At the request of MPCA senior managers, technical staff reviewed literature to compare WTE plants and landfills on five criteria:

- Energy recovery per ton
- Effect on recycling rates
- Costs at existing facilities
- Greenhouse-gas emissions
- Air pollution other than GHG emissions

This matrix summarizes the finding of MPCA staff:

	Landfill with recovery of gas for energy (LFGE)	Mass Burn Waste to Energy (WTE)	Notes and Comments
Key assumptions behind models and consensus data	• Based on existing U.S. large MSW landfills with LFGE, no thermal energy sales • LFGE is internal combustion • WARM assumes dry tomb	• Based on existing U.S. large mass burn WTE plants • 18% efficiency since is hardwired into models available • Ferrous recovery from ash, but not front-end separation	
Energy production in millions of BTU per MSW ton	0.2 to 1.05 MMBTU/ton • Uncertainties: Need model that can be adjusted for higher or lower LFG capture efficiency	8.9 to 9.7 MMBTU/ton • Reason WTE plants have so much more energy available per ton of MSW (almost an order of magnitude) is due to ability to use both fossil and biogenic content • Uncertainties: Need model that can be adjusted for higher or lower LFG capture efficiency	• Total electricity production would be less than 2%, if hypothetical 1.5 million tons/year extra were redirected from LF to WTE • Under MN RES law all LF and WTE electricity is currently classified as renewable though 45% of WTE is from fossil-derived

		• Assuming that the approximate 1.5 million tons of MSW that is landfilled annually is combusted in WTE, this would account for approximately 1.6% of Minnesota's total electric generation	
Greenhouse gases per MSW ton, life cycle, from generator to disposal point	GHG avoided per MSW ton, at 75% efficient landfill with LFGE: 0.7 MTC02E (100 year calculation) or 2.8 MTCO2E (WARM tool) Uncertainties: (1) rate of LFG production in situ in the landfill (2) LFG capture efficiency (3) rate of avoided grid-based emissions from on-site electricity production (4) landfill soil oxidation rate. LFG capture efficiency is not known because operating landfills take no continuous measurements of methane emissions from the uncovered portions, openings through cover for wellheads, and fissures. Models of methane emissions after closure are also based on unvalidated assumptions, e.g., assume no moisture will enter a dry tomb landfill and restart anaerobic digestion after 30-yr postclosure period has finished.	GHG avoided per MSW ton, for WTE selling electricity only: 0.8 MTC02E (100 yr method) or 3.2 MTCO2E (WARM tool) Sensitive to: rate of avoided grid-based emissions from on-site electricity production, actual thermal efficiency compared to assumptions in WARM, percentage of fossil vs biogenic waste in waste burned	• Two runs, one based on Peter C's calculation using "100 year carbon" (detailed as Option 1 in his 12/14/09 memo) and another on using the WARM model, version 10 • Small difference in GHG emissions avoided per MSW ton, compared to landfill without any gas recovery; LFGE has slight edge if 100 yr method is used, WTE has slight edge if WARM is used and would have larger advantage when plants have higher efficiency • But difference in GHG emissions would be less than 1/1000th of annual MN GHG emissions, for 1.5 million tons MSW switched from one method to the other • It is important to reduce uncertainties around LFG capture efficiency, the proper timeline to use, and carbon sequestration.

<table>
<tr>
<td>Life cycle air emissions per MSW ton, assuming that the electricity generated offsets the Minnesota mix of electric generation.</td>
<td>
<table>
<tr><th>Parameter</th><th>Units</th><th>Landfill Gas to Energy</th></tr>
<tr><td>Energy Consumption</td><td>MMBtu/Ton</td><td>-0.2</td></tr>
<tr><td>Total Particulate</td><td>lb./ton</td><td>-0.04</td></tr>
<tr><td>Nitrogen Oxides</td><td>lb./ton</td><td>1</td></tr>
<tr><td>Sulfur Oxides</td><td>lb./ton</td><td>-1</td></tr>
<tr><td>Carbon Monoxide</td><td>lb./ton</td><td>1</td></tr>
<tr><td>Hydrocarbons (non CH4)</td><td>lb./ton</td><td>0.06</td></tr>
<tr><td>Lead (Air)</td><td>lb./ton</td><td>0</td></tr>
<tr><td>Ammonia (Air)</td><td>lb./ton</td><td>0</td></tr>
<tr><td>Methane (CH4)</td><td>lb./ton</td><td>15</td></tr>
<tr><td>Hydrochloric Acid</td><td>lb./ton</td><td>0.01</td></tr>
</table>

Criteria and toxic air pollutant data quality from landfills are generally low with very low quality data available for important pollutants such dioxins/furans and mercury. Data are generally from a small number of facilities monitored for short periods of time. At this time the EPA is developing the procedures for monitoring landfill fugitive air emissions. There are no accepted methods to continuously monitor these emissions.
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<table>
<tr><th>Parameter</th><th>Units</th><th>Waste to Energy</th></tr>
<tr><td>Energy Consumption</td><td>MMBtu/Ton</td><td>-8.9</td></tr>
<tr><td>Total Particulate</td><td>lb./ton</td><td>-0.94</td></tr>
<tr><td>Nitrogen Oxides</td><td>lb./ton</td><td>-1</td></tr>
<tr><td>Sulfur Oxides</td><td>lb./ton</td><td>-5</td></tr>
<tr><td>Carbon Monoxide</td><td>lb./ton</td><td>0</td></tr>
<tr><td>Hydrocarbons (non CH4)</td><td>lb./ton</td><td>-0.5</td></tr>
<tr><td>Lead (Air)</td><td>lb./ton</td><td>0</td></tr>
<tr><td>Ammonia (Air)</td><td>lb./ton</td><td>0</td></tr>
<tr><td>Methane (CH4)</td><td>lb./ton</td><td>-2</td></tr>
<tr><td>Hydrochloric Acid</td><td>lb./ton</td><td>0.34</td></tr>
</table>

Criteria and toxic air pollutant data from waste to energy facilities are very high quality, the result of more than ten years of continuous (for O_2, CO, SO_2, and NO_x) and frequent (for particulate, fine particulate, hydrogen chloride, dioxins/furans, lead, cadmium and mercury) monitoring.
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Based on Municipal Solid Waste Decision Support Tool (MSW DST); the estimated emissions are based on <u>Life Cycle Environmental Aspects of Municipal Solid Waste Management Alternatives for the Minnesota Pollution Control Agency</u>, (RTI International 6/30/08.
The study does not assess the spatial or temporal variation of local concentrations of pollutants emitted, the human health or environmental impacts from exposure to the emitted pollutants. A more holistic life cycle assessment could include a more complete list of air (GHG, criteria and toxic) and water pollutants, identification of impacts and weighting of those impacts.

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<tr>
<td>Effect of this disposal</td>
<td><u>SCORE</u>: Minnesota “centroid” counties relying entirely on landfills have a 34% average recycling rate for 2008</td>
<td><u>SCORE</u>: Minnesota “centroid” counties relying on some degree of WTE have a 47% average recycling rate for 2008, or</td>
<td>While WTE has an edge here, it can be difficult to compare recycling rates across states and</td>
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</table>

method on local source-separated recycling rates		13% higher than centroid counties that use no WTE at all. Statewide the advantage to WTE is narrower, probably 4-6%. U.S.: Consultants hired by the WTE industry report average 4% higher recycling rates in the 94 U.S. urban areas with WTE, compared to the national average. EU: Eurostat figures for 2007 MSW recycling rates in the European union: The average MSW recycling rate at the 8 high-WTE countries was 47% and the MSW recycling rate for the 19 low-WTE countries was 21%. ("low WTE" means nations that directed less than 20% of their MSW to WTE, 20% being the average WTE rate in the EU for 2007)	nations. California's rate tends to be artificially high compared to Minnesota because non-MSW wastes are counted there.
Price needed per MSW ton at gate to break even, if run as merchant facility without subsidies	$30-40/ton, including financial assurance set-aside. Lower price is for large commercial LFs, higher price for small publicly operated LFs.	$40-60/ton if bonds are paid off; costs can exceed $100 per ton for small WTE paying debt service.	Ultimate cost of burying biologically or chemically reactive waste is unknown at this time.