting the state of existing knowledge.

- Review of literature on advanced solid waste management (SWM) technologies was conducted. Reports were collected from several reliable sources at the national, state, and local levels from both public and private utilities (i.e., United States Environmental Protection Agency, UK Department for Environment Food & Rural Affairs, Solid Waste Association of North America).
- Information about advanced SWM projects of various counties and companies around the US were found from government and company websites.
- Exemplary works for each advanced SWM technology within United States were found and requests for additional information about them were sent via e-mails.
- Subject matter experts on solid waste management field are searched and their evaluation for criterion set is requested.
- Factors to categorize Floridian counties and the categorization procedure based on these defined factors are identified.
- Criterion sets were weighed based on the preliminary ranking of collected data from subject matter experts. Further evaluation for criteria weights will be conducted in the second quarterly report for each group of county separately.
- In order to obtain data for AHP, 107 requests were placed to Floridian counties including Alachua, Baker, Bay, Bradford, Brevard, Broward, Calhoun, Charlotte, Citrus, Clay, Collier, Columbia, Desoto, Dixie, Duval, Escambia, Flagler, Gadsden, Gilchrist, Glades, Gulf, Hamilton, Hardee, Hendry, Highlands, Holmes, Indian River, Jackson, Jefferson, Lafayette, Lake, Lee, Leon, Levy, Liberty, Madison, Manatee, Marion, Martin, Miami-Dade, Monroe, Nassau, Okaloosa, Okeechobee, Orange, Osceola, Palm Beach, Pasco, Pinellas, Polk, Putnam, Santa Rosa, Sarasota, Seminole, St. Johns, St. Lucie, Sumter, Suwannee, Taylor, Volusia, Wakulla, Walton, Washington counties.
- Experts contacted from given counties come from various backgrounds related to solid waste. Their backgrounds and job titles include solid waste specialists, solid waste managers,
environmental service directors, public works directors, solid waste recycling coordinators, hazardous waste professional engineers, recycling coordinators, utility operations directors, solid waste facility directors, sanitation directors, and environmental managers.

The preliminary assessment of advanced SWM technologies is completed 40% during this report period. The collection of data for this study is 65% completed during this report period and will be ongoing at through the later phases of this study in conjunction with Analytical Hierarchy Process calculations.

INFORMATION DISSEMINATION ACTIVITIES
Site Visits and Presentations:
- **TAG I Meeting:** Our first TAG meeting took place on February 20th, 2015 at the McArthur Engineering Building of the University of Miami. We also had set up a conference call for those who wanted to attend the meeting remotely.

  Several comments were given during our first TAG meeting. Attendees suggested our team to consider whether technologies have been applied earlier in the US or not, and focus on the ones those implemented in the US. After inspection of several data sources about technologies, we realized that some of the advanced SWM technologies such as anaerobic digestion and composting have had various implementations around the US for several years while some of them (including hydrothermal carbonization) only had one demonstration facility in the entire world. In order to select an appropriate technology for counties, existence and implementation of technologies has a significant impact as it shows if the technology vendors and the demand for outputs exist in the market. The methodology and the data collection are reformed based on these comments.

  Attendees also suggested focusing on the technologies and related facilities within the US as the regulations, waste types, and markets are more similar to those within the State Florida. Also of attention was the concerns regarding the gas level that any technology might produce. It is an important issue since our main goal is to find a technology to manage the waste of Floridian counties in a more environmentally friendly way than traditional landfiling or other conventional treatment methods. As such, environmental impact is considered as one of the criteria in AHP evaluation. Attendees also expressed that the county goals should be considered in evaluation. As suggested in the TAG meeting, the recommendations will differentiate for each county based on their goals, current management programs and specific situations. AHP results will be reviewed and rearranged for various counties separately.

  In the next quarter, further data for technologies will be collected to perform AHP. The categorization of Floridian counties will be done based on the selected factors and AHP results will be obtained for each group of counties.

  - **TAG II Meeting:** The team will be hosting the second TAG Meeting on May, 2015 in order to obtain feedback on their objectives, and discuss the drawbacks of currently available data from the technical awareness committee and other interested parties. Team will also seek suggestions for the progress of their study.
Website: The team has set up an updated website describing the project. The website is accessible at [http://coe.miami.edu/simlab/swm_2015.html](http://coe.miami.edu/simlab/swm_2015.html).

1. INTRODUCTION

Over the past several decades, both the volume and diversity of Municipal Solid Waste (MSW) generation has increased markedly worldwide, with the United States exhibiting the greatest rate of growth, both overall and per-capita, by a significant margin. In 2006, the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tons, representing a 7% annual increase since 2003 [1]. It is further demonstrated that after 2010 global generation of municipal waste has exhibited approximately a 9% increase per year. This burgeoning growth, combined with the concomitant increase in the regulation of disposal operations and dwindling availability of suitable disposal sites, has made the planning and operation of integrated Solid Waste Management (SWM) systems progressively more challenging. According to the concept of sustainable waste disposal, a successful treatment of MSW should be safe, effective, and environmentally friendly [2]; However, existing waste-disposal methods cannot achieve this goal. As a result of these factors, and growing pressures for environmental protection and sustainability, the State of Florida has established an ambitious 75% recycling goal, to be achieved by the year 2020. At present, the recycling rate in the State of Florida is approximately 30%, based on a goal set by the landmark Solid Waste Management Act of 1988. However, Municipal solid waste (MSW) landfills represent the dominant option for waste disposal in many parts of the world. Based on 2013 municipal solid waste management data, combustion and landfilling has constituted the 62% of Florida [3]. Conventional waste landfills occupy large amounts of land and lead to serious environment problems [4]. While the use of landfills is decreasing in many parts of the State of Florida, there are nonetheless thousands of closed landfills and thousands more that are operating but will close over the next 10–30 years. Furthermore, landfill facilities lead to significant operational and post-operational care period and costs (Figure 1).

![Figure 1: Management phases of a MSW landfill throughout life-cycle](image)

On the other side, incineration technology was developed to reduce the total volume of waste and make use of the chemical energy of MSW for energy generation. However, the emissions of pollutant species such as $NO_x$, $SO_x$, HCl, harmful organic compounds [5,6], and heavy metals [7,8] are high in the incineration process. Another problem with MSW incineration is the serious
corrosion of the incineration system by alkali metals in solid residues and fly ash [7]. Furthermore, due to the low incineration temperature related to the low energy density of MSW, the energy efficiency of MSW incineration is relatively low [9,10]. Due to aforementioned problem of conventional technologies, many stakeholders, such as utilities, regulators, governmental agencies, municipalities, and private firms, have recognized the necessity of establishing advanced solid waste technologies and integrated solid waste management programs. Developing these technologies is essential for the State of Florida for several reasons. These technologies have the potential to enable the State to reduce its waste, and increase its recycling rate such that its goal of reaching 75% recycling rate by 2010 can be achieved, not by particular counties that have strong solid waste management structure in place, but by the majority of the State of Florida counties, including the ones currently struggling with their waste operations. The new and emerging solid waste technologies also show potential to create new jobs, produce renewable energy, and promote economic growth. In addition, while higher recycling rates may enable lower disposal rates in the landfills, which reduces the land sources utilization and leaves more room for humans and wildlife, improper implementation of these new technologies may cause serious problems such as infectious diseases, waste contamination, toxic emissions, and occupational health issues for solid waste workers. Moreover, current implementation of these technologies is limited by aspects such as regional divergence, political factors, market forces, technical supports, amongst many others. Thus, a comprehensive top-to-bottom assessment of each of these significant technologies as well as their comparison against each other becomes crucial before their applications are discussed for or appear in the counties of the State of Florida. However, in light of the inherently challenging nature of the MSW stream and management, combined with the fiscal difficulties befalling municipalities throughout the state, numerous technical and social challenges to all parties of solid waste management are presented. Because these technologies are emerging or being researched in different geographical locations (other states or maybe other countries), a unified and consistent evaluation scheme has to be developed before these technologies are considered to be implemented (in part or fully) in the State of Florida counties. To this end, the purpose of this study is to identify and evaluate new and emerging advanced solid waste management technologies and their potential to help state reach its recycling goal by 2020 in a manner that is structurally unified, and useful for practitioners in terms of various criteria such as cost, impact on the waste generation and recycling rates, impact on the landfill emissions, and byproducts, and impact on the promotion of sustainable economic development.

2. BACKGROUND AND LITERATURE REVIEW OF ADVANCED SOLID WASTE MANAGEMENT TECHNOLOGIES

Solid waste generation is a result of every activities and the importance and social and economic complexity of problems related to solid waste management in industrialized countries have increased during the last three decades ([11]-[13]). The ideal of completely eliminating waste is highly unrealistic; therefore, the best approach is to handle solid waste in sustainable way not to
protect the environment and conserve the natural resources. Accordingly, significant modifications to existing waste management technologies and programs have become necessary in order to achieve the 75% recycling goal established by the state government and obtain most optimal handling of municipal solid waste for all stakeholders, including environmental managers, regulators, policy makers, and the affected communities in the state. As a general definition, integrated solid waste management (SWM) systems are systems that provide for the collection, transfer, and disposal or recycling of waste materials from a given region. These systems handle a wide variety of materials collected from the generation units and require numerous specialized facilities and technologies to process, recycle and disposal these collected materials. Therefore, researchers have conducted a series of studies on the technologies required for the integrated SWM systems throughout the MSW life-cycle.

For any solid waste management treatment method, the primary implementation goal is to ensure that the public health is protected while cost effectiveness is maintained. Compared to traditional disposal landfills which provide an open loop of MSW life cycle, the advanced disposal technologies usually combine the recycling and recovery methods, leading to a closed loop of MSW life cycle (see Figure 2) and thereby improving the recycling rate.

Figure 2: Traditional open loop (left) and advanced disposal landfills close loop cycles (right)

Several researchers have performed evaluation of advanced technologies and analysis for MSW processing and disposal, in order to decrease landfill utilization and increase the waste recycling and recovery ([13], [14]). Advance municipal solid waste management technologies can be categorized in three major groups including thermal, biological/chemical, and physical technologies. These technologies are known to be environmentally sound, cost-effective and implementation acceptable ([8]-[10]). Aforementioned technologies are categorized in Figure 3 to show the technologies in each group. Similar study has been conducted in New York by New York City Economic Development Corporation and Department of Sanitation (2004) to provide information for future plan of solid waste management system. The evaluation considered 43 technologies in total and is conducted based on a series of criteria, such as readiness and reliability, size and flexibility, beneficial use of waste, marketability, public acceptability, cost, etc. According to evaluation of advanced MSW technologies, City of Los Angeles evaluated various technologies and demonstrated that technologies best suited for processing black bin post-source separated MSW on a commercial level are the thermal technologies [17]. Chirico [18] has conducted a study with the purpose of evaluation, analyzing, and comparing SWM
technologies and their potential to decrease landfill utilization and emissions, promote sustainable economic development, and generate renewable energy in Georgia. In this report, initially a brief description of advanced SWM technologies will be provided in subsections of Section 2. Proposed methodology including analytic hierarchy process (AHP) and data collection will be presented in Section 3.

Figure 3: Categorization of Advanced Solid Waste Management Technologies

2.1 Thermal Treatment Technologies

The most important reason for the growing popularity of thermal processes for the treatment of MSW has been the increasing environmental, technical and public dissatisfaction with the performance of conventional incineration processes. MSW is difficult to handle, segregate and feed in a controlled manner to a waste-to-energy facility. MSW has a high tendency to form fused ash deposits on the internal surfaces of furnaces and high temperature reactors, and to form bonded fouling deposits on heat exchanger surfaces. Combustion treatment produces very aggressive gases which can lead to high rate of metal wastage because of high temperature corrosion. Thermal technologies operate in high temperature which usually ranges from 700°F to
10,000°F. The main output (byproduct) of thermal technologies is to produce electricity. Thermal technologies can be seen in Figure 3 while advanced thermal recycling and thermal conversion are known as the most efficient technologies [17].

### 2.1.1 Gasification

Gasification technologies majorly involve the reaction of carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam or carbon dioxide, generally at temperatures more than 1400°F. It involves the partial oxidation of a substance which indicates that oxygen is added but the amounts are not sufficient to make the fuel completely oxidized. The process is largely exothermic but some heat may be required to initialize and sustain the gasification process. Gasification has several advantages over traditional combustion processes for MSW treatment. It processes in a low oxygen environment that limits the formation of dioxins and of large quantities of SOx and NOx. Additionally, it requires just a fraction of the stoichiometric amount of oxygen necessary for combustion. As a result, the volume of process gas is low, requiring smaller and less expensive gas cleaning equipment. Finally, gasification generates a fuel gas that can be integrated with reciprocating engines, combined cycle turbines, and potentially, with fuel cells that convert fuel energy to electricity more efficiently than conventional steam boilers.

### 2.1.2 Plasma Arc Gasification

Plasma gasification is a multi-stage process which starts with feed inputs ranging from waste to coal to plant matter, and can include hazardous wastes. The initial step in arc gasification is to process the feed stock to make it uniform and dry, and have the usable recyclables sorted out. The second step is gasification, where extreme heat from the plasma torches is applied inside a sealed, air-controlled reactor. During gasification, carbon-based materials break down into gases and the inorganic materials melt into liquid slag which is poured off and cooled. The heat destroys the poisons and hazards completely. The third stage is gas clean-up and heat recovery, where the gases are scrubbed of impurities to form clean fuel, and heat exchangers recycle the heat back into the system as steam. In The final stage, the output can vary from electricity to a variety of fuels as well as chemicals, hydrogen and polymers.

### 2.1.3 Pyrolysis

MSW pyrolysis and in particular gasification are attractive technologies to reduce and avoid corrosion and emissions by retaining alkali and heavy metals (except mercury and cadmium), sulphur and chlorine within the process residues, prevent largely PCDD/F formation and reduce thermal NOx formation due to lower temperatures and reducing conditions. Gasification may additionally provide for destructing hazardous compounds and nitrification of various residues. However, Cl and S species such as HCl and H2S may still occur in the fuel gas yielded. Advantageously, smaller fuel gas volumes require lower dimensioned gas cleanups saving
investment costs while using oxygen, raises these costs but also the fuel gas calorific value (CV) and prevents thermal NO\textsubscript{x} formation. Collier County had a plan to construct pyrolysis facility; however, the proposed project has been removed from consideration as a solid waste management option for the County due to inability of contractor to maintain a viable proposal in accordance with the requirements of the County.

### 2.1.4 Advanced Thermal Technologies

Advanced thermal technologies contain multiple technologies including advanced thermal recycling and steam gasification. An advanced thermal recycling system converts MSW into either electricity or steam for district heating or industrial customers. The combustion bottom ash and the combustion fly ash, along with the air pollution control system fly ash, are treated to produce products that can be beneficially reused. The process steps of advanced thermal recycling can be mentioned as converting waste heat to electricity, air pollution, converting combustion residue to marketable byproducts, and fly ash treatment.

### 2.1.5 Hydrothermal Carbonization

One of the advanced SWM technologies is hydrothermal carbonization (HTC) which may convert municipal solid waste into hydrochar. Using HTC as a solid waste management process has numerous benefits. One of the advantages of hydrothermal carbonization is that it process wet biomass. Hence, it requires no drying of waste. The other advantage of this technology is that it reduces fugitive greenhouse gas emissions since a large amount of carbon stays inside solid material. However, there is not much information about implementing it to convert solid waste. Only one demonstration facility exists in the world which is in Karlsruhe, Germany.

### 2.2 Biochemical Treatment Technologies

Biochemical (Biological) technologies operate at lower reaction rates and lower temperatures. Biochemical technologies work material that is biodegradable. Some technologies involve the synthesis of products using chemical processing carried out in multiple stages. Byproducts can vary, which include: electricity, compost and chemicals. The most important advanced solid waste management technologies are defined as follows:

#### 2.2.1 Anaerobic Digestion

Anaerobic digestion (AD) is a method engineered to decompose organic matter by a variety of anaerobic microorganisms under oxygen-free conditions. The end product of AD includes biogas (60 – 70% methane) and an organic residue rich in nitrogen. This technology has been successfully implemented in the treatment of agricultural wastes, food wastes, and wastewater sludge due to its capability of reducing chemical oxygen demand (COD) and biological oxygen demand (BOD) from

![Figure 4: Harvest’s Energy Garden in Central Florida](image-url)
waste streams and producing renewable energy [18]. Harvest’s Energy Garden in Central Florida uses low solids anaerobic digestion to turn bio solids and food waste into clean energy and natural fertilizers.

2.2.2 Depolymerization

A significant, valuable percentage of today's municipal solid waste stream consists of polymeric materials, for which almost no economic recycling technology currently exists. This polymeric waste is incinerated, landfilled or recycled via downgraded usage. Thermal plasma treatment is a potentially viable means of recycling these materials by converting them back into monomers or into other useful compounds [19].

2.3 Physical Technologies

Physical technologies are used to alter the physical characteristics of the MSW feedstock. These materials in MSW may be shredded, sorted, and/or dried in a processing facility. The output material is referred to as refuse-derived fuel (RDF). It may be converted into high dense homogeneous fuel pellets and transported and combusted as a supplementary fuel in utility boilers.

3. METHODOLOGY AND DATA COLLECTION

In this study, our aim is to identify and evaluate the new and emerging advanced solid waste management technologies for different counties in Florida. The collection of reliable data from various sources comprises a major task in this work, since these technologies are not currently in widespread commercial use.

After new and emerging advanced solid waste management technologies which promise significant reduction in the municipal solid waste (MSW) sent to landfills are identified, the next step is to define a quantitative analysis method to evaluate these technologies for Floridian counties. In this study the Analytical Hierarchy Process (AHP) is chosen as the qualitative decision making tool in selection of appropriate technologies for different communities in the State of Florida. The AHP is a strong and effective tool and deals with complex decision making problems using a set of criterion to find the optimum alternative. The model is hierarchically structured, consisting of objectives, criteria, sub-criteria, and alternatives. The criterion set is weighed using pairwise comparison matrices which are built based on subject matter expert (SME) opinions. For each criterion, alternatives have different performance scores. Global scores are determined by combining criteria weights and performance scores of alternatives. The AHP structure for the assessment of advanced SWM technologies is as shown in the Figure 5.
### 3.1 Defining Criterion Set

The criterion set was defined after inspection of a wide range of journal and white papers. Several issues such as environmental policies, regulations, public health and characteristics of advanced SWM technologies were taken into consideration while building the criterion set for assessment and evaluation of advanced SWM technologies. The criterion set and the explanations are given below.

**Figure 5: Hierarchical structure model for the selection of advanced SWM technologies**

- **Alternatives**
  - Gasification
  - Plasma Arc Gasification
  - Pyrolysis
  - Steam Classification
  - Advanced Thermal Recycling
  - Hydrothermal Carbonization
  - Aerobic Process
  - Anaerobic Digestion
  - Catalytic Cracking
  - Hydrolysis
  - Depolymerisation
  - Waste Converter

- **Criterion Set**
  - Revenue
  - Tipping Fees
  - Capital Cost
  - Operation/Maintenance
  - Development Period
  - Flexibility of Process
  - Landtake of Facility
  - Net Conversion Efficiency
  - Ease of Permitting
  - Marketability
  - Environmental Impact
  - Public Acceptability
  - Number of Facilities in the World

- **Explanations**

- **Revenue**

- **Tipping Fees**

- **Capital Cost**

- **Operation/Maintenance**

- **Development Period**

- **Flexibility of Process**

- **Landtake of Facility**

- **Net Conversion Efficiency**

- **Ease of Permitting**

- **Marketability**

- **Environmental Impact**

- **Public Acceptability**

- **Number of Facilities in the World**
Revenue, $C_1$, is the profit that the facility earns by selling the outputs of the selected process. Chemicals and products which the process generates are used to create energy or make new products. Selling the energy and products should provide a satisfactory profit.

Tipping fee, $C_2$, is a charge for a given quantity of waste received at a waste processing facility. For financial feasibility of project, tipping fee should be cost competitive and should provide a significant contribution to the revenue of the facility.

Capital cost of the project, $C_3$, will be researched separately for each country depending on their investment capabilities.

Operation cost, $C_4$, is the ongoing for maintenance of facility.

Development period is $C_5$.

Flexibility of process, $C_6$, should be considered since the municipal solid waste has a highly variable nature. The process should be flexible enough to keep up with the change in the content of the waste.

Land requirements, $C_7$, of the facility might be an important issue for some counties who does not own a readily available land to establish the facility.

Net conversion efficiency, $C_8$, shows how much of the received waste is diverted into energy/marketable products.

Ease of permitting, $C_9$, is the criterion to measure how capable the process is at obtaining the necessary local and state permits.

Marketability of recovered products, $C_{10}$, shows how much demand exists in the current market for the outputs of the process.

Environmental impact of the process, $C_{11}$, indicates the level of damage that the process or its byproducts have on the environment. The process itself should not contradict one of its main purposes which is to reduce the damage on the environment.

Public acceptability, $C_{12}$, is the criterion which measures the level of public support to alternative technology. It is not possible for a solid waste management facility to function properly without public support.

Number of facilities in the world, $C_{13}$, is the last criterion which is considered in this evaluation. This criterion affects the availability of data and the size of vendors for advanced solid waste management technology.

3.2 Weighing Criteria

The first step of an AHP is to weigh the criterion set by averaging the SME opinions. SMEs rank the criterion set based on their importance and the ranking is converted into values in a 1-9 scale. A 1-9 scale is used to create pairwise comparison matrix of the criterion set. The explanation for the 1-9 scale is shown in Table 1.

<p>| Table 1: Explanation of 1-9 Saaty Scale |</p>
<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Weak or slight</td>
<td>Experience and judgement slightly favor one activity over another</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgement slightly favor one activity over another</td>
</tr>
<tr>
<td>4</td>
<td>Moderate plus</td>
<td>Experience and judgement strongly favor one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Strong plus</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
<td>An activity is favored very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>8</td>
<td>Very, very strong</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>Reciprocals of above</td>
<td>If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i</td>
<td>A reasonable assumption</td>
</tr>
</tbody>
</table>

After ranking the above listed SME opinions, a group matrix is formed by using geometric average of the elements from each unique pairwise comparison matrix. To conclude the finding of criteria weights, each column is summed up and each cell is divided by the sum of the related column. The average of each row gives the weight of each criterion.

### 3.2.1 Preliminary Weighing the Criterion Set

Subject matter experts are various specialists who work on solid waste management area in Floridian Counties. During preparation of this report, emails are sent to various solid waste management departments including Florida Department of Environmental Protection, Solid Waste Divisions of Bay, Bradford, Brevard, Broward, Charlotte, Citrus, Clay, Collier, Columbia, Desoto, Flagler, Gadsden, Gilchrist, Hamilton, Hardee, Hernando, Indian River, Jackson, Jefferson, Lafayette, Lee, Levy, Madison, Miami-Dade, Monroe, Nassau, and Orange Counties. For the preliminary weighing, the criterion set was ranked based on the ranking from experts from some of Floridian counties. Data was collected from Florida Department of Environmental Protection, solid waste management divisions of Collier, Lee, Charlotte and Leon counties. Initial weights of criterion set are calculated based on this information. The group matrix and the criterion weights are shown in Table 2.

#### Table 2: Preliminary Weighing the Criterion Set

<table>
<thead>
<tr>
<th>Weighing</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
<th>$C_7$</th>
<th>$C_8$</th>
<th>$C_9$</th>
<th>$C_{10}$</th>
<th>$C_{11}$</th>
<th>$C_{12}$</th>
<th>$C_{13}$</th>
<th>Criteria Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>0.08</td>
<td>0.11</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.08</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0.13</td>
<td>0.14</td>
<td>0.13</td>
<td>0.17</td>
<td>0.15</td>
<td>0.15</td>
<td>0.13</td>
<td>0.12</td>
<td>0.13</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Based on this calculation the most important criterion is capital cost, while the least important one is land requirement of facility.

### 3.3 Categorization of Counties

Our approach for our project is to categorize the Floridian counties into different groups based on predefined factors. Categorization will be performed in order to classify counties that can manage their waste using same advanced SWM technology. Even though AHP results give the same result for the counties in the same group, recommendations will be differentiate by considering specific situations of each county.

The main factors consist of the landfill life cycle, disposal types, and waste generation. For further arranging of the groups, county budgets and greenhouse gas emission rates can be used. However, emissions and budget factors will be used only for last arrangement of the groups, since the availability of these data for each county is limited. The combination of factors will be obtained by including each factor sequentially based on their importance. At the first step counties will be classified based on disposal types. Formed groups will be divided into subgroups based on current landfill life cycles. Lastly, subgroups will be rearranged based on the last factor which is the waste generation.

Until second quarterly report, evaluation for criteria weighing will be done for each group of county separately based on the ranking which will be obtained from these counties.

### 3.4 Collecting Advanced SWM Technology Data

The second part of the necessary data, which includes primarily the values that each advanced SWM technology has under each criterion, will be provided from internet sources and the facilities in the US. The identified facilities for each advanced SWM technology are shown in Table 3. Emails for request for the necessary data are sent to facilities. Taylor Biomass Energy has provided some information about the Montgomery Project Gasification Facility in Orange County. Lee County Solid Waste Division also has provided the data that were requested about Lee County Compost Production Facility.

<table>
<thead>
<tr>
<th>$C_4$</th>
<th>0.11</th>
<th>0.11</th>
<th>0.08</th>
<th>0.11</th>
<th>0.13</th>
<th>0.13</th>
<th>0.10</th>
<th>0.12</th>
<th>0.11</th>
<th>0.09</th>
<th>0.11</th>
<th>0.12</th>
<th>0.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_5$</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.04</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>$C_6$</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
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| 1.00 |
Table 3: Facilities from US for advanced Solid Waste Management Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Facility Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification</td>
<td>The Montgomery Project Gasification Facility in Orange County</td>
</tr>
<tr>
<td>Plasma Arc Gasification</td>
<td>St. Lucie Plasma Arc Gasification Project</td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>Dry Fermentation Anaerobic Digestion Facility in San Jose, CA</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>The JBI Niagara Falls Pyrolysis Facility</td>
</tr>
<tr>
<td>Steam Classification (Autoclaving)</td>
<td>The Autoclave Technology Testing Program</td>
</tr>
<tr>
<td>Composting</td>
<td>Lee County Compost Production Facility</td>
</tr>
<tr>
<td>Catalytic Cracking</td>
<td>Green Power Inc. Catalytic Cracking Technology</td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>Harvest Power Orlando Energy Garden Anaerobic Digestion Facility</td>
</tr>
<tr>
<td>Hydrolysis</td>
<td>There are no commercial hydrolysis facilities in the world today</td>
</tr>
<tr>
<td>Hydrothermal Carbonization</td>
<td>AVA-CO2 Hydrothermal Carbonization Demonstration Facility, Karlsruhe, Germany</td>
</tr>
</tbody>
</table>

The data for technologies will be collected from the facilities given in Table 3 and online sources. These data will be used to calculate the global scores of advanced SWM technologies for each group of county.

The preliminary assessment of advanced SWM technologies is completed 40% during this report period. The data collection for this study is 60% completed and will be ongoing at through the later phases of this study in conjunction with Analytical Hierarchy Process calculations.

In the next version of the report, further data for technologies will be collected to perform AHP. The categorization of Floridian counties will be done based on the factors defined in section 3.3. Furthermore, AHP results will be obtained for each group of county.

**PROGRESS AND THE FUTURE WORK**

**Task I: Assessment of Advanced Solid Waste Management Technologies (%40 complete)**

In this study, we propose to identify and evaluate the new and emerging solid waste management and recycling technologies and their potential benefits to various Floridian counties in order to help the State reach its 75% recycling goal by 2020. For the purposes of this evaluation study, “new and emerging technologies” are defined as technologies (e.g., biological, chemical, mechanical and thermal processes) that are not currently in widespread commercial use in the State of Florida, or that have only recently become commercially operational [21] [32]. Compared to the conventional technologies, such as landfilling, incineration, stand-alone material recovery recycling technologies, these technologies hold a great potential to create
renewable energy from waste matter and may address environmental issues raised by conventional SWM technologies. Therefore, in Task I, we have first identified those emerging technologies, and assess the status of SWM processing and disposal technologies in selected counties in the state. Finally, exemplary projects have been found for each technology and requests for technology information have been sent these facilities.

**Task II: Data Collection Technologies (%60 complete)**
Various data regarding the advanced solid waste programs is collected by utilizing multiple data collection techniques. Data are collected by reviewing materials and interviewing. Waste management literature is collected from on-line databases at University of Miami and County Waste Management Plans is collected from Florida Department of Environmental Protection and County government websites. The considered advanced solid waste management programs, such as waste handling and treatment, composting, digestion and gasification technologies etc., are investigated starting with the technologies that are currently operational, in process of being adopted, or considered by the County officials for implementation. The collected data is stored in a human-readable database for ease of modification and addition. In order to implement AHP, we have contacted to solid waste management divisions of each county. Requests for evaluation of criterion set by SMEs are sent to all Floridian Counties. Site visits will also be conducted to several Floridian counties. Interviews will be targeted for a better understanding of the technologies and policies with regard to waste management.

**Task III: Comparative Evaluation of Identified Technologies**
Once the advanced solid waste technologies that are feasible to be implemented in different Floridian counties are identified, their benefits and drawbacks will be evaluated using a quantitative analysis. In this study, the Analytical Hierarchy Process (AHP) is chosen as the qualitative decision making tool in selection of the appropriate technologies for different communities in the State of Florida. The model is hierarchically structured, consisting of objectives, criteria, sub-criteria, and alternatives. Based on several pre-defined criteria such as environmental impact, market potential, public acceptability, development period, etc., the analysis will provide a priority lists for these technologies as an output. In this reporting period, various data regarding the advanced solid waste technologies and their implementation details are collected for comparison purposes. Experts of the solid waste industry are surveyed, and the inputs obtained from them will be incorporated into pairwise comparison matrix to rank these identified technologies.

**Task IV: Recommendations**
Combining obtained quantitative and qualitative findings (through the output obtained from the AHP analysis), final recommendations will be provided. These recommendations will be developed for the State of Florida and its counties considering various factors including their current MSW collection rates, MSW practices (including recycling, recovery, landfilling, open dumping, composting and incineration etc.), costs, required operational expertise, public
acceptance/opposition, environmental impacts, and implementation feasibilities. State-wide recommendations will be provided considering the potential wide audience of this study including various stakeholders of the solid waste industry, city officials, private companies, solid waste practitioners, waste generators (residential and commercial), environmental agencies, and communities at large. Overall advantages and disadvantages of implementing advanced solid waste technologies as part of currently existing conventional facilities, waste-to energy plants, or landfills, or as stand-alone applications will be discussed as part of our state-wide recommendations.

APPENDIX A: SELECTED DOCUMENTS REVIEWED


