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 second phase of this study, the work has majorly focused on contacting 67 Floridian counties to obtain SME ranking on AHP criteria, collecting technology data for plasma arc gasification, gasification and pyrolysis technologies and grouping the counties to conduct AHP. Recommendations were given for each group of county based on the obtained results from AHP.

- Florida Department of Environmental Protection solid waste management 2013 annual reports are used to obtain solid waste disposal types, landfill lifecycles, and waste generation data of each county and counties are categorized based on obtained data.
- 67 counties are divided in to 8 groups based on collected data of least recycled solid waste type and annual waste generation.
- The Montgomery gasification facility in Orange County, St. Lucie plasma are gasification project and JBI Niagara Falls pyrolysis facility are contacted to obtain the necessary data for technologies.
- Criteria set are weighed using Expert Choice Decision Support Software for 8 groups.
- AHP is performed for 8 groups and the most optimum advanced thermal SWM technology among plasma arc gasification, gasification and pyrolysis are selected for each group of county.
- Recommendations are given based on the obtained results at the end.

The assessment of advanced thermal SWM technologies is completed 100% during this report period. The collection of data for this study is 100% completed during this report period. At later phases of this study advanced biological SWM technologies will be analyzed for 8 categories of counties.
INFORMATION DISSEMINATION ACTIVITIES

The progress of this study that has been detailed in this report has also been formalized in terms of research publications as the following.

Journal Paper(s):

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 landfilling 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 differentiate for groups of counties based on their overall criteria ranking. AHP results are reviewed and rearranged for groups of counties.

  In the second phase of the project, the categorization of Floridian counties is done based on the selected factors and AHP results are obtained for each group of counties.
- **TAG II Meeting:** The team will be hosting the second TAG Meeting in June, 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 waste management method [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-url)

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 2020 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 management 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 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.

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]. Advanced SWM 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. A 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 SWM 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 quarterly report, initially a brief description of advanced SWM technologies will be provided. Data collection stages will be presented in Section 3. It is followed by the description of methodology in Section 4. Section 5 will elaborate the AHP methodology. Finally, recommendations are presented in Section 6.

**Figure 3: Categorization of Advanced Solid Waste Management Technologies**

2.1 **Thermal Treatment Technologies**

Data for this category will be provided in data collection section since these technologies are evaluated using AHP in this quarterly period.

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 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 (Figure 4).

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. DATA COLLECTION

3.1 Advanced Thermal SWM 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. Thermal technologies operate in high temperatures which usually ranges from 700°F to 10,000°F. They typically process carbon-based
waste such as paper, petroleum-based wastes like plastics, and organic materials such as food scraps. The main output (byproduct) of thermal technologies is syngas which can be converted into electricity. In this section, obtained data for thermal technologies will be presented.

### 3.1.1 Gasification

The technology data for gasification are obtained from Montgomery Project Gasification Facility and publicly available online sources. Gasification technology mainly involves the reaction of carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam or carbon dioxide, generally at temperatures above 1400°F. It contains the partial oxidation of a substance which indicates that the amount of oxygen is not sufficient for entire oxidization of fuel. 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. Low oxygen environment where the process takes places binds the formation of dioxins. Hydrocarbon pollutants are either not formed or removed in the gas clean-up process. Additionally, it requires just a fraction of the stoichiometric amount of oxygen necessary for combustion. As a result, it requires less expensive gas cleaning equipment. In terms of efficiency, it is stated that 90% of incoming energy is available for end use. 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. Commercial gasification plants that use MSW as inputs exist in various countries including Japan, Europe, and North America.

### 3.1.2 Plasma Arc Gasification

Plasma gasification is a multi-stage process which starts with inputs ranging from waste to coal to plant matter, and can include hazardous wastes. Feedstock is not combusted since the environment inside the vessel is deprived of oxygen. Rather feedstock is broken down into elements such as hydrogen, carbon monoxide, and water. The initial step in plasma arc gasification is to process the feedstock 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 gas that is created is called synthesis gas or “syngas”. The syngas created in the gasifier undergoes a clean-up process to make it suitable for conversion into other forms of energy including electricity, heat, and liquid fuels since it contains dust (particulates) and other undesirable elements like mercury. 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 ranges from electricity to a variety of fuels, hydrogen, and polymers. The entire conversion process is a closed system so no emissions are released. According to the Westinghouse Plasma Corporation Report, only about 2-4% of the material introduced into a WPC plasma gasification plant needs to be sent to landfill. This technology was going to be
implemented in St. Lucie County for the first time in the U.S. in 2007, however the project was cancelled in 2012.

3.1.3 Pyrolysis

Pyrolysis systems thermally break down solid waste in the absence of air or oxygen at temperatures of approximately 600°C and 800°C. It has the advantage of being relatively simple and adaptable to a wide variety of feedstock and it can produce several usable products from typical waste streams. However, solid fuel must be shredded and the moisture content inside solid waste must be reduced to below 10%. This is one of the reasons that pyrolysis plants have not been successful in large scale. Pyrolysis produces gases and a solid char product such as activated carbon, international grade diesel, and synthetic gas as byproduct. Pyrolysis can convert a wide variety of waste including hazardous waste since it can generate excess heat to reduce moisture content of waste below 10%. However, it is impractical for large amount of waste. Although pyrolysis of biomass keeps developing on a relatively small scale, no commercial plants for the pyrolysis of MSW are operating in the United States today.

3.2 Data Collection Stages

In this quarterly period, advanced thermal SWM technologies are evaluated 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. Data collection is composed of four stages. In the first stage, the criteria set are defined for AHP. In the second stage of data collection, SMEs from Floridian counties are contacted to compute the criteria weights. In the third stage, Florida Department of Environmental Protection solid waste management 2013 annual reports are explored to obtain the annual waste generation for each waste disposal type of Floridian counties. This data are used to categorize the counties. In the last stage of data collection, advanced thermal SWM technology data are collected from publicly available sources and defined facilities.

3.2.1 Defining Criteria Set

The criterion set was defined after inspection of a wide range of journal and white papers in the first phase of data collection. Several issues such as environmental policies, regulations, public health and characteristics of advanced thermal SWM technologies were also taken into consideration. The criterion set and the explanations are given below:

- Revenue is the profit that the facility earns by selling the outputs of the process. There are three potential sources of revenue from a MSW conversion facility which are energy sales, sales of other outputs, and tipping fees. Revenue from the sale of energy highly depends on the price for electricity and the net amount of electricity generated. Selling the energy and products should provide a satisfactory profit.

- Tipping fee is a charge for a given quantity of waste received at a waste processing facility. For financial feasibility of project, tipping fees should be cost competitive and
should provide a significant contribution to the revenue of the facility. Tipping fees typically constitute the largest source of revenue for a waste disposal facility.

- Capital cost of the project is the amount of money which is invested in SWM project.
- Operation cost is the ongoing expenses for maintenance of facility.
- Development period should not be too long, since competitors could jump into the market since the solid waste industry is very competitive even in the public sector.
- Flexibility of process should be considered since the municipal solid waste has a highly variable nature. The process should be flexible enough to keep up with the changes of the content of the waste. Flexibility of process may affect operation costs and tipping fees. The ability of converting different waste types through a single process lowers the costs as well as fees.
- Land requirements of the facility might be an important issue for some counties that do not own a readily available land to establish the facility.
- Net conversion efficiency shows how much of the received waste is diverted into energy/marketable products. Net conversion efficiency directly affects the tipping fee since less efficient processes lead to higher operating costs which are generally paid by higher tipping fees.
- Ease of permitting is the criterion to measure how capable the process is at obtaining the necessary local and state permits.
- Marketability of recovered products shows how much demand exists in the current market for the outputs of the process. It is not possible to generate the necessary revenue to support the process if the markets for the outputs being produced don’t have market demand or current markets are too distance or unstable.
- Environmental impact of the process 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 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 affects the availability of data and the size of vendors for ATSWM technologies.

AHP structure for explored ATSWM technologies and defined criterion set is built and given in Figure 5. AHP structure is designed in a way that environmental, social, economic, technical, and regulatory issues can be adequately considered. In the second stage of data
collection, criteria weights are determined after contacting SWM of Floridian counties and Florida Department of Environmental Protection through email communication.

3.2.2 Contacting SMEs

In the second stage of data collection, criteria weights are determined after contacting SMEs from SWM divisions of Floridian counties and Florida Department of Environmental Protection via surveys. In order to obtain data for AHP, 173 email requests were placed to waste management experts in various 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.

3.2.3 Categorization of Counties
As a third stage of data collection, similar counties are categorized based on their abilities to manage waste using similar advanced SWM technology. Hence, the categorization of counties into different groups is conducted based on the pre-defined factors, including the landfill life cycle, disposal types, and waste generation. Florida Department of Environmental Protection solid waste management 2013 annual reports are used to obtain solid waste disposal types, landfill lifecycles, and waste generation data of each county [10]. The first step is classifying counties based on least recycled disposal types. Here, the formed groups are then divided into subgroups based on their annual waste generation amounts.

### 3.2.3.1 Municipal Solid Waste Types in Floridian Counties

According to United States Environmental Protection Agency (EPA), MSW heavily consists of everyday items that are discarded by the residents and businesses such as newspapers, office papers, paper napkins, plastic films, clothing, food packaging, cans, bottles, food scraps, yard trimmings, product packaging, grass clippings, furniture, wood pallets, appliances, paint, and batteries [21]. In this work the definition provided by the EPA for MSW is used to categorize the counties based on the waste types. Waste types that are not considered in categorization of counties and reasons for not using them are discussed in this section.

For some waste types that are 100% recyclable, recycling technologies are already well established with their associated markets. For instance non-ferrous metals such as brass, stainless steel, copper, aluminum are, overall, 100% recyclable and can be easily recovered during the recycling process. They perform well when used in new products since they retain their properties when recovered. Moreover, 48% of Floridian counties have a recycling rate greater than 50% for non-ferrous metals. As such, these wastes do not need to be converted by advanced SWM technologies and therefore are not considered as part of the categorization.

Construction and demolition (C&D) debris is comprised of waste that is generated during new construction, renovation, and demolition of buildings, roads, and bridges. C&D debris often contains bulky, heavy materials that include concrete, asphalt, doors, windows, gypsum, and bricks. C&D waste is mainly disposed in landfills that are permitted to accept only C&D waste or that receive primarily MSW. C&D debris waste includes building related construction, renovation, and demolition debris whereas non-MSW C&D debris contains roadways, bridges, and other non-building related C&D debris generation. The largest percentage of C&D debris generation and recovery is made up of non-MSW C&D debris. In addition, C&D debris has a separate disposal stream than MSW. For these reasons, C&D debris is also not considered as one of the waste types to categorize the counties.

### 3.2.3.2 Floridian County Categories for AHP

The main purpose of using advanced SWM technologies is to reduce the amount of landfilled waste. For this reason, categorization is performed based on the least recycled waste type in each county. The counties that have the lowest recycling rates of yard trashes fall into the same group while the counties that have the lowest recycling rates of various paper waste including
newspaper, office paper, cardboard were collected under another group. AHP calculations are performed for each group and suggest the same advanced thermal SWM technology for the counties in the same group. The most widely generated waste type is chosen when more than one type has the lowest recycling rate.

Three groups, food-yard trash, paper, and plastic trash, are obtained in the first categorization as these are the three waste types that have the lowest recycling rates in each county. Subgroups are obtained in the second step based on the waste generation amount of each county.

Grouping procedure is also shown in Figure 6. 2013 Solid Waste Annual Report County MSW and Recycling Data are used for grouping these counties. The grouping process shown in Figure 6 can be implemented to rearrange the groups as the more annual waste generation data becomes available.

Formed county groups are as follows:

- Group 1 is formed by Lafayette, Holmes, Liberty, Dixie, Gilchrist, Wakulla, Union, Hamilton, Madison and Calhoun. They have the least recycling rates for food where their annual waste generation varies from 4500 to 15,000 tons.
- Group 2 consists of Glades, Taylor, Franklin, Desoto, Levy, Washington, Hendry, Okeechobee, Gadsden and Columbia. They have the second to least recycling rates for food where their annual waste generation varies from 15,000 to 80,000 tons.

- Group 3 consists of Nassau, Walton, Citrus, Flagler, Clay, Okaloosa, Osceola, Marion, Bay and Alachua. They have the least recycling rates for food and yard trash where their annual waste generation varies from 100,000 to 400,000 tons.

- Group 4 is formed by Escambia, Lake, Manatee, Seminole, Collier, Volusia and Polk. They have the least recycling rates for food where their annual waste generation varies from 450,000 to 950,000 tons.

- Group 5 is formed by Lee, Brevard, Pinellas, Duval, Hillsborough, Orange, Broward and Dade. They have the least recycling rates for paper product where their annual waste generation varies from 1 million to 3.5 million tons.

- Group 6 is formed by Jefferson, Baker, Bradford, Jackson, Putnam and Highlands. They have the least recycling rates for paper product where their annual waste generation varies from 10,000 to 100,000 tons.

- Group 7 is formed by Gulf, Hardee, Suwannee, Charlotte, Sarasota, Indian River, Palm Beach, Santa Rosa, St. Johns and St. Lucie. They have the least recycling rates mainly for plastic products where their annual waste generation varies from 15,000 to 300,000 tons.

- Group 8 consists of Sumter, Hernando, Monroe, Martin, Leon and Pasco. They have the least recycling rates for other paper products where their annual waste generation varies from 100,000 to 700,000 tons.

3.2.4 Technology Data

In the last stage, data for advanced thermal SWM technologies are collected from publicly available sources and from facilities in the U.S. The Montgomery gasification facility in Orange County, St. Lucie plasma arc gasification project and JBI Niagara Falls pyrolysis facility are contacted to obtain the necessary data for technologies. Necessary data are the capital cost and operation cost of technologies, revenue that the facility obtain by selling the outputs of the process, tipping fees of the facility, permitting issues of project, efficiency and the flexibility of the process.

4. METHODOLOGY

Our aim in this research project is to assess the emerging advanced SWM technologies for Floridian counties. Considering SWM literature, AHP is chosen for comparing advanced thermal SWM technologies and find an optimum technology to manage their wastes for each county. After advanced SWM technologies are defined, the inputs obtained from solid waste management divisions of Floridian counties are incorporated into a pairwise comparison matrix to rank the identified technologies. Our methodology is defined in the following subsections.
4.1 AHP

The AHP method is a strong and effective tool that deals with complex decision making problems using a set of criteria to find the best alternative [22]. 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 experts (SMEs) opinion. For each criterion, alternatives have different performance scores. Global scores are determined by combining criteria weights and performance scores of alternatives.

After defining criterion set, the first step of an AHP is to weigh them by averaging the SME opinions. SMEs rank the criterion set based on their importance and the rankings are converted into values in a 1-9 scale. A 1-9 scale is used to create a pairwise comparison matrix of the criterion set and is shown in Figure 7. If activity i has one of the non-zero numbers in 7 assigned to it when compared with activity j, then j has the reciprocal value when compared with i.

Subject matter expert judgments provided from each county are converted into pairwise comparison matrices. Aggregation of individual judgments (AIJ) is completed using geometric mean of corresponding elements. Each matrix element of the consolidated decision matrix is the geometric mean of corresponding elements of SMEs’ individual decision matrices. The consolidated matrix is used to compute the global priorities of criteria for each group of counties. Meanwhile, their consistencies need to be checked in order to achieve a convincing result. In this study, Expert Choice Decision Support Software is used to establish the AHP model.

5. AHP RESULTS

The next task is to compute the weights of criteria for each group of counties. In this study, criteria weights are computed using Expert Choice Decision Support Software. Subject matter expert judgments provided from each county are converted into pairwise comparison matrices. Aggregation of individual judgments (AIJ) is completed using geometric means. Each matrix element of the consolidated decision matrix is the geometric mean of corresponding elements of SMEs’ individual decision matrices. The consolidated matrix is used to compute the global priorities of criteria for each group of counties. Expert Choice Software uses the consolidated matrix to compute the weights of criteria. After pairwise comparison matrices are incorporated into the AHP model, results are obtained from Expert Choice Decision Support Software for each group. The computed criteria weights are shown in Figure 5.
Using computed criteria weights, gasification, pyrolysis, and plasma arc gasification technologies are compared. According to AHP results obtained from our model, the optimum alternative with respect to given criteria set is gasification while the poorest one is the pyrolysis for all groups. The inconsistency ratio which indicates the amount of inconsistency of comparisons is computed for each group of counties. Inconsistency ratio below 0.1 mean that the pairwise comparisons are consistent and do not require revision. Results show that the overall inconsistencies for all groups are below 0.1 as shown in Figure 6.
6. RECOMMENDATIONS

AHP results show that gasification has the highest ranked score for all groups as shown in Figure 7. However, it can be seen that weights of the plasma arc gasification and gasification technologies for groups 5 and 8 are approximately the same. For these counties capital cost is among the most important criteria. Plasma arc gasification can be an option for them, if the weight of capital cost of technology is decreased because plasma arc gasification requires the highest capital cost among alternatives.

For the first and seventh groups, where the most important criterion is public acceptability, plasma arc gasification is not a good option unless a public outreach to inform the public about plasma arc gasification is done. There is still public concern about this technology. The most important criterion for second group is environmental impact. Gasification and plasma arc gasification perform similarly on reducing greenhouse gas emissions. Any of these two technologies can satisfy this criterion well. Revenue is the most important criterion for the third and sixth groups. Plasma arc gasification brings the highest revenue among alternatives and plasma arc gasification may serve better to increase revenue in long term. Capital cost is the most important criterion for fourth group. Hence, gasification is the most viable option providing that counties ranked this criterion high because of their limited budget.
Counties which are interested in output of the process may select any of alternatives since all of the thermal technologies generate syngas as output which can be converted into energy. When technology availability is considered gasification technology has been commercially used worldwide and vendors also can be found in the U.S. For counties which can collaborate with the facilities in other countries, plasma arc gasification can also be a viable option.

These evaluations and recommendations provide a robust basis and structural framework for the counties which will initiate an advanced solid waste management project. Further evaluations can be built based on this study for conceived SWM projects of Floridian counties.

**PROGRESS AND THE FUTURE WORK**

**Task I: Assessment of Advanced Solid Waste Management Technologies (%50 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]. During second quarterly period, advanced thermal SWM technologies are identified as gasification, plasma arc gasification and pyrolysis. Required data to perform AHP are collected and commercial status of regarding these technologies are assessed.

**Task II: Data Collection Technologies (%100 complete)**

Various data regarding the advanced thermal SWM technologies are 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. In order to implement AHP, we have contacted to solid waste management divisions of each county. 173 email requests for evaluation of criterion
set by SMEs are sent to all Floridian Counties. Site visits will also be conducted to several Floridian counties. Conversion technology division manager of Salinas Valley Solid Waste Authority was contacted to obtain information for Autoclaving Technology Testing Program. The Montgomery gasification facility in Orange County and JBI Niagara Falls pyrolysis facility are contacted to obtain the necessary data for technologies. Plasma arc gasification data are obtained the online documents provided for St. Lucie plasma arc gasification project.

**Task III: Comparative Evaluation of Advanced Thermal SWM Technologies (100%)**

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 provides a priority lists for these technologies as an output. In this reporting period, AHP is conducted to assess gasification, plasma arc gasification and pyrolysis for 67 counties in Florida. Expert Choice Decision Support Software is used for analysis. SME opinions and data for technologies are incorporated into the software and results give the most optimum thermal technology to be implemented for each group of county.

**Task IV: Recommendations (100%)**

Combining obtained quantitative and qualitative findings (through the output obtained from the AHP analysis), final recommendations are provided. These recommendations are developed for the State of Florida and its counties considering various factors costs, required operational expertise, public acceptance/opposition, environmental impacts, and implementation feasibilities. State-wide recommendations are 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 thermal SWM technologies as part of currently existing conventional facilities, waste-to energy plants, or landfills, or as stand-alone applications is discussed as part of our state-wide recommendations.

**APPENDIX A: SELECTED DOCUMENTS REVIEWED**


