**Materials and Waste Integration Model Methodology**

*By Tala Daya, Senior Fellow*

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The Drawdown Waste Integration model is designed to model the interactions between waste generation and the materials solutions models. Additionally the integration directly interacts with the Food Sector: specifically with plant-rich-diets and reduced food waste; and with the Electricity Sector: specifically with waste-to energy and landfill methane. Below is a step by step instruction sheet intended to provide sufficient guidance to future fellows on how the waste integration model works.

In order to start the waste integration, there are two key steps to take into consideration:

1. The waste TAM should be updated to reflect new global waste values
2. The other material solutions and the respective food sector and electricity solutions should also be updated independently of integration

*Waste TAM Updates*

Within the Waste Cluster Integration Analysis file, you will find a “Total MSW TAM Data” sheet. This is where global waste data is updated from various sources. Please see Waste TAM Methodology document (found in Box under: 02- Solution Models & Technical Reports >> Sector- Materials >> 05- General Resources). Once the TAM is updated, integration is ready to take place.

**Integration Methodology**

***STEP 1: Pre-Integration Setup***

The first step in the integration methodology is to set up the Pre-Integration global MSW. This Pre-Integration data is considered to be the same for PDS1, PDS2 and PDS3. Therefore, the methodology listed below is applicable on the following sheets:

* “MSW Integration Calcs PDS1”
* “MSW Integration Calcs PDS2”
* “MSW Integration Calcs PDS3”

Each of these three sheets are set up in the same manner and contain Table numbers and descriptions for your reference within the Excel file. Pre-Integration setup covers Tables 1 through 6.

1. Copy the global Waste TAM into Table 1: cells C7 through C53. Repeat this for each of the regional and country level data too.
2. Next, obtain the organic waste fraction over time from the Composting materials model. Enter the global organic fraction over time under the “Compost” sheet, in cells J4 through J52. This will update Table 2 in the MSW Integration Calcs PDS sheets to reflect the amount of MSW that is organic.
   * In addition, enter the regional and country level composting fractions under the Integration PDS sheets, in cells P5 through X5. Again, these values are obtained from the Compost model. The regional and country level fractions are assumed to be constant over time.
3. Next, obtain the recyclable waste fraction over time from the Household and Commercial recycling model. Enter the recyclable fractions over time under the “H&C Recycling” sheet, in cells M2 through M50. This will update Table 23 in the MSW Integration Calcs PDS sheets to reflect the amount of MSW that is recyclable.
   * IN addition, enter the regional and country level recycling fractions under the Integration PDS sheets, in cells AC5 through AK5. These values are obtained from the Household and Commercial recycling model. The regional and country level fractions are assumed to be constant over time.
4. Finally, the remaining MSW will be automatically calculated in Table 4. This takes the initial global MSW in table 1 and subtracts the organic waste MSW from Table 2, and the recycle waste from Table 3.
5. Just a note- Table 5 is used for benchmarking amount of plastics found in MSW.
6. Table 6 will be automatically updated to reflect the global waste fractions in percentages instead of by weight.

***STEP 2: 1st Order & 2nd Order Integration***

The next steps of the integration process is to adjust the global MSW waste TAM and it’s fractions. This is done by considering the effects of the different solutions have on waste. The same methodology will be used on all three MSW Integration Calcs PDS sheets, however, each sheet will draw upon it’s respective PDS scenario. The 1st and 2nd order integration happen on Tables 7 through 17.

1. First, obtain the reduction in Food Waste due to both reduced food waste and adoption of plant rich diets from the Food Systems sector. This information should be inputted under the “Food Systems” sheet, where PDS1 will be inputted in cells C12 through C58; PDS2 in cells F12 through F58; and PDS3 in cells I12 through I58. These values will automatically update Table 7 in the Integration sheets.
2. A new total Global MSW TAM will be automatically calculated in Table 8. This new global MSW TAM = Pre-Integration global MSW TAM – Reduction in Food Waste (both from reduced food waste and plant rich diets).
3. In addition, if the Food Systems sector is specifying that food waste will be reduced, therefore, it means the organic MSW composition will also be reduced by that same amount. Therefore Table 9 will automatically update and calculate a new organic MSW fraction = Pre-integration organic MSW TAM – Reduction in Food Waste
4. Now, under the “Bioplastics” sheet, enter the Bioplastics Adoption scenarios from the bioplastics model into each PDS scenario (PDS1 in cells B10 to B56; PDS2 in cells B60 to B106; and PDS3 under B110 to B156). This will automatically updated Table 10 in the Integration sheets to reflect those adoption scenarios.
   1. Please note- the “Bioplastics” sheets checks that there is not feedstock limitations. Please see the Appendix A for more details on how this sheet is set up and how to deal with feedstock limitations.
5. Under Table 11 for each of the Integration sheets, obtain the % of bioplastics assumed to be compostable and enter the values in cells R60 through R106. This % can be obtained from the Bioplastics model.
6. Now that we have the bioplastic adoption in our integration, the Waste TAM can be adjusted to take into consideration the effect of bioplastics. The compostable fraction of bioplastics will automatically be add to the Organic Waste TAM under Table 13. In addition, assuming that the bioplastic material would have otherwise been recyclable plastic, that same portion of compostable bioplastics will be automatically subtracted from the Recyclable Waste TAM under Table 14.
7. Finally, the Total Global MSW remainder in Table 15 will automatically be calculated and is equal to the adjusted global waste TAM (from Table 8) – the adjusted organic waste TAM (Table 13) – the adjusted recyclable waste TAM (Table 14).
8. Just a note- Table 16 is used for benchmarking the amount of plastics found in MSW with adjustment of bioplastics.
9. Table 17 will be automatically updated to reflect the adjusted global waste fractions in percentages instead of by weight.

***STEP 3: Integrated PDS Adoptions in Consideration of Integrated MSW TAM (post 2nd Order Integration)***

The goal of this series of steps is to check that each of the materials solutions has enough Waste TAM to meet their respective adoption scenarios. If a solution’s adoption exceeds the available Waste TAM, then a feedstock limitation is applied that matches the Waste TAM allocation. The material solution will then have a new adoption scenario that matches that of the feedstock limitation, and therefore the solution should be re-run using the new adoption values in the scenario for final results.

1. Under the “Compost” sheet, enter the pre-integration adoption scenarios from the Composting model into cells B5 through B51 for PDS1 adoption; cells B56 through B102 for PDS2 adoption; and cells B107 through B153 for PDS3 adoption.
2. Within the same “Compost” sheet, column C will automatically update and bring in the revised organic MSW TAM that was calculated in Table 13 in the Integration sheet.
3. Column D within the “Compost” sheet will check to see if the pre-integration adoption scenarios are lower than the available organic MSW TAM.
   1. If the pre-integration adoption scenario is less than the available Compost MSW TAM- then the adoption scenario is left as is for that year. Column D will display a value of zero, while column E will display the pre-integration number from column B.
   2. If the pre-integration adoption is greater than the available organic MSW TAM, then the difference between the two will be displayed in Column D and the adoption for that year will be equal to the organic MSW TAM from column C and displayed in Column E.
4. Column E will display the final Composting adoption scenarios that will feed into integration and can also be used to re-run the Compost model if necessary.

Table 18 will display the adjusted composting adoption scenarios in each of the Integration sheets.

1. Under the “H & C Recycling” sheet, enter the pre-integration adoption scenarios from the Household and Commercial Recycling model into cells B5 through B51 for PDS1 adoption; cells B56 through B102 for PDS2 adoption; and cells B107 through B153 for PDS3 adoption.
2. Within the same “H&C Recycling” sheet, column C will automatically update and bring in the revised recyclable MSW TAM that was calculated in Table 14 in the Integration sheet.
3. Column D within the “H&C Recycling” sheet will check to see if the pre-integration adoption scenarios are lower than the available recyclable MSW TAM.
   1. If the pre-integration adoption scenario is less than the available Compost MSW TAM- then the adoption scenario is left as is for that year. Column D will display a value of zero, while column E will display the pre-integration number from column B.
   2. If the pre-integration adoption is greater than the available recyclable MSW TAM, then the difference between the two will be displayed in Column D and the adoption for that year will be equal to the recylable MSW TAM from column C and displayed in Column E.
4. Column E will display the final Composting adoption scenarios that will feed into integration and can also be used to re-run the Household and Commercial Recycling model if necessary.

Table 19 will display the adjusted recycling adoption scenarios in each of the Integration sheets.

1. Table 20 in the Integration sheets will automatically calculate the remainder global MSW fraction left, after adjusting the adoption scenarios for composting and recycling.
2. Under the “Paper” sheet, you will see that column B displays the adjusted values from Table 20 in the Integration sheet. From the Recycled Paper model, obtain the waste paper collected in a given year and enter it into column C for each PDS scenario (C6 through C52 for PDS1; C61 through 107 for PDS2; C116 through C162 for PDS3). Column D and E will automatically adjust according to the values from Columns B and C.
   1. Column D calculated how much of the Remainder MSW in column B is made of paper (according to the values entered in Column C).
   2. Column E adjusts the value of how much paper is in the Remainder MSW. If the amount of paper collected (Column C) is greater than the Remainder MSW (Column B), then a limitation is applied and it is assumed that all Remainder MSW is made up of paper.
   3. Obtain the adoption scenarios for Recycled Paper and insert them into Colum F according to each of the PDS scenarios. Please note, the Recycle Paper is currently modeled to assume that a certain amount of recovered paper is needed in order to produce 1 unit of recycled paper output. That value for each of the PDS scenarios can be obtained from the Recycled Paper model and please insert the value under cells G3 for PDS1; G58 for PDS2; G113 for PDS3.
   4. Column G calculates the amount of recycled paper waste needed in order to meet the adoption scenarios from Column F. Finally, Column H calculates how much paper remains after adoption of recycled paper. It takes the values from Column E – Column G.
   5. From the Buildings Model, obtain values for the demand of paper for insulation and insert them into Column I under the “Paper” sheet for each PDS1, 2 and 3 scenarios.
   6. Column J calculates how much paper is left in MSW after using it for recycled paper and after insulation.
3. Going back to the MSW Integration Calcs sheets, you will see the following automatic updates regarding the use of the “Paper” sheet:
   1. Table 21 will update with the values from Paper adoption and the amount of MSW paper needed in order to meet adoption.
   2. Table 26 will update column U with the amount of paper needed for insulation
4. Under the MSW Integration Calcs PDS sheets, Table 22 will automatically update to show the remaining MSW Waste after composting, recycling and recycled paper solutions. Column V is the total remaining global MSW waste. Column W is the portion of that waste that is organic; Column X is the portion of the waste that is recyclable; Column Y is the portion of the waste that is considered remainder. Columns Z through AB give those portions in percentages instead of weights. These values are important to know as they will affect the integration between waste and electricity as described in the next section.

**STEP 4- Integration of Remainder MSW TAM with Electricity**

This step technically still falls under STEP 3, however, there is a special focus here on the integration of the remaining Waste TAM after composting, recycling and recycled paper. This portion of integration references Tables 23 and 24 in the MSW Integration Calcs sheets.

To start off waste integration with electricity solutions, a few items are needed and are descried below:

* Waste materials have different lower heating values (LHV). This is important because the LHV is the energy released by combustion of that material and therefore will affect how much energy can be generated from the remaining waste. LHV values for different materials are collected under the “WTE Tonnes and Composition” sheet. Different sources have different LHV values reported. In addition, waste materials are broadly grouped into organics, recyclables and remainder to mimic that of the Drawdown methodology. An average of all the LHV values reported along with the average % composition is used to calculate LHV values for organic, recyclables and remainder (shown in cells M52 through M54). In addition, an average of all the LHV values is calculated in cell M49 and reported again in cell C1. All the work related to LHV and % composition can be found in the first 50 rows of this sheet.
* In addition, it is important to note that the remaining Waste is first allocated to the Waste to Energy (WTE) solution and then the remainder is allocated to the Landfill Methane Capture solution. Therefore, WTE affects Landfill Methane Capture. Both these solutions will have a Pre-Integration Adoption scenario and a Post-Integration adoption scenario. The post-integration of WTE is affected by the remaining Waste TAM, while the post-integration scenario of Landfill Methane Capture is affected by the WTE.

1. Obtain the Baseline, Conservative and Ambitious adoption cases from the Waste to Energy model. In the “WTE and LM Analysis,” enter the ambitious case in cells C11 to C57, the baseline case in cells I11 to I57 and the conservative case in cells O11 to O57.
2. Obtain the Baseline, Conservative and Ambitious adoption cases from the Landfill Methane Capture model. In the “WTE and LM Analysis,” enter the ambitious case in cells C72 to C118, the baseline case in cells I72 to I118 and the conservative case in cells O72 to O118.
3. In the sheet “WTE Tonnes and Composition,” scroll down to cell B65. In that cell, enter the WTE adoption case that you want to get integrated. For example, if you want to integrate the Conservative WTE adoption center, type “Conservative” in cell B65. This will update the Pre-Integration column in cells B67 to B113 with the corresponding WTE adoption data. What happens in the next occurs between the MSW Integration Calcs PDS sheets and the WTE Tonnes and Composition Sheet in the following order:

*In WTE Tonnes & Composition sheet:*

* 1. An average LHV waste mix is automatically calculated in the MSW Integration Calcs PDS sheet (discussed below) and updated in cells E67 to E113 for PDS1; M67 to M113 for PDS2; and T67 to T113 for PDS3.
  2. The pre-integration WTE is given in TWh, therefore, using the net electrical efficiency of WTE and the average LHV, the waste needed in MMT to achieve the WTE TWh is calculated in cells G67 to G113.

*In MSW Integration Calcs sheet:*

* 1. Table 23 gets updated automatically. In this table, first the LHV values entered in the “WTE Tonnes & Composition” are automatically entered into cells AF111 through AH111.
  2. Column AE in Table 23 also gets automatically updated. Column AE represents the amount of waste that is going to the waste to energy solution. Therefore, it compares the waste needed and calculated in “WTE Tonnes and Composition” sheet in order to achieve the TWh the needed for the PDS scenario (from step b above), to the total available remainder waste calculated in Table 22, column V under the MSW Integration Calcs sheet.
     1. If the calculated waste needed < total remainder waste, then the column AE takes the calculated waste needed value for that year.
     2. If the total remainder waste < the calculated waste needed, then all the remainder waste is allocated to the waste to energy solution for that year in column AE.
  3. Columns AF through AG in Table 23 get updated to reflect the LHV values. It takes the waste reported in column AE, multiplied by the fraction of organics, recyclable, or remainder calculated in Table 22, and then multiplied by the respective LHV values.
  4. A total LHV value for each year is then calculated based on the waste composition in column AI in Table 23. This LHV value is also automatically updated within the WTE Tonnes and Composition sheet.

*In WTE Tonnes & Composition sheet:*

* 1. Using the waste allocated to the waste to energy solution reported in Column AE under Table 23 in the MSW Integration Calcs sheet, the final post-integration TWh Output is calculated for PDS1 under cells I67 to I113; O67 to O113 for PDS2; and V67 to V113 for PDS3 in the WTE Tonnes and Composition sheet.
  2. **Copy and paste these post-integration TWh values to the “WTE and LM Analysis”** 
     1. *If Ambitious analysis for WTE was done, then copy PDS1 results to cells C190 to C236; PDS2 to cells C240 to C286; and PDS3 to cells C290 to C336*
     2. *If Conservative analysis for WTE was done, then copy PDS1 results to cells I190 to I236; PDS2 to cells I240 to I286; and PDS3 to cells I290 to I336*

1. **NOTE: Make sure to keep the Waste to Energy scenario chosen under cells B65 in the WTE Tonnes and Composition sheet constant for the next steps:**
   1. After waste is allocated to the Waste to Energy solution, the total available waste remaining is all allocated to the Landfill Methane Solution and is calculated in Table 24, column AK in the MSW Integration Calcs sheet.
      1. In addition, under Table 24, the fraction of the remainder waste is automatically calculated in columns AM through AO, along with the average Degradable Carbon (DOC) per year in columns AP through AR.
      2. The Total DOC Fraction over time is calculated in column AT.
   2. Under the “Landfill Methane” sheet, column B will automatically get updated according to the remainder waste calculated in the MSW Integration Calcs sheet, Table 24 column AK for PDS1, PDS2 and PDS3 .
   3. Cell D4 in the Landfill Methane sheet, contains the tonnage conversion of MMT to kWh. Therefore in Column C under the Landfill Methane Sheet, the total possible TWh that can be generated by the remaining waste assuming it all goes to landfill and is captured, is calculated.
   4. Column D pulls the conservative landfill methane data entered under the WTE & LM Analysis sheet (obtained from the Landfill Methane Model as described previously) and Column H pulls the ambitious landfill methane data.
   5. Column E and I then calculates the difference between the possible TWh generated from the remaining waste versus the reported conservative or ambitious case data respectively.
   6. Finally column F represents the post-integration adjusted Landfill Methane TWh generation for the conservative case and column J represents the same for the ambitious case. Column F takes the minimum between the total possible TWh generated based on the remaining waste or the reported TWh from the landfill methane model.
   7. **Copy and paste these post-integration TWh values to the “WTE and LM Analysis.”** 
      1. *If Ambitious analysis for WTE was done, then:*
         1. *Copy the ambitious landfill methane adjusted PDS1 results (from column J in the Landfill methane sheet) to cells C126 to C172; PDS2 to cells D126 to D172; and PDS3 to cells E126 to E172*
         2. *Copy the conservative landfill methane adjusted PDS1 results (from column F in the Landfill methane sheet) to cells G126 to G172; PDS2 to cells H126 to H172; and PDS3 to cells I126 to I172*
   8. *If Conservative analysis for WTE was done, then:*
      * 1. *Copy the ambitious landfill methane adjusted PDS1 results (from column J in the Landfill methane sheet) to cells L126 to L172; PDS2 to cells M126 to M172; and PDS3 to cells N126 to N172*
        2. *Copy the conservative landfill methane adjusted PDS1 results (from column F in the Landfill methane sheet) to cells P126 to P172; PDS2 to cells Q126 to Q172; and PDS3 to cells R126 to R172.*
2. After these steps are completed, repeat this process starting at Step 3 (under the general larger section of STEP 4- Integration of Remainder MSW TAM with Electricity). If the Conservative case was chosen for cell B65 in sheet “WTE Tonnes and Composition,” (in step 3) now change it to Ambitious case.
   1. When this process is complete, all the columns C through M, starting at row 190 in the “WTE & LM Analysis” sheet should be filled out.
3. **Share the completed information from the “WTE & LM Analysis” with the Senior Fellow for the Electricity Sector, and decide on what combination of scenarios will be used for the Plausible, Drawdown, and Optimum scenarios. The values from these scenarios will then be used in the Electricity Sector integration.**
   1. Just as a general note, typically if an ambitious scenario is chosen for WTE, then an ambitious scenario should be chosen for landfill methane. If a conservative scenario is chosen for WTE, then a conservative scenario is chosen for landfill methane.
4. Depending on the WTE scenario chosen (ambitious or conservative), make sure to re-enter the scenario within cell B65 under the WTE Tonnes & Composition sheet. Once done, enter the MSW Integration Calcs sheets and the following information will be needed to calculate CO2 emissions for the waste to electricity models:
   1. **Copy the average LHV values from Column AI from each of the MSW Integration Calcs sheet for PDS1, PDS2 and PDS3. Enter these values in the Waste to Energy Model under the “Emissions\_Factoring” sheet, in Rows 23, 24 and 25 for PDS1, PDS2 and PDS3 respectively.**
   2. **Copy the Total DOC Fraction over Time from Column AT from each of the MSW Integration Calcs sheet for PDS1, PDS2 and PDS3. Enter these values in the Waste to Energy Model under the “Emissions\_Factoring” sheet, in Rows 28, 29 and 30 for PDS1, PDS2 and PDS3 respectively.**

**Integration is now complete!**

**Step 5: Integration- MSW Fraction Analysis**

This is just a final check conducted in the MSW Integration Calcs PDS sheets, and Table 29 in the final values allocated to each solution.

**Appendix A:**

**How to complete the Bioplastics Sheet within the Material & Waste Integration Excel Model**

1. Column B in the Bioplastics sheet is the adoption scenarios copied from the Bioplastics model for PDS1, PDS2 and PDS3.
2. Column C in the Bioplastics sheet is the maximum bioplastic production scenarios copied from the Food Supply model (land use change sheet) for PDS1, PDS2 and PDS3.
3. Column D calculates to see if a surplus of biomass is needed in order to meet the Bioplastics adoption scenario from Column B. In the most ideal scenario, no surplus will be needed and the model is good as is and this sheet can be left alone. If surplus is needed, then use the Biomasss model in order to determine where this allocation can be attained from.
   1. Just as a note, even if no surplus is needed, it is good practice to update this sheet from the Biomass model to have a completed and up-to-date reference.
   2. The Biomass model allocates a certain amount of herbaceous biomass, algae, and woody biomass available to bioplastics if needed. Each of these values should be obtained from the biomass model and entered into the Bioplastics sheet as described below. Please note, the biomass model starts PDS1 under the “Plausible Scenario” table starting at row 93; PDS2 under the “Drawdown Scenario” table starting at row 185; and PDS3 under the “Optimum Scenario” table starting at row 277.
      1. Obtain the Total Herbaceous biomass allocated to Bioplastics from the Biomass model. This can be located either under the “Solutions Summary” sheet in column AW or under the “herbaceous biomass surplus” sheet by summing columns AK + AM. Enter the values in column F in the Bioplastics sheet for PDS1,2, and 3.
      2. Obtain the Marine Algae feedstock allocated to Bioplastics from the Biomass model. This can be located either under the “Solutions Summary” sheet in column AY or under the “algae, cork and hemp surplus” sheet in column P. Enter the values in column J in the Bioplastics sheet for PDS1,2, and 3.
      3. Obtain the Other Woody Biomass feedstock allocated to Bioplastics from the Biomass model. This can be located either under the “Solutions Summary” sheet in column AT or under the “other woody biomass surplus” sheet by summing columns DC + DE + DG + DI +DK + DM +DO+ DQ + DS +DU. Enter the values in column N in the Bioplastics sheet for PDS1,2, and 3.
      4. Obtain the total Surplus Herbaceous Biomass (in general) from the “herbaceous biomass surplus” sheet under column E. Enter the values in column F in the Bioplastics sheet for PDS1,2, and 3.
   3. The remaining columns within the Bioplastic sheet calculates how much of each of these surplus feedstocks allocated to bioplastics would be needed if there was a shortfall of feedstock to meet the bioplastic adoption. If this is the case, please contact the Senior Fellow for the Food Supply and Biomass model in order to inform them of the feedstocks needed to meet the bioplastic adoption.

**Appendix B:**

**Other Integration that happens outside of the Materials & Waste Integration Excel Model-**

**Integration between WDE and Low Flow Fixtures from Building Sector**

The Water Distribution Efficiency (WDE) Solution is Integrated with the Low Flow Fixture (LFF) solution from the Building Sector (the model was previously named: Water Saving - Home). The water saved in the LFF solution should be removed from the Water Distribution TAM as this results in less wastage, and reduced impact of the Water Distribution Solution. To do so, subtract the LFF adoption scenarios from the WDE REF TAM and that will result in the integrated WDE TAM. This calculation Takes place in the WDE model under the “Water Saved at Home” sheet. Column P has the LFF Adoption, Column Q has the WDE TAM, and the total WDE Integrated TAM is displayed in column AB.