Life Cycle Management of Municipal Solid Waste:
Perspectives and Tradeoffs

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RTI is an independent, non-profit research organization formed in 1958 and dedicated to improving the human condition. RTI’s main areas of research include:

- Health Sciences
- Environmental Sciences
- Education and Training
- Social and Economic Development
- Advanced Technology
NPR’s *All Things Considered*: May 4, 2007

- If I'm concerned about global warming what should I do with my banana peel?

- Possible options:
  - Landfill
  - Compost
    - backyard
    - dedicated facility
  - “Waste-to-energy”

- What if I’m concerned about cost, energy conservation, and/or sustainability?
Quick Points on Municipal Solid Waste

- There is a lot generated and disposed even after aggressive recycling.
- It’s a mix of different materials, not homogeneous.
- It has energy value (perhaps 3,000 to 5,000 btu/lb on average).
- It is a local burden and/or resource.
- It stinks…

U.S. Waste Generation

- **Total**
- **Per Capita**

Pounds/Person/Day

Million Metric Tons

0 1 2 3 4 5


0 50 100 150 200 250 300
California Organics Waste Stream Characterization

- About 40 million tons of organics are disposed statewide.
- Organics breakdown:
  - 70% carbon-based organics
  - 30% is readily compostable
  - 21% is paper
  - 15% is food
- Regional characterization of organics being developed.
Introduction of the application of the life cycle concept to waste management.

Review of waste management options:
- Energy producers:
  - Landfill
  - Waste-to-energy
- Energy savers:
  - Recycling
  - Composting

Summary of life cycle tradeoffs.
Life Cycle Assessment

- A systems analysis, not isolated operations.
- Considers upstream and downstream burdens.
- Multi-media and multi-pollutant.
- Main components:
  - Inventory Analysis
  - Impact Assessment
  - Interpretation
Life Cycle of Solid Waste

Collection

- Composting
  - Compost Product
    - End Use
- Landfill
- Recycling
  - Remanufacturing Facility
- Waste-to-Energy
  - Ash Landfill
Life Cycle Process Boundaries

Solid Waste → Waste Management Activity/Operation

Energy → Products

Materials → Energy

Air Emissions

Water Pollution

Residual Waste
Life Cycle GHG Emission Boundaries for Solid Waste Management

**Virgin Inputs**
- Materials Extracted: Trees, Ore, Oil, etc.

**Life Cycle Stage**
- Raw Materials Acquisition
- Manufacturing
- Use
- Recycling
- Waste Management
- Composting
- Landfilling

**GHG Emissions**
- \(\text{CO}_2\) + Energy and Non-Energy-Related Emissions
- \(\text{CO}_2\) Energy and Non-Energy-Related Emissions
- \(\text{CO}_2\) Energy-Related Emissions
- \(\text{CO}_2\) Emissions
- \(\text{CH}_4\) Uncontrolled \(\text{CH}_4\) or Fugitive and Combusted \(\text{CH}_4\) & Recovered Energy

**Sinks & Emission Offsets**
- Carbon Storage in the Soil
- Carbon in Long-Term Storage in Landfill
- Increased Forest Carbon Sequestration
- Avoided Fossil Fuel Use
- Avoided Fossil Fuel Use
Landfill

- Designed and operated according to Federal regulations.

- Conventional, bioreactor, and ash landfill design types.

- Different gas management options:
  - Venting
  - Collection and flaring
  - Collection and utilization for energy recovery
US Federal MSW Landfill Standards

- Location restrictions.
- Composite liners requirements.
- Leachate collection and removal system requirements.
- Operating practices.
- Groundwater monitoring requirements—requires testing.
- Closure and postclosure care requirements.
- Corrective action provisions for control and clean up of landfill releases to meet groundwater protection standards.
- Financial assurance for environmental protection during closure and post-closure care.
Landfill Leachate Collection and Treatment: Offsite or Onsite

Leachate Collection System

Offsite Treatment

Onsite Treatment
Landfill Gas Collection and Management: Flare or Energy Recovery

Landfill Gas Collection System

Flare

Energy Recovery
Landfill Burdens and Benefits

**Life Cycle Burdens**
- Energy and emissions associated with material inputs (e.g., liner)
- Energy and emissions associated with landfill operation
- Landfill gas emissions
- Energy and emissions associated with leachate collection and treatment

**Life Cycle Benefits**
- Energy recovery and offset of utility sector emissions
- Revenue from sale of energy
- Long term carbon storage
Landfill gas contains about 50% methane which is a potent greenhouse gas.

Gas collection and control can greatly reduce methane emissions.

Assumed gas collection efficiency can significantly impact carbon emissions.
“Waste-to-Energy” Systems

- **Thermal Systems:**
  - Mass Burn
  - Gasification
  - Pyrolysis
  - Plasma Arc

- **Non-Thermal Systems:**
  - Anaerobic digestion
  - Hydrolysis (fermentation)
Mass Burn Technology

- Well proven technology for MSW.
- Minimum waste preparation required.
- Designed to meet Federal, State and Local environmental regulations.
- Higher capital cost.
- Reduces waste volume by 90%.
- Metals can be recovered for recycling.
- Ash can be reused or landfilled.
Mass Burn WTE Plant: Water and Air Pollution Control Systems

Modern Mass Burn WTE Plant

Wastewater

Baghouse
Many new and emerging waste technologies are being developed and marketed to communities.

Cost and environmental performance of new and emerging waste treatment technologies is uncertain.

Better understanding of all issues associated with adopting new waste treatment technologies is needed.
Waste-to-Energy Burdens and Benefits

**Life Cycle Burdens**
- Energy and emissions associated with facility operation
- Energy and emissions associated with transport of recovered metals to remanufacturing plants
- Energy and emissions associated with transport of ash to landfill
- Energy and emissions associated with ash disposal

**Life Cycle Benefits**
- Diversion of MSW from landfills
- Energy production and offset of utility sector emissions
- Metals recovery and recycling
- Revenue from sale of energy and recyclables
Net Total Energy Consumption for WTE and Landfill Options

![Bar chart showing annual energy consumption in MBTU for WTE and landfill (vent), landfill (flare), and landfill (energy).]
Net Total Life Cycle Carbon Emissions for WTE and Landfill Options

![Bar graph showing annual carbon emissions for different landfill options and WTE.](chart.png)
Components of WTE Carbon Balance

![Bar chart showing the components of WTE carbon balance. The chart includes categories such as Net Total, WTE Plant, Electricity Offset, Ash Landfill, and Ferrous Offset. The chart displays the offsets in MTCE (metric tons of carbon dioxide equivalent).]
The mix of fuels used to produce electricity varies throughout the U.S.

The fuel(s) displaced by WTE can significantly impact results of an environmental analysis.
Recycling

- Designed to accept different types of material:
  - Mixed MSW
  - Commingled recyclables
  - Presorted recyclables
- Automated or manual
- Market for recycled materials are regional and fluctuate.
Recycling Burdens and Benefits

**Life Cycle Burdens**

- Energy and emissions associated with separate collection
- Energy and emissions associated with MRF operation
- Energy and emissions associated with transportation of materials to remanufacturing

**Life Cycle Benefits**

- Diversion of MSW from landfills
- Conservation of energy and virgin resources
- Revenue from sale of recyclables
- Forest carbon storage associated with paper recycling
Composting

- Designed to accepted different types of material:
  - Organics only
  - Mixed MSW
- Highly automated in-vessel to less automated windrow and aerated static pile designs.
- Markets for compost product are regional and dependant on product quality.
Composting Burdens and Benefits

**Life Cycle Burdens**
- Energy and emissions associated with separate collection
- Energy and emissions associated with compost operation
- Energy and emissions associated with for transportation of compost product and residuals

**Life Cycle Benefits**
- Diversion of MSW (organics) from landfills
- Potential for offset of other products (fertilizer, etc.)
- Revenue from sale of compost product
- Soil carbon storage
Summary of Life Cycle Tradeoffs

- Landfills and WTE are well established and tested, accept unprocessed waste, have pollution control requirements, and can recover significant amounts of energy from waste.
- Recycling and composting typically require separate collection and can save significant energy by offsetting upstream production activities.
- Landfill has generally been the cheapest option while WTE typically the most expensive option, and recycling and composting typically fall in-between.
- WTE most efficient at producing energy while recycling most efficient at saving energy.
- WTE, recycling, and composting all avoid landfill methane generation.
- Materials and energy recovery create significant (upstream) benefits.
Back to the NPR Question: What should I do with my banana peel?

- Backyard composting perhaps the best, but all options are pretty good…
- Answers are typically site-specific and depend on values:
  - waste management facility design and operation
  - cost versus GHG emission reductions
  - local versus global impacts
- What about other organic and inorganic materials in the waste?
  - glass
  - plastics
  - metals
  - paper
  - yard waste
Municipal solid waste can provide feedstock for bioenergy production…but perhaps challenging to use.

All waste management options cost money, consume energy, and create environmental burdens.

Waste management options can create significant energy related benefits:
- Energy savings (recycling, composting)
- Energy production (LFG to energy, WTE)

Where is the tipping point between energy consumption and energy savings/production?

Energy savings/production from waste can also produce significant savings of GHG emissions.

Source reduction is perhaps a win-win option.
Municipal Solid Waste Decision Support Tool (Web-MSWDST)

Virtually every community faces the question of how to manage their solid wastes most efficiently and effectively. In an effort to conserve landfill space and resources, many states and local governments in the United States have mandated recycling of certain waste components. Although these efforts are well intentioned, substantial controversy exists as to whether the costs of these programs are justifiable. In addition, some critics have questioned whether and when recycling programs actually accrue significant environmental benefits, because they require added steps for materials collection, separation, and reprocessing.

RTI has been a world-leader in the development of a comprehensive municipal solid waste decision-support tool (MSW-DST), designed to aid in evaluating the cost and environmental aspects of integrated MSW management strategies. The MSW-DST enables users to simulate existing MSW management strategies and conduct scenario analyses of new strategies based on cost and environmental objectives. The tool can model multiple design options for waste collection, transfer stations, materials recovery facilities, mixed MSW and yard waste composting, combustion, refuse-derived fuel combustion, and disposal. It can also be used to identify low-cost ways to meet recycling and waste diversion goals, quantify potential environmental benefits associated with recycling, identify strategies for optimizing energy recovery from MSW, and evaluate options for reducing greenhouse gases, air pollutants, and environmental releases to waterbodies or ecosystems.

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