NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Waste-to-Energy Technologies and Applications

E^2S^2 Conference

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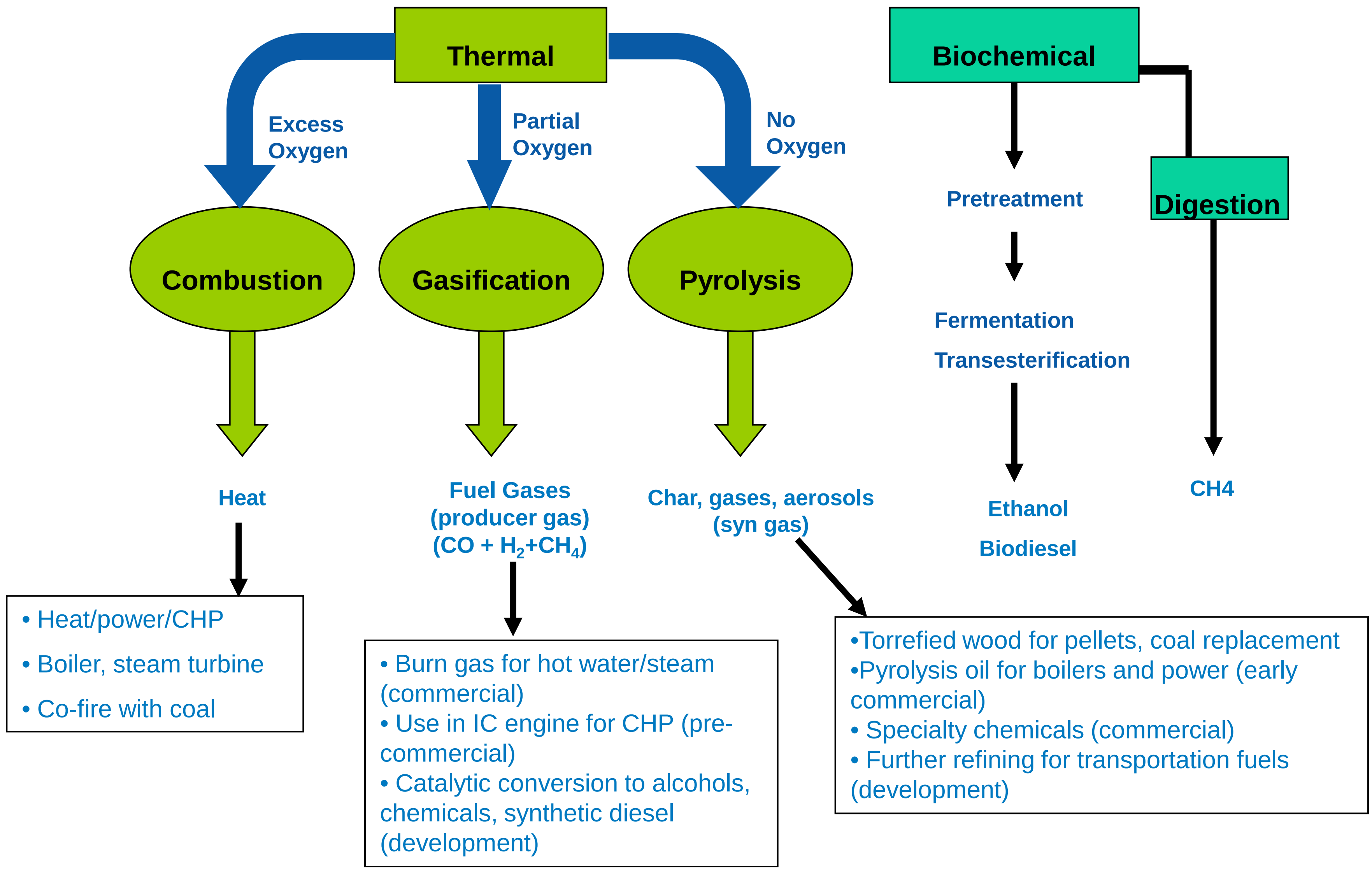
NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

Overview

- Technology Overview
- Commercial and Emerging Applications
- Driving Factors for Waste-to-Energy (WTE)
- Variables to Consider for WTE Projects
- Hybrid Plant Study

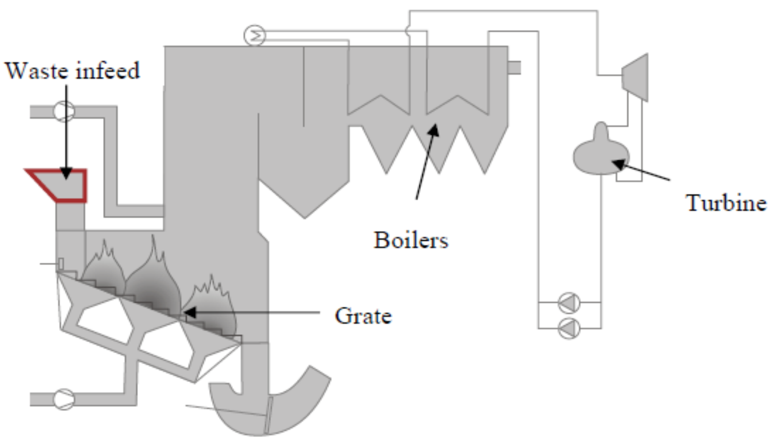
Energy Pathways



Combustion Overview

- 86 existing commercial facilities combust 26 million tons of MSW per year in 24 states.
- Typical minimum for feasibility is 300 tons per day (tpd)

Typical Mass Burn WTE Layout



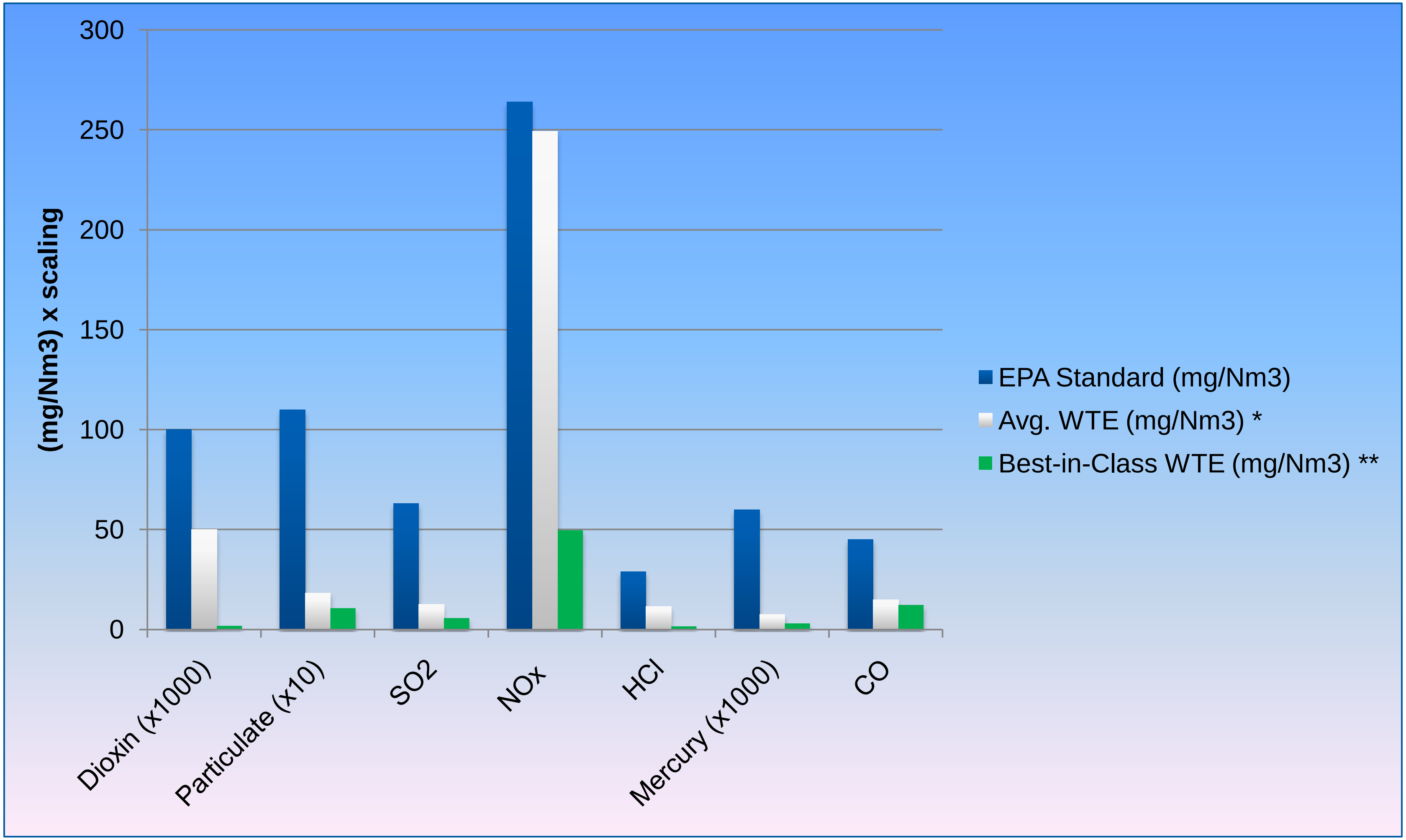
Avg. Emissions Profile: U.S. WTE Plants

Pollutant	Average emission	US EPA standard	Average emission (% of US EPA standard)	Unit
Dioxin/furan, TEQ basis	0.05	0.26	19.2%	ng/dscm
Particulate matter	4	24	16.7%	mg/dscm
Sulfur dioxide	6	30	20%	ppmv
Nitrogen oxides	170	180	94.4%	ppmv
Hydrogen chloride	10	25	40%	ppmv
Mercury	0.01	0.08	12.5%	mg/dscm
Cadmium	0.001	0.020	5%	mg/dscm
Lead	0.02	0.20	10%	mg/dscm
Carbon monoxide	33	100	33.3%	ppmv

dscm: dry standard cubic meter of stack gas.

Source: C.S. Psomopoulos et al (2009), Waste Management 29, 1718-1724)

Combustion: Emissions Profile



* Source: C.S. Psomopoulos et al (2009), Waste Management 29, 1718-1724

** Source: Themelis, N.J. (2007), Thermal treatment review, Waste Management World (July-August), 37-45

Gasification Overview

Exothermic/Combustion Reaction

$C + O_2 \rightarrow CO_2$

Endothermic/Gasification Reactions

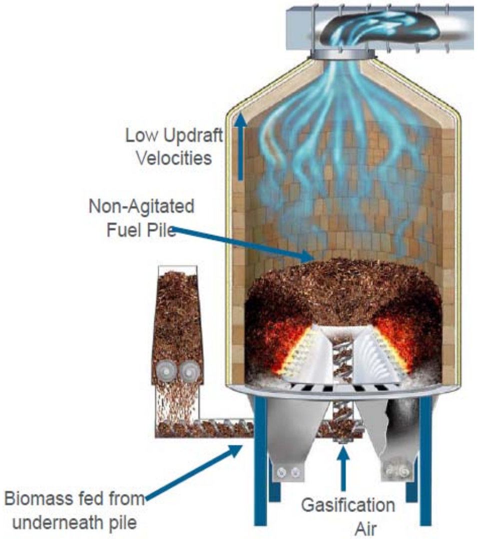
$C + H_2O \Leftrightarrow CO + H_2$

$C + CO_2 \Leftrightarrow 2CO$

$C + 2H_2 \Leftrightarrow CH_4$

$CO + H_2O \Leftrightarrow CO_2 + H_2$

Example of Biomass Gasifier



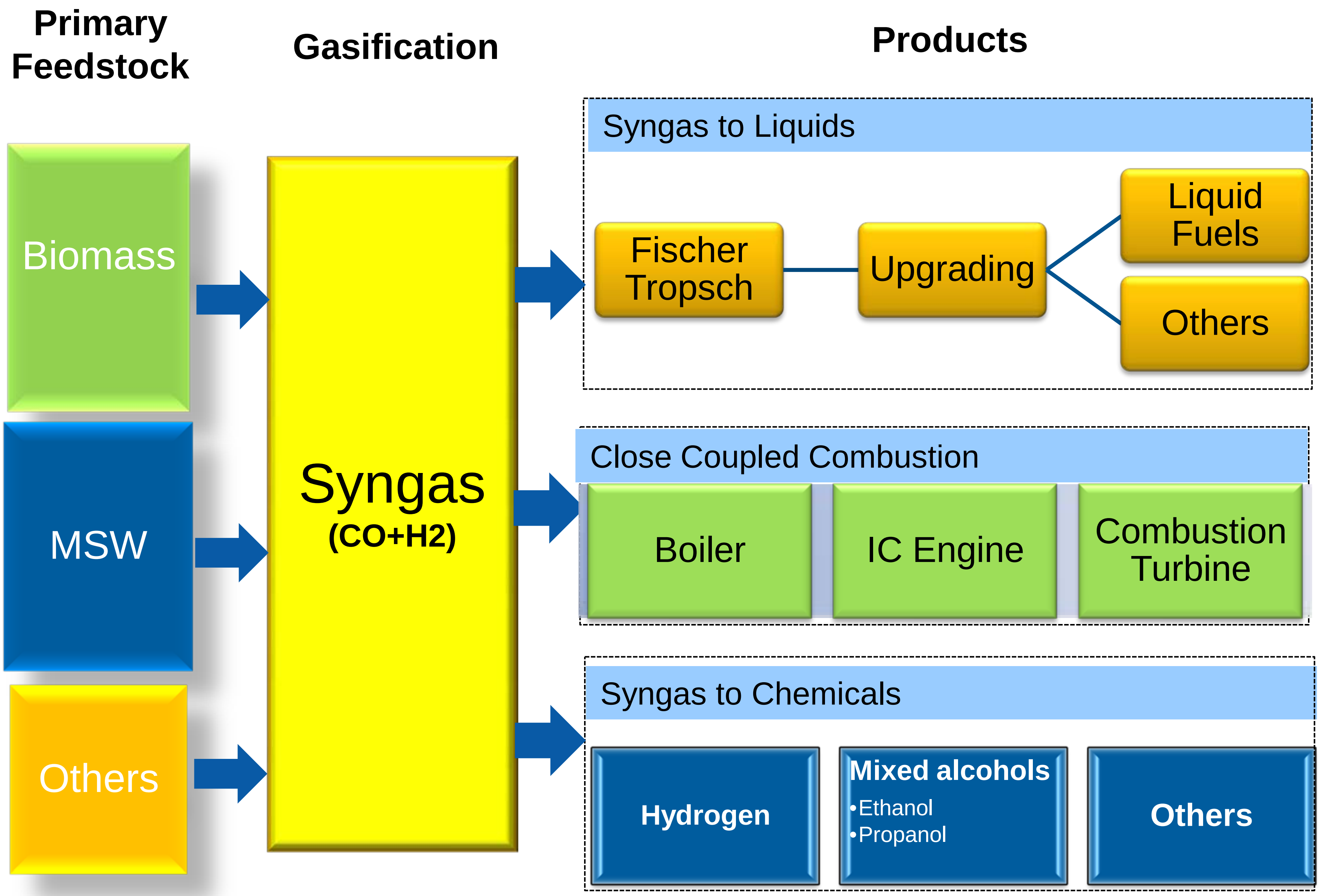
Gasification Emissions Profile: Kinsei Technology

Item Tested	Location	Test Result	Unit	EPA Standard	Princeton vs EPA
Particulate	Stack	00.0014	gr/dscf	0.0015	10% lower
CO	Stack	32.2	ppmv	100	60% lower
HC	Stack	Not detectable	ppmv	10	99% lower
NOx	Stack	66.81	ppmv	150	60% lower
SO_2	Stack	15.88	ppmv	30	50% lower
HCl	Stack	12.068	ppmv	25	50% lower
Cl2 + HCl		9.068	ppmv	21	60% lower
Hg/	Stack	0.0081	ug/m^3	8.1	99% lower
Dioxin /Furan	Stack	0.098	ngTEQ/dscm	0.11	10% lower
Opacity	Stack	10%		10%	Same

Source: Princeton Environmental

- **About 25 units operable in the U.S. using waste material feedstocks, including biomass**
- **Primary challenge for WTE application is inconsistency of MSW as feedstock**

Gasification Flexibility



Commercial Applications

- Large scale (>300 tpd) combustion units commercially viable
  - Economy of scale due to high capital cost of emissions control equipment
  - Almost all commercial power systems are combustion/steam turbine
  - Efficiencies in 15% – 30% range power only, (60% – 70% CHP)
  - 550-650 kWh per ton of MSW
  - Stoker and fluidized bed boilers
  - Avg. size in the U.S. is 20 MW
  - Installed cost: $4,000 per kW
  - Residual material (ash) about 10% by volume, 20% by weight
  - LCOE = $0.06 – $0.20 per kWh (depends on tipping fee revenue)

Emerging WTE Applications

- Small scale (10 – 300 tpd) advanced conversion technologies in demonstration phase
  - Potentially better suited to small scale applications
  - More efficient than combustion, 30% – 40%
  - 600 – 800 kWh per ton of MSW
  - Syngas can be used in IC engines, gas turbines, steam turbines or to make liquid fuels
  - Potential for reduced water usage
  - Installed cost: $6,000+ per kW
  - Residual material about 10% by volume, 20% by weight
  - LCOE = $0.15 – $0.20+ per kWh (LCOE depends on tipping fee revenue)

IES 30 tpd unit Mecca, CA

Emerging WTE Applications

- Expeditionary scale (.5 – 3 tpd) WTE entering limited demonstration phase
  - Demonstration projects at Fort Irwin, Aberdeen Proving Grounds, Edwards Air Force Base
  - Potential forward operating base (FOB) applications
    - Estimated loads of .32 KW – .8 KW per person
    - 3 – 18 lb of waste generated per person per day
    - 250 – 600 kWh per ton MSW
    - WTE may provide 7 – 38% of the power requirement

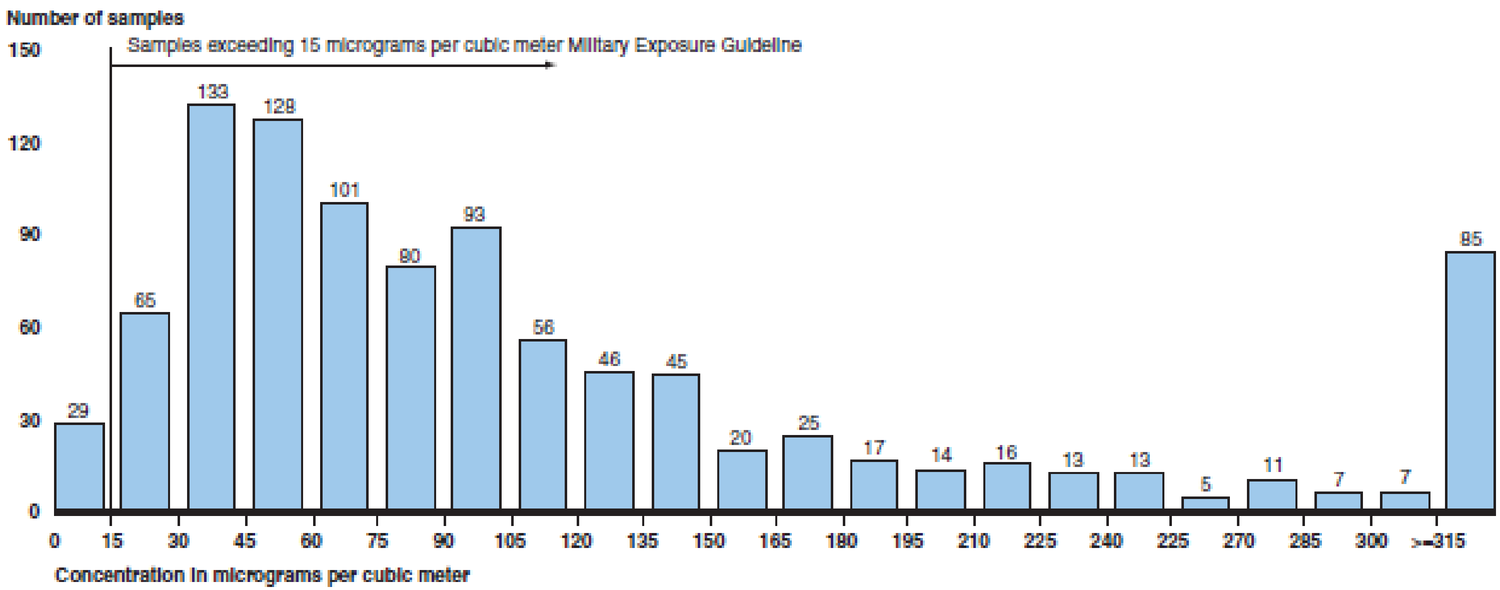
Community Power Corp: MEWEPS System

Driving Factors: DoD Installations

- Cost
  - National average solid waste disposal cost is $44 per ton
  - Lifecycle costs for DoD landfills can exceed $100 per ton
- Space
  - 71 active landfills on DoD installations; these are quickly reaching capacity
  - 400 closed landfills occupy over 5000 acres; may be possible to “mine” these landfills for WTE and recover the land for use
  - Currently not considered diversion per DoD’s Integrated Solid Waste Management plan (a challenge for net zero waste goals)
- Energy
  - WTE contributes to renewable energy generation and greenhouse gas reduction executive orders and goals

Driving Factors: Operational Energy

- Fully Burdened Cost of Waste Disposal
  - $500 per ton
- Government Accountability Office (GAO) Report
  - 251 burn pits in Afghanistan, 21 in Iraq as of Aug. 2010
  - Poor air quality: Over 90% of air samples exceeded Military Exposure Guidelines for particulate matter (see graph below)
  - Lawsuits filed in 43 states against Government waste management contractors



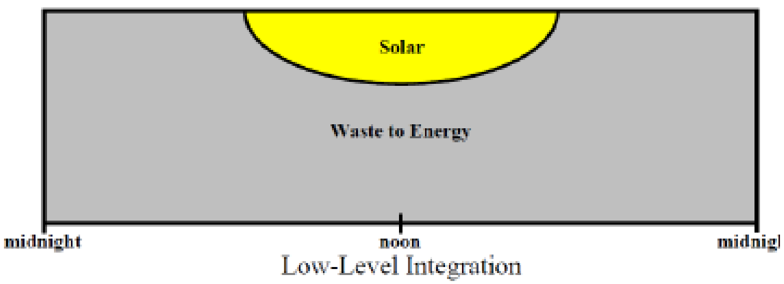
Source: GAO analysis of DOEHRS ambient air sampling data.

Evaluating Opportunities: Variables

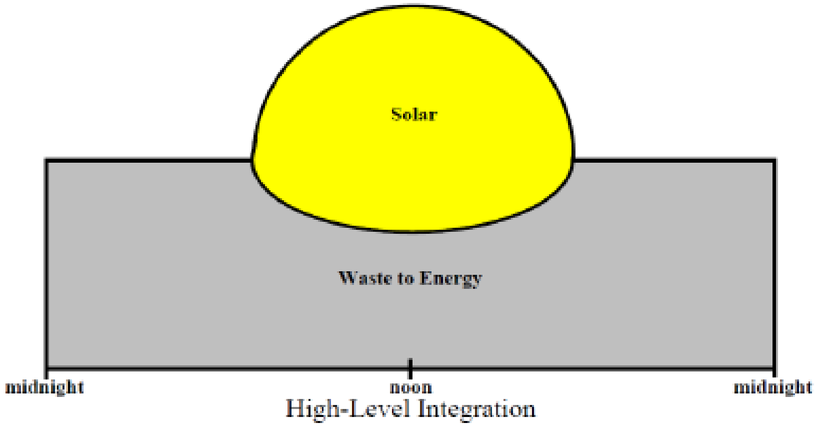
- Waste stream
  - Large-scale, commercially proven, systems require >300 tpd
    - For a DoD installation, this requires partnership with a local municipality
  - Small-scale, yet-to-be proven systems can operate with smaller waste streams
    - Possible use of plasma arc gasification for destruction of medical or hazardous waste improves WTE project economics
- Solid waste disposal cost
  - Coastal or island locations typically favorable due to land constraints and high costs to build new landfills
  - Over $70/ton may support WTE
- Energy costs
  - Over $.12/kWh is favorable for WTE

WTE – CSP Integrated Plant Study

- Based on 320,000 tons per year (approximately 1000 tpd) with an 85% capacity factor
- WTE (mass burn) and concentrating solar power (CSP) providing heat for a common steam cycle
- LCOE about 11¢/kWh
- Scenario 1: Low-level solar contribution for consistent generation
  - Solar contribution makes up 12% of annual generation
- Scenario 2: High-level solar contribution for increased peak generation
  - Solar contribution makes up 26% of annual generation



Scenario 1



Scenario 2

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