TECHNICAL ASSESSMENT FOR COMPOST

SECTOR: MATERIALS [FOOD – BOOK EDITION]

AGENCY LEVEL: TOWNS AND CITIES

KEYWORDS: COMPOST, ORGANICS, WASTE MANAGEMENT

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*Note: For some of the technical reports, the result section is not yet updated. Kindly refer to the model for the latest results.

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EXECUTIVE SUMMARY

Composting is a method of processing organic waste that utilizes the natural biological processes of aerobic bacterial communities. These bacteria eliminate materials such as leaf litter, converting the organics into stable soil carbon, which serves to sequester biogenic carbon while buffering nutrients in the soil, controlling moisture content, and even removing pathogens. Currently, there is a global problem of urban organic municipal waste, which not only takes up a significant portion of landfills but also creates methane emissions, a potent greenhouse gas contributing to climate change. Composting is a flexible and scalable approach that can contribute to a suite of solutions to mitigate greenhouse gas emissions from organic municipal solid waste (MSW) and sequester a portion of the carbon within the waste in the form of a valuable soil amendment.

Composting is not yet a major method of waste disposal despite organic waste contributing to around half of the volume of waste going to landfills worldwide. In the United States composting accounts for less than half of the treatment of organic wastes, while the European Union composts at rates closer to 57%. Because it is difficult to determine how wastes are being handled in rural communities globally and municipal scale management occurs in cities, this report focuses on organic waste that is largely being managed via landfills and, in some developing regions, through open dumping. OECD countries were assumed to have a current composting rate of 18%. There is little data on composting in developing countries and this report uses the data coming mainly from the global report from the World Bank 'What a Waste 2.0' to elaborate on the estimates. Current trends portend a global increase of composting of organic MSW, though there are few long-term prognostications in the literature.

This report accompanies a model that forecasts three scenarios for adoption of composting, which calculates costs for landfilling and composting on a per million metric ton basis and incorporates revenue associated with the sale of compost. The model estimates the difference between a counterfactual reference (REF) scenario of mostly landfilling and Project Drawdown (PDS) scenarios which shows a significant global adoption of composting of organic municipal solid waste.

The results of the model show growth of composting from 131.5MMT /year to **441, 662, and 1,226 MMT/year**, from 2014 to 2050, in the PDS1, 2, and 3 scenarios, respectively. The carbon mitigation effect of such an adoption of composting would result in, a total reduction of greenhouse gas emissions of 1.2, 2.2, and 7.2 Gt CO_2-eq in each scenario.

The source of the emissions mitigation comes from the decrease in methane emissions from organic MSW that decomposes anaerobically in landfills and open dumps. Composting, as considered in this analysis, is an aerobic process that does release CO_2, but multiple studies show data that the emissions from composting are less than the emissions of landfilling and dumping. This difference accounts for all emissions in collecting, transporting and processing. Finished compost, when applied to soils as an agricultural fertility amendment mitigates significant emissions from the production of nitrogen fertilizer by acting as a substitute or partial substitute and mitigates emissions by reducing irrigation water need and its associated energy use. These mitigation effects are not considered in this model and report. Additionally, the bio-sequestration of organic carbon into long term soil carbon storage aggregates facilitated by composting and possible carbon bio-sequestration resulting from increased biomass response from application of organic compost amendment in agricultural settings is also not considered in this report or model.

While there are costs to establishing composting facilities, they are significantly lower than landfilling first costs, while operating costs are almost comparable.

Composting of MSW can have a significant greenhouse gas emissions mitigation impact if adoption grows to an optimistically plausible potential. While the emissions mitigation impact is featured in this model and report, it is also the soil nutrient return, hydrology benefits, soil biodiversity and resilience benefits that make compost a compelling strategy for humanity to adopt on the pathway to Drawdown. When the additional mitigation and bio-sequestration impacts of composting are considered along with the local economic activity generated from the collection and processing of organic waste at different scales around the world and the nutritional enhancement of agricultural yields, composting could become the primary strategy for the treatment of organic solid waste.

1. LITERATURE REVIEW

1.1. STATE OF COMPOSTING

Composting is a method of processing organic waste that utilizes the natural biological processes of aerobic bacterial communities that eliminate materials such as leaf litter, converting the organics into stable soil carbon which serves to buffer nutrients in the soil, control moisture content, sequester biogenic carbon and even remove pathogens. The benefits of composting allow for the elimination of waste and the creation of a useful soil amendment that can be sold for landscaping, gardening, and farming. Furthermore, composting processes scale from the individual household level to the cooperative and farm level, and continue all the way up to full-scale commercial waste management operations. Despite the benefits, composting has largely been the purview of a few farmers and gardeners but with slowly increasing levels of municipal scale waste management. The composting process reduces the volume of wastes by up to 50%[1] which has made it useful in niche municipal services like neighborhood leaf litter collection which is dealing with high volume, low density bulk organic materials that would otherwise go to landfill. More recently, composting has been used as a pretreatment for landfill wastes to reduce the overall volume and convert organics to CO_2 rather than risk CH_4 generation once the wastes are in the landfill[2], avoiding the severe climate change implications of methane emissions. This report focuses on the modeling of organic material in municipal solid waste as its total addressable market. The composition of this waste varies depending on the country but mainly includes food scraps and yard wastes. However, the expansion of composting could allow for additional processing of materials like newspaper, cardboard, and compostable bioplastics, which is practiced by many of the early adopters of this technology.

The technology for municipal scale composting is well developed with published best practices and equipment available for the chipping, mixing, and hauling of organic wastes. The process itself requires little more than monitoring of moisture content and heat to ensure efficient thermophilic conditions conducive for rapid degradation of organic materials. Composting is not widely adopted because of the ease and historically low costs of landfilling, which is the status quo, and the complications of diverting wastes for feedstock acquisition. This is largely due to contamination in consumer separated wastes or the

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[1] CalRecycle, C. D. of R. R. and R. (2006, May 5). Compost--What Is It? Retrieved April 28, 2015, from http://www.calrecycle.ca.gov/organics/compostmulch/CompostIs.htm

[2] Komilis, D. P., Ham, R. K., & Stegmann, R. (1999). The effect of municipal solid waste pretreatment on landfill behavior: a literature review *. *Waste Management and Research*, *17*(1), 10–19. http://doi.org/10.1034/j.1399-3070.1999.00005.x

complexity in sorting unseparated wastes[3]. However, the potential of organic wastes to increase methane generation in landfills and the challenges of climate change have driven interest in composting as a more environmentally friendly approach to waste management.

Organic wastes account for 46% of global solid wastes[4] and while composting does not eliminate the overproduction and underutilization of these resources, it provides an opportunity to process these wastes with fewer harmful emissions than landfill while retaining nutrients and value in the compost material. As a region, the EU has the highest rate of composting with 40% of total organic wastes being composted[5]. There is little information about composting as a waste management strategy in developing countries. This report focuses on modeling organic waste in urban settings where organic wastes must be managed through municipal services, as opposed to rural settings where food wastes and other organics may already be composted or used as animal feed.

1.2. ADOPTION PATH

Global adoption of composting would not require a lot of technology or a comprehensive distribution network the way some other waste management approaches, like anaerobic digestion or landfill gas capture, do. Food wastes can easily be managed with some of the same equipment that is already used in typical landfill waste management. For composting to be implemented successfully, however, there would need to be educational efforts and targeted collection strategies to achieve high rates of diversion to keep organic waste out of landfills. Composting may prove to be a successful alternative if the composting can become cheaper than landfilling[6]. Composting, however, is an active approach to waste management, which requires additional processing and handling (Figure 1) as opposed to landfilling which is a passive approach, i.e. dumping wastes in a hole to be covered with soil[7]. The cost competitiveness of composting can be a

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[3] Platt, B., Goldstein, N., Coker, C., & Brown, S. (2014). *State of Composting in the US: What, Why, Where, & How*. Institute for Local Self-Reliance. Retrieved from http://ilsr.org/wp-content/uploads/2014/07/state-of-composting-in-us.pdf

[4] Hoornweg, D., & Bhada-Tata, P. (2010). *What a Waste: A Global Review of Solid Waste Management*. The World Bank. Retrieved from http://go.worldbank.org/BCQEP0TMO0

[5] EUROSTAT. (2016) Municipal Waste Statistics. Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics

[6] Hoornweg, D., Thomas, L., & Otten, L. (1999). *Composting and Its Applicability in Developing Countries*. Washington, DC: The World Bank. Retrieved from http://www.worldbank.org/urban/solid_wm/erm/CWG%20folder/uwp8.pdf

[7] Renkow, M., & Rubin, A. R. (1998). Does municipal solid waste composting make economic sense? *Journal of Environmental Management*, *53*(4), 339–347. http://doi.org/10.1006/jema.1998.0214

result of subsidies, taxes, revenue from compost sales, the increasing costs of siting new landfills or anything else that raises the cost of landfilling relative to composting.

Figure 1. Composting equipment at a commercial composting facility. Source: http://www.geograph.org.uk/photo/2741459

Despite being a straightforward approach to handling organic wastes, there are major hurdles to composting. These hurdles are the ease of the status quo, which is characterized by dumping, landfilling and the problem of the incredible volume of food waste, which is easy to ignore largely due to the seeming convenience of landfilling[7]. As an active approach to waste handling, composting would require a certain level of expertise and understanding of the composting process to effectively manage large volumes of waste. Regardless of how simple the process is, it is another layer of training that complicates the expansion of composting globally. Additionally, depending on the collection method and the desired product, composting may require educating the residents who live in municipalities offering composting services. Contamination from plastic materials continues to be a challenge for composting companies who are trying to sell the compost,[3] as a valuable product. Composting organic wastes as a pretreatment prior to landfilling, however, is not limited by contaminating materials but the loss of revenue from sales of compost products may limit the growth of this approach (for more information on the benefits and constraints of composting in the developing world see Hoornweg 1999[6]).

There are some larger trends that may influence the rate of adoption of composting urban organic waste. The trends that favor composting are generally related to the deleterious effects of landfilling in regards to both local environmental hazards and climate change emissions, namely methane, and, on the other hand, the positive benefits of composting such as carbon sequestration and soil improvement. In developed countries, the movement towards more corporate social responsibility and sustainability has led many organizations to set specific goals to reduce landfill wastes through ‘zero waste’ efforts. Composting is an important solution for zero waste programs. While recycling can eliminate paper, plastic, metal, and glass from the landfill, food wastes and other organics cannot be recycled and are a confounding factor in the recycling stream that causes contamination[8]. In developing countries, there are attempts to manage waste flows for cities experiencing dramatic growth, and to reduce the smell and health hazards associated with urban dumps (Figure 2). Urban open dumps are both legally and illegally operated. Composting at these dumps would be a relatively simple pathway to provide additional economic benefits[6].

Figure 2. The 100-acre Olusosun landfill in Lagos, Nigeria with delivery trucks making drop offs and informal housing off to the left. Open dumps are common in undeveloped and developing coutries. Source: http://newlotus.buddhistdoor.com/en/news/d/40238

The trend away from landfilling is also expected to encourage the development of other approaches to manage organics, which will come to be an important resource for energy and soil fertility. The primary competition with composting of urban food wastes is the effort to reduce waste before it occurs by both suppliers (e.g. grocers and restaurants) and consumers. By eliminating food wastes at the source, the raw material that drives composting efforts is less available; however, there are wastes that cannot be completely

[8] Hottle, T. A., Bilec, M. M., Brown, N. R., & Landis, A. E. (2015). Toward zero waste: Composting and recycling for sustainable venue based events. *Waste Management*, *38*, 86–94. http://doi.org/10.1016/j.wasman.2015.01.019

eliminated such as plate waste and trimmings from food preparation. In addition to food waste reduction, other methods of managing waste may provide more social and environmental benefits. These include feeding the hungry, other methods of waste processing, such as anaerobic digestion, or generating animal feed. The US EPA food waste hierarchy lists composting as the last option for handling food wastes to avoid landfilling[9]. These alternatives that reduce the rate of composting should not be viewed as barriers towards implementation, but rather options in a suite of solutions to address the very large, global problem of organic waste management. Composting remains a very attractive solution because of the ease and low cost of implementation. The process can handle undulations in feedstock availability and capacity can be added very rapidly. Composting will likely remain as the main alternative to landfilling of organic wastes. Landfill wastes in Estonia were reduced by 70% over 15 years due in part to urban food waste collection programs where the organic fraction of municipal solid waste is 47%[10, 4].

Very few forecasts of the growth in adoption of composting globally or regionally exist. The model considers the mean of a baseline, a conservative and an ambitious adoption case. The ambitious case scales current adoption globally to the current adoption level of the EU by 2050. This is considered plausible because the EU currently achieves this benchmark. Another, more conservative adoption scenario, scales regional and global adoption to match that of the USA in 2014 by 2050. This case shows an increase in adoption, but not as optimistic as the first case. Another case uses the IPCC dataset on composting adoption (per capita) from 2006 to forecast future adoption, scaled by population increase Composting is likely to continue to grow all over the world as the emissions benefits and co-benefits become more recognized and possibly, partially subsidized.

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[9] USEPA. (2014). Resource Conservation - Food Waste [Collections & Lists]. Retrieved April 29, 2015, from http://www.epa.gov/foodrecovery/

[10] Levitan, D. (2013). The Global Progress of Composting Food Waste. Retrieved June 4, 2015, from http://ecowatch.com/2013/08/13/global-progress-composting/

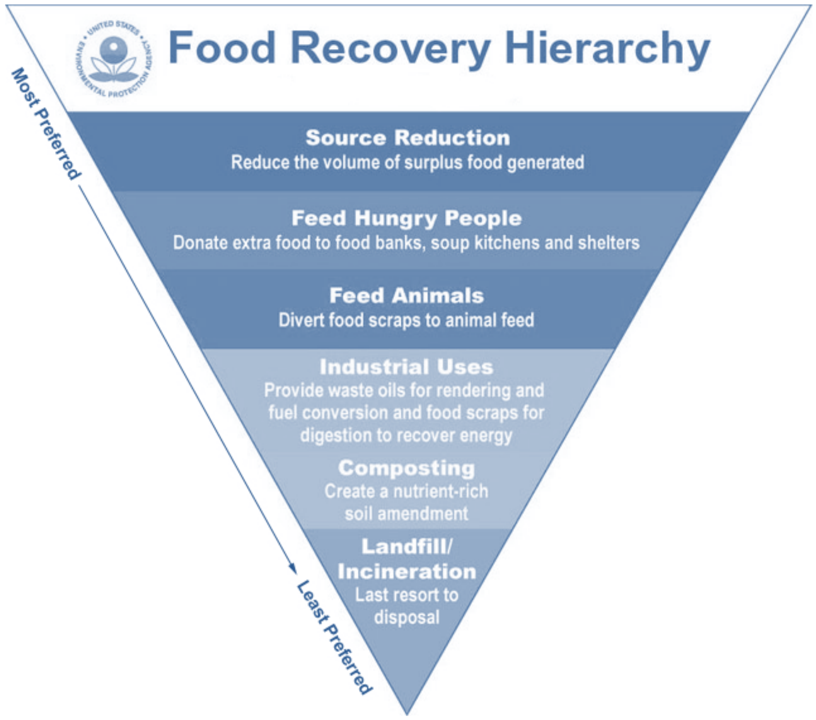

Figure 3. The USEPA Food Recovery Hierarchy prioritizes food waste treatment based on environmental impact reductions. Source: http://www.epa.gov/foodrecovery

1.2 Advantages and Disadvantages of Composting

Composting organic wastes has many advantages to landfilling, which is currently the dominant method of disposal, particularly volume and emissions reductions, however there are other strategies that can help remedy the problem of organic waste. Anaerobic digestion, the most similar solution in terms of the point of intervention, can create methane for energy recovery and, like composting, produces solids and slurry, which can be applied to land to improve carbon content of soils and provide nutrients[11]. The effluent and solids produced from anaerobic digestion can also be composted prior to using the materials, resulting in a higher value product[12]. Unlike composting however, anaerobic digestion is much more difficult to scale and requires significant capital investment to produce clean facilities capable of capturing the methane generated by the process. The ease of composting and diversity of approaches available to produce high

[11] Murphy, J. D., & Power, N. M. (2006). A Technical, Economic and Environmental Comparison of Composting and Anaerobic Digestion of Biodegradable Municipal Waste. *Journal of Environmental Science and Health, Part A*, *41*(5), 865–879. http://doi.org/10.1080/10934520600614488

[12] Bustamante, M. A., Alburquerque, J. A., Restrepo, A. P., de la Fuente, C., Paredes, C., Moral, R., & Bernal, M. P. (2012). Co-composting of the solid fraction of anaerobic digestates, to obtain added-value materials for use in agriculture. *Biomass and Bioenergy*, *43*, 26–35. http://doi.org/10.1016/j.biombioe.2012.04.010

quality, valuable compost make it an attractive first step towards more environmentally friendly food waste management. Additionally, as landfilling continues to increase in cost[3], composting operations may get cheaper (via improved processing methods and increasing revenues from sales), further improving the outlook for compost in the future. Compost can however aid in emissions reduction at landfills when municipal solid waste is composted prior to landfilling, regardless of the composition. In this way the waste is transformed and will release CO_2, reducing the potential for methane (CH_4) emissions after landfilling.

Composting is currently being adopted and continued investments in this solution should be made to increase adoption rates globally. It is an effective approach to managing large amounts of wastes that would otherwise continue to create significant environmental impacts if not properly addressed. Composting can provide a method of triage for severely overused landfills (Figure 2), and can also be a boutique product, providing extremely high value soil amendments for gardeners and horticulturalists. In addition to the range of waste streams composting can handle, it can also be implemented on almost any scale, from the backyard all the way up to municipal scale waste management, making it a very flexible approach for reducing waste. Compost whether applied to a garden, a farmer's fields, or simply spread over unused land enhances the carbon storage of the soil resulting in improved soil texture and cation exchange capacity, which is the ability for the soil to hold onto nutrients and make them available to plants.

Despite the benefits provided by composting there are some drawbacks that need to be addressed to achieve all the benefits from the solution. These limitations are largely related to the fact that composting is a strategy that requires active management, requiring some education for both the compost operators and the consumers providing the waste. If it is not a consumer separated waste stream, the benefits are either lost to contamination or a large amount of picking and screening must be done to eliminate plastic wastes and other debris from the compost if it is intended to be used for soil improvement. For some developing countries, there may be no perceivable benefit to all this additional processing in the absence of policies or regulations that discourage landfilling.

2 METHODOLOGY

2.1 INTRODUCTION

Project Drawdown's models are developed in Microsoft Excel using standard templates that allow easier integration since integration is critical to the bottom-up approach used. The template used for this solution was the Reduction and Replacement Solutions (RRS) which accounts for reductions in energy consumption and emissions generation for a solution relative to a conventional technology. These technologies are assumed to compete in markets to supply the final functional demand which is exogenous to the model, but may be shared across several solution models. The adoption and markets are therefore defined in terms of functional units, and for investment costing, adoptions are also converted to implementation units. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from a base year of 2016) and the comparison of these scenarios (for the 2020-2050 segment[1]) is what constituted the results.

2.2 TOTAL ADDRESSABLE MARKET

The total addressable market for this model is determined in the Waste TAM model. It is based on What a Waste and What a Waste 2.0 approximations of the global organic fraction of MSW in 2010, 2016, and 2025. These percentages were extrapolated to determine a trend for the entire time period of 2015-2050, and applied to the total global Waste TAM.

2.3 ADOPTION SCENARIOS

Composting is an alternative treatment for organic wastes based on natural biological processes. This report and the corresponding model are based on an increasing market share for composting of the still growing urban food waste streams. This model is based upon sources within the literature that show that composting may be the dominant strategy being employed to reduce the amount of global food wastes going to landfill[10,13,14]. Although there are many possible solutions to address this problem, composting remains as

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[13] CalRecycle. (2013, June 18). COMPOSTING AND ANAEROBIC DIGESTION. Retrieved from http://www.calrecycle.ca.gov/Actions/Documents%5C77%5C20132013%5C900%5CComposting%20and%20Anaerobic%20Digestion.pdf

[14] De Baere, L., & Mattheeuws, B. (2013). Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe. Retrieved from http://www.ows.be/wp-content/uploads/2013/02/Anaerobic-digestion-of-the-organic-fraction-of-MSW-in-Europe.pdf

the most adaptable technology for dealing with food wastes. There is an additional possibility that expanding services for organics management will expand the amount of wastes being treated beyond the REF projections; however, since these consequential factors are difficult to determine, the model does not incorporate this growth.

Two different types of adoption scenarios were developed: a Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

2.3.1 Reference Case / Current Adoption

The REF scenario for composting rate was set to about 14% (of global organic MSW) for the entire period being modeled.

2.3.2 Project Drawdown Scenarios

The PDS scenarios are based on scaling the amount of compost produced each year per region from the current adoption % along varying adoption paths, all based on real historical adoption of composting. PDS1, the plausible scenario, is based on growth of composting in the US, which has a current adoption of 31%. US composting data was taken from years 2000 and 2017, and a trend was derived. This trend was then applied to the current adoption of all Drawdown regions. PDS2, the plausible scenario, is based on EU composting adoption data, which has a higher current adoption at 39%, and historically faster growth. Again, 2000-2017 data were used to derive a trend, which was applied to the current adoption of all Drawdown regions. The optimum scenario, PDS3, is based on an EU adoption goal set in 1996, and accomplished by Austria, showing that this scenario is feasible given the correct political actions, such as organic waste landfilling bans and increased tipping fees. This scenario requires organic waste in OECD nations to be reduced to 35% of current levels over the course of 20 years, and that other Drawdown regions can increase at the same rate.

2.4 INPUTS

2.4.1 Climate Inputs

Climate indicators were taken from several sources that described reductions of methane emissions that would otherwise be released because of the anaerobic conditions generated through the piling of waste with lack of aeration in landfilling (i.e. food wastes). The numbers utilized were chosen based on specific emissions from the composting activities and disregarded all bio-sequestration benefits from the use of soil amendment and potential savings from reducing demand for artificial soil conditioners. All emissions were accounted for in the direct emissions, as most data in the literature did not separate the values from machinery use such as tractors for aeration in windrow composting. The results suggest composting can reduce emissions from organic waste by more than half than the emissions from landfilling with landfilling emitting 559 kT/MMT of organic waste compared to composting with 160 kt/MMT.

2.4.2 Financial Inputs

The prices used for modeling both composting and landfilling were generated using historical data from the literature. Many of the values used are based on World Bank's 'What a Waste' and UNEP data which provided worldwide averages.

This data aggregation method includes multiple price points from several sources, which were averaged in the Variable Meta-analysis within the model and collectively averaged to provide the values used as the landfill and compost costs which are incorporated in modeling the REF and PDS scenarios. The uncertainty concerning these markets is high and any results should be seen as general trends and relationships rather than accurate predictors of future prices. This is an area that would benefit from future efforts not only in generating regionally specific data but also in estimating future prices. The first cost of landfilling is \$272M/ MMt of waste, where the first cost of composting facilities is only \$139M/ MMt of waste; however, the operational cost of composting is comparable to that of landfilling, both averaging about \$139M/MMt of waste.

The selling price of compost generates revenue for composting facilities, and was also estimated by averaging values found within the literature. This average was found to be \$38/metric ton of compost. The value of these materials adds up in dramatic fashion because of the large quantity of waste generated over the 30-year period being modeled.

2.5 Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that infrastructure required for solution is available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at www.drawdown.org. Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

Assumption 1: The literature review, especially the life cycle analyses providing carbon emission results of virgin vs. recycled paper, are very specific in that they consider a specific region (Europe, the US, China), a particular paper grade (newsprint, office paper, corrugated cardboard), and particular aspects of the production process (including transportation emissions, or regional mills), and local energy mixes. Approach taken was to find data points that were as comparative as possible in order to absolutely compare conventional (virgin) and recycled paper alternatives. By averaging data in case of numerous sources, results derived can be described as conservative regarding the emission mitigation potential.

Assumption 2: The effects of woody by-product, also known as black liquor, is currently playing a large role in supplying energy to conventional paper mills. The long-term effects (20-50 years out) of combusting black liquor are unknown at this time, and depending on sources, it may or may not be considered carbon-neutral.

Assumption 3: Paper production and consumption is projected to increase globally and especially in developing economies for the next 15 years. However, as electronic media is becoming more commonplace (there are nearly 700 million smartphone users in China currently), newsprint may decrease (by 2020 newsprint consumption is predicted to decrease to 7.6 million tons, which is equivalent to the level last experienced in the mid-1960s) (Hetemäki et al. 2002). Office paper and packaging, however, may increase. In this report, the global projection of paper production and recycled paper adoption is increasing, but the market may change rapidly and necessitate a re-evaluation of these results, especially after 2030 and through 2060.

Assumption 4: Sustainable forest management is a small but growing aspect of the forestry industry. Unfortunately, sustainable forestry and the associated third-party certifications required are voluntary, and exist in certain regions only. Because foreign markets are under less strict standards regarding sourcing and can produce cheaper products, the continued stewardship of forest resources may be undermined. For paper production to continue at its current pace, forests must be managed sustainability or a resource shortage will occur. The materials management aspect of recycled paper is limited without a materials reduction strategy as well, which is beyond the scope of this report.

2.6 INTEGRATION

This solution is integrated within the larger Waste system. The organic fraction of the Waste TAM is allocated to Composting, and serves as the Composting TAM. This varies from 44 – 48% of total MSW.

3 Results

3.1 Adoption

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

Table 3.1 World Adoption of the Solution

Solution	Units	Base Year (2016)	World Adoption by 2050		
			Plausible	Drawdown	Optimum
Solution Name	*Million Metric t (Organic Waste)*	131.5	441	662	1226
	(% market)	14.2%	26%	37%	73%

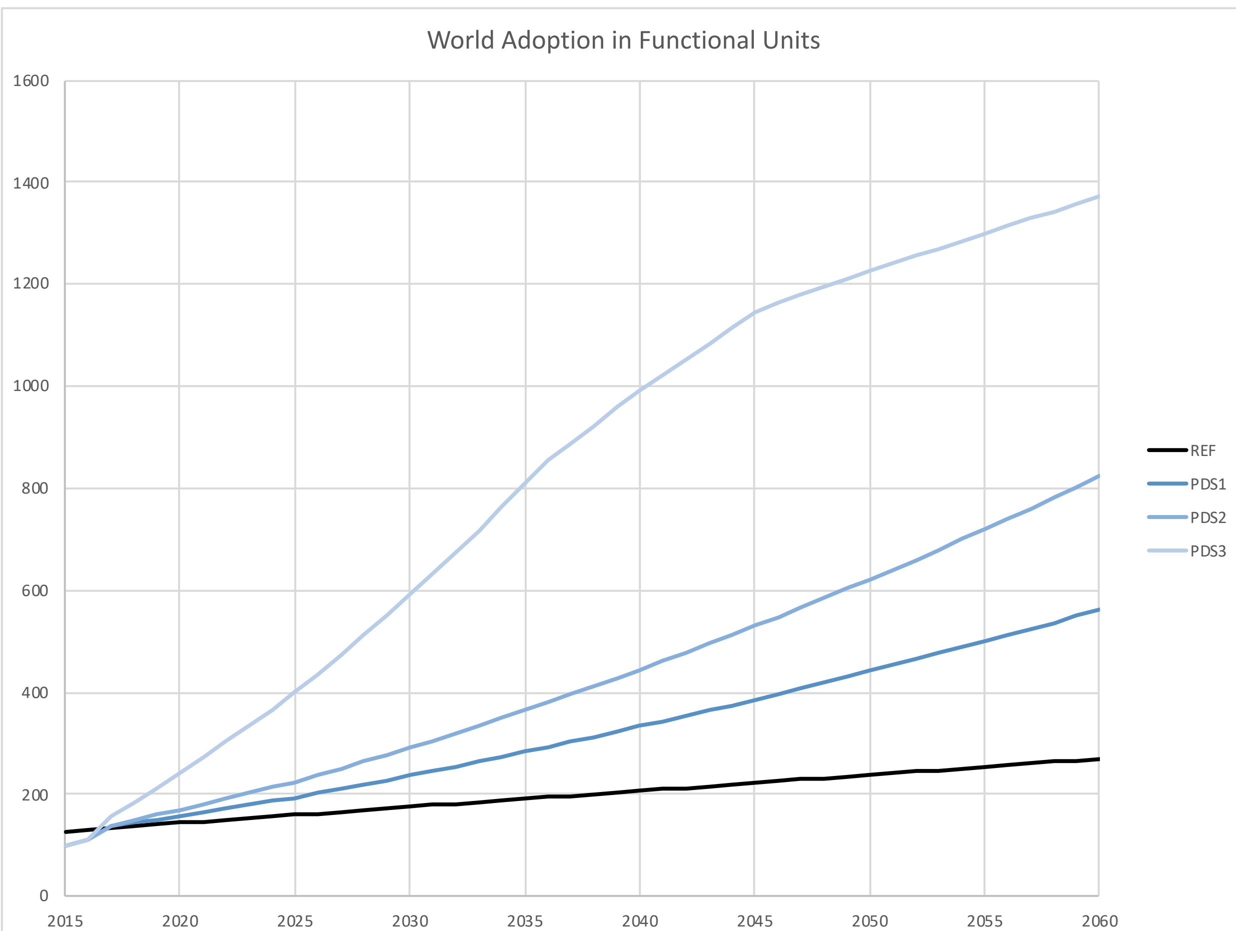

Figure 3-1 World Annual Adoption 2020-2050

3.2 CLIMATE IMPACTS

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Table 3.2 Climate Impacts

Scenario	Maximum Annual Emissions Reduction	Total Emissions Reduction
	(Gt CO_2-eq/yr.)	*Gt CO_2-eq/yr. (2020-2050)*
Plausible	0.081	1.21
Drawdown	0.153	2.28
Optimum	0.394	7.25

The solution was integrated with all other Project Drawdown solutions and may have different emissions results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

Table 3.3 Impacts on Atmospheric Concentrations of CO_2-eq

Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	PPM CO_2-eq (2050)	*PPM CO_2-eq change from 2049-2050*
Plausible	.103	.006
Drawdown	.194	.012
Optimum	.029	.606

3.3 Financial Impacts

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Table 3.4 Financial Impacts

Scenario	Cumulative First Cost	Marginal First Cost	Net Operating Savings	Lifetime Operating Cost Savings	Lifetime Cashflow Savings NPV (of All Implementation Units)
	2015-2050 Billion USD	*2015-2050 Billion USD*	*2020-2050 Billion USD*	*2020-2050 Billion USD*	*Billion USD*
Plausible	57.90	-37.77	-2.08	-4.50	12.46
Drawdown	84.26	-62.75	-3.92	-8.48	19.25
Optimum	176.06	-149.71	-12.47	-22.48	49.89

4 Discussion

Whereas the model demonstrates that composting organic MSW has the potential to be climate beneficial, the impact of composting is bounded the amount of organic waste created. If humanity can reduce the gross amount of organic waste, paradoxically the impact of composting, as modeled, will decrease. ThePDS scenario was created by using available, peer reviewed prognostications and extrapolating from peer-reviewed regional composting rates per capita. It is unknown if the potential per capita adoption would increase if there were to be less overall organic waste. In a vision of a world without waste, composting would play a key role, along with anaerobic digestion and appropriate waste to energy facility after the gross amount of waste per capita is reduced. There are some indicators that as regions develop the per capita amount of waste increases and then plateaus (see the model for total addressable market for organic fraction of MSW for EU and USA). Whereas, food waste appears to be a necessary evil of feeding people around the globe, but through efforts to reduce this waste through methods ranked in the Food Recovery Hierarchy (Figure 3) the impacts from these wastes can be minimized. Through minimizing the waste via composting, not only are methane emissions replaced with more benign carbon dioxide emissions, but some of the food waste remains as recalcitrant carbon in the soil and a saleable soil amendment is created. This amendment has the potential to improve horticulture and agriculture by cycling nutrients back to the soil while improving the texture and water holding capacity of the land.

The globalPDS scenario is highly dependent on a significant increase in adoption in the Asia (sane Japan) region. There is little or no current data to justify such an increase given current trends of investment in biogas and waste to energy facilities, while the growth the model projects is still plausible it should be regarded as optimistic. In the model, we have chosen more conservative growth scenarios for both China and Asia (sans Japan) to reflect this uncertainty. If China is slow to adopt composting, then the overall global mitigation impact of composting will need to be discounted further.

Whereas the model shows an uninspiring business case for adopting composting due to the increased operating cost of a compost facility over a managing a landfill, it would take only an increase in market price of finished compost (driven by demand of more climate friendly agricultural practices) and/or a decrease in the operating costs through innovation and process design to make a compelling financial argument in favor of composting over landfill. Where regulations, space and logistics create cost barriers to landfill expansion, there is already a self-evident business case for composting (as evidenced by the positive NPV result in the model).

Compost is an ancient technology derived from natural biological processes occurring constantly throughout the natural world. By harnessing the efforts of thermophilic bacteria, food wastes can be processed into relatively stable soil carbon and CO_2 rather than the acutely damaging effects of methane generated when food wastes are dumped in the absence of complex landfill gas capture technologies. Although composting does not avoid the creation of wastes, it does provide what can be considered a catch-all strategy that is highly flexible and scalable based on the needs of the town or city looking to implement composting as a waste management approach for organic wastes.

In conclusion, this analysis suggests that the composting market can grow to offset a significant portion of landfilling, the dominant treatment of organic waste globally, while reducing climate emissions. This replacement can be extremely aggressive since the technology to implement composting is like current management strategies. The real limiting factors will be the education required for composters and consumers using their services as well as the realization of a financial advantage that compost may have over landfilling (particularly in areas with informal and unregulated dumps). The implementation of a suite of solutions to deal with food wastes and the rates at which each solution are able to expand to remove more food waste from landfills will play an important role in minimizing emissions associated with global organic waste.

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6 GLOSSARY

Adoption Scenario – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

Approximate PPM Equivalent – the reduction in atmospheric concentration of CO_2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

Average Abatement Cost – the ratio of the present value of the solution (**Net Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic "*Marginal Abatement Cost*" curves when Average Abatement Cost values for each solution are ordered and graphed.

Average Annual Use – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

Cumulative First Cost – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

Direct Emissions – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

Discount Rate- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

Emissions Factor– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO_2e/kWh.

First Cost- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

Functional Unit – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

Grid Emissions – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

Implementation Unit – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV's in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

Indirect Emissions – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

Learning Rate/Learning Curve - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

Lifetime Capacity – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

Lifetime Operating Savings–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

Lifetime Cashflow NPV-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

Marginal First Cost – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

Net Annual Functional Units (NAFU) – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

Net Annual Implementation Units (NAIU) – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

Net Operating Savings – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

Operating Costs – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

Payback Period – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

PDS/ Project Drawdown Scenario – this is the high growth scenario for adoption of the solution

PPB/ Parts per Billion – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

PPM/ Parts per Million – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

REF/ Reference Scenario – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

Regrets solution has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

Replacement Time- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

TAM/ Total Addressable Market – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

Total Emissions Reduction – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as "emissions avoided" as they may have occurred in the REF Scenario, but not in the PDS Scenario.

Transition solutions are considered till better technologies and less impactful are more cost effective and mature.

TWh/ Terawatt-hour – A unit of energy equal to 1 billion kilowatt-hours