Understanding Life-Cycle Environmental Trade-offs for Diverting Materials from Landfills

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Composition of U.S. Municipal Solid Waste*

*As of 2007, 254 million tons were generated in the U.S.

- The average national waste composition
  - 77% biogenic and 23% fossil origin
  - 5,300 BTU/lb on the average
Management of U.S. MSW*

- Discards to Landfills: 53%
- Recovery for Recycling: 25%
- Recovery for Composting: 9%
- Waste-to-Energy: 13%
Resource Conservation Challenge

• Goals
  – Prevent pollution and promote recycling and reuse of materials
  – Reduce the use of chemicals at all life-cycle stages
  – Increase energy and materials conservation

• 2020 Vision –
  – Reduce wastes and increase the efficient sustainable use of resources
Inefficient Materials Management (Cradle – to – Grave)

Material Inputs → Design and Manufacturing → Material Processing → Material Outputs

Stocks

Safe Disposal & Management

Releases Emissions
Efficient Materials Management (Cradle – to – Cradle)

- Pollution Prevention
- Waste Minimization
- Reuse
- Recycle
- Material Processing
- Material Outputs
- Safe Disposal & Management
To Evaluate Alternatives for Waste Management – A Holistic Approach is Needed

• Need for credible, objective analysis, science-based approach.

• Optimal solution may vary for different regions depending upon population density, energy offset, infrastructure, waste characteristics, and proximity to facilities.
  – E.g., Delaware Case Study

• Different materials (steel, aluminum, glass, paper, plastics) have varying environmental burdens and revenue streams.

• Options can be interrelated, and environmental benefits might be overlooked
  – Recycling vs WTE for paper and plastics
  – Composting vs LFGTE for food or yard waste
  – WTE vs. LFGTE to be included in renewable portfolio standards

• How do the cost and environmental emissions change as additional materials are included in a recycling program?
Sustainable Materials And Residuals management
Decision Support Tool (SMART-DST)

• A computer model to assist in decision making
  – Present quantitative information to screen management alternatives
    • Cost, energy consumption, emissions
    • Life-cycle methodology
      – Account for direct and indirect emissions from a management operation, such as collection or transportation
    – Compare many alternatives
      • Model existing waste management system
      • Identify an optimal solution with respect to cost or environmental emissions such as GHGs, energy, waste diversion targets
      – Perform sensitivity and uncertainty analysis on key model inputs
• Over ~80 studies conducted for regional, community, and national assessments of materials and discards management
Flow Diagram for Materials and Waste Management

Municipal Solid Waste → Energy → Materials

MSW MANAGEMENT ACTIVITIES

Collection, Materials Recovery, Combustion, Landfill

Electricity, Gas, Heat, Compost, Recyclables

Air Emissions, Water Releases, Solid Waste

Materials Offset Analysis = Recycle process emissions - Virgin process emissions

Recent Study Comparing LFGTE and WTE for Electricity Production

• Evaluated range of scenarios for both LFGTE and WTE

• Less variability in calculating emissions for WTE
  – Design and operation similar across facilities
  – Excellent dataset documenting emissions for 100% of U.S. facilities

• More variability for LFGTE
  – Modeling biological process
  – Less available data documenting emissions
  – More differences in design and operation than WTE

• Evaluated range of conditions for LFGTE & WTE
Assumed Boundaries for Waste Management System

Excluded from the calculations, since it is assumed to be same for both alternatives.
Baseline Assumptions for Landfills

• Considered a regional landfill that is subject to federal air emissions regulations
  – Operational LFG collection system
• Modeled a single cell in the regional landfill
  – Initial waste placement in a new cell was set to Year 0.
• Considered variety of LFG management schemes
  – combination of venting, flaring and energy recovery
• Energy recovered through an internal combustion engine (ICE)
  – 15 years of lifetime
  – Excluded the offline time that is required for the routine maintenance of the internal combustion engine
  – Emission factors for internal combustion engine (US EPA, 1998)
• Regardless of the duration of the energy project, the LFG will be controlled until Year 65, via either flaring devices or ICE
Conceptual Life-Cycle Model for Landfills

(Municipal Solid Waste)

Placement

Landfill Construction and closure

Decomposition in a Landfill

Water Effluent Management

Air Emissions Management (*)

Non degraded materials

Net water effluents

Net air emissions

Air emissions & Water effluents & Solid Waste

Raw materials & fuel use

(*) includes energy recovery from methane emissions and the subsequent economies of emissions
Methodology – Landfill gas to energy

- The total LCI emissions are the summation of the emissions associated with:
  - the construction, operation and post-closure operation of a landfill,
  - the decay of the waste under anaerobic conditions,
  - the equipment utilized during landfill operations and landfill gas management operations,
  - the production of diesel required to operate the vehicles at the site, and
  - the treatment of leachate

Ref: Camobreco et al. (1999)
Baseline Assumptions for Waste to Energy

• Heat rate of 18,000 BTU/kWh (~19% system efficiency)
• Excluded steel recovery from baseline runs
• U.S. national average MSW composition used
• Derived stack emissions (g/ton of waste item)
  – Performance data and regulations on flue gas concentration limits
• Included full emission control equipment
  – Scrubbers for SOx emissions
• Included full LCI for the disposal of the ash
Methodology – Waste to Energy

• The total LCI emissions are the summation of the emissions associated with:
  – the controlled stack gas emissions
  – the allocated emissions from the use of limestone in the scrubbers
  – the allocated emissions from the disposal of ash

*Ref: Harrison et al. (2000)*
Comparison of MSW Discards Management to Conventional Electricity Generating Technologies

![Bar chart showing CO2e emissions from various energy sources.](image-url)
Comparison of MSW Discards Management to Conventional Electricity Generating Technologies

NOx Emissions [g/MW h]

VENT  FLARE  LFGTE  WTE  COAL  NATURAL  OIL  NUCLEAR

MSW Alternatives  Pre-combustion Emissions  Operational Emissions
Comparison of MSW Discards Management to Conventional Electricity Generating Technologies
Sensitivity of Results

At landfill:

• Various landfill gas management scenarios, oxidations rates considered to estimate total CH$_4$ capture and use
  – From 2.3 to 8.2 MTCO2e/MWh

At waste-to-energy facility:

• The efficiency of the power plant varied from 15% to 30%
  – From 0.4 to 0.7 MTCO2e/MWh

• Biogenic and fossil content of the MSW varied while using the default efficiency of 19%
  – 0.02 MTCO2e/MWh for all biogenic composition
  – 1.5 MTCO2e/MWh for all fossil composition
Findings from Recent Study Comparing LFGTE and WTE for Electricity Production

• When comparing electricity (kWh) per ton of municipal waste, WTE is on average six to eleven times more efficient at recovering energy from wastes than landfills.

• For even the most optimistic assumptions about LFGTE, the net life-cycle environmental tradeoffs is 2 to 6 times the amount of GHGs compared to WTE.

  - GHGs for WTE ranged from 0.4 to 1.4 MT MTCO2e/MW h whereas the most aggressive LFGTE scenario is resulted in 2.3 MTCO2e/MWh.

• In addition, WTE also produces lower NOx emissions than LFGTE, whereas SOx emissions depend on the specific configurations of WTE and LFGTE.
Example Study for State of Delaware

• Help State of Delaware in their materials and waste management planning
  – Cost efficient waste management
  – Meeting state mandated recycling goals
  – Improved waste collection systems
  – Environmental impacts

• Generate multiple alternatives for solid waste management while considering
  – Greenhouse gas emissions
  – Other environmental emissions (local/regional)
  – Energy consumption and offsets
  – Policy implications of technology choices
  – Municipality budgets
  – Need for new facilities (e.g. new landfills)
  – Social preferences

SMART-Decision Support Tool was utilized
Outline for Conducting a Study

• Determine goals/objectives for study
  – To increase diversion rate? Decrease GHGs? Expand curbside collection? Determine least cost for discards management?

• Modeling approach
  – Boundary and scope definitions

• Data Collection

• Location-specific strategies
  – Residential and commercial waste
  – Least-cost and least environmental emissions scenarios
    • Combinations of curbside recycling, yard waste composting and combustion
    – Alternative strategies to consider “other” factors such as equity, political and economic feasibility, ability to site facility

• Sensitivity and Uncertainty Analysis
Modeling SWM System in Delaware

<table>
<thead>
<tr>
<th>County</th>
<th>Population</th>
<th>Type</th>
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<tbody>
<tr>
<td>New Castle</td>
<td>64%</td>
<td>Urban</td>
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<tr>
<td>Kent</td>
<td>16%</td>
<td>Rural</td>
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<td>Sussex</td>
<td>20%</td>
<td>Rural</td>
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### Example Scenarios for the Delaware Study

<table>
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<tr>
<th>Scenario #</th>
<th>1</th>
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<th>5</th>
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<td>X</td>
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<td>Curbside Recycling</td>
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<td>28</td>
<td>35</td>
<td>30</td>
<td>88</td>
<td>31</td>
<td>85</td>
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</tbody>
</table>

**Minimizing on GHE**

- Scenario 1: X
- Scenario 2: X
- Scenario 3: X
- Scenario 4: X
- Scenario 5: X
- Scenario 6: X
- Scenario 7: X
- Scenario 8: X

Comparison of Net Energy Consumption of Example Scenarios for Delaware Study

<table>
<thead>
<tr>
<th>Energy Consumption, TBTU/year</th>
<th>Recycling</th>
<th>Composting</th>
<th>WTE</th>
<th>Objective</th>
<th>Diversion</th>
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</table>
Comparison of Net GHG of Example Scenarios for Delaware Study

![Graph showing comparison of Net GHG scenarios]

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<thead>
<tr>
<th>Recycling</th>
<th>Composting</th>
<th>WTE</th>
<th>Objective</th>
<th>Diversion</th>
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<td>GHG</td>
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Greenhouse Gas Equivalents, thousands tons/year
Comparison of Net Costs of Example Scenarios for Delaware Study

![Graph showing net costs for different scenarios with bars representing different objectives.](image)

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<th>Objective</th>
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Recycling Scenarios
Variation of Mass Flows and GHE with Diversion

- Pre-sorted and mixed waste MRFs are utilized throughout
- Cheapest option to divert waste through mixed waste MRF
- Commingled recyclables only collected in max diversion case
- Cost escalates with implementation of curbside recycling
- In Sussex County, GHE decrease is minimal with use of curbside collection
- GHE decrease by 50% in New Castle County, compared to only a 10% decrease in Sussex County
Recycling and Composting and Combustion Scenarios

Variation of Mass Flows and GHE w/ Diversion

- WTE is utilized to meet diversion constraint
  - estimated to be less expensive than alternatives
- GHE increases near maximum due to composting
- Cost and GHE increase near maximum case illustrate extremes of numerical solution
  - composting and curbside recycling
- Ash content of yard waste leads to use of composting
- In Sussex County, a mixed waste MRF is utilized upstream of WTE to reduce transport costs and capture valuable recyclables
Summary for Delaware Study

• SMART-DST used for statewide analysis replacing default data with site-specific data
• Quantified tradeoffs among cost, waste diversion, and life-cycle emissions
• Provided counter-intuitive and creative results
  – A uniform statewide strategy will be sub-optimal
    • New Castle County contributed more to state-wide diversion
  – Effectiveness of yard waste composting influenced by transport distance
  – In least-cost strategies, combustion provides more diversion than recycling
Final Remarks

• To understand the energy benefits from materials and waste management, a holistic approach is needed that considers life-cycle environmental tradeoffs and moves toward cradle-to-cradle management
  – Differences occur for different materials (metals, paper, plastics, glass, yard and food waste)
  – Regional differences can occur based on population density and infrastructure

• Studies using the SMART-DST are providing information helpful in
  – making more informed decisions regarding materials and waste management
  – meeting waste diversion and environmental goals

• Analysis for discards management found WTE is on average is six to eleven times more efficient at recovering energy from waste than landfills.
  – However, results are sensitive to consideration of carbon storage credits in landfills and different MSW management schemes
THANK YOU

QUESTIONS?