The History and Future of Landfilling

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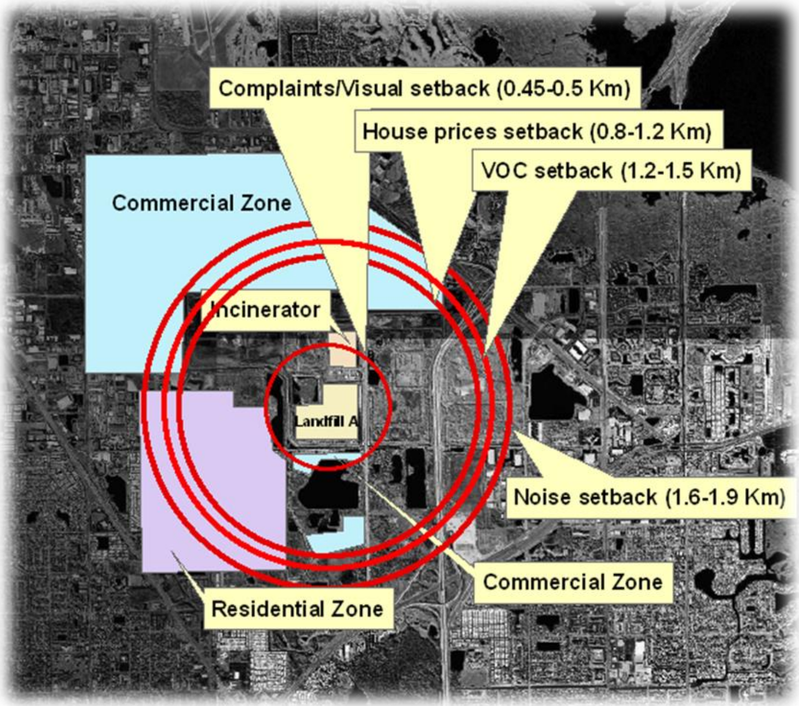
History

Prehistoric Days

- **Landfills have existed for over 5,000 years**. Archaeological evidence of landfills dates back to 3000 BC in Crete, where waste was deposited in pits that were subsequently covered up with earth when full

First Landfill Setback Law

- **500 B.C.** | Athens, Greece, developed a law requiring garbage to be dumped at least **one mile** from the city to preserve its beauty and prevent illness.



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Open Dumps

- Clay or gravel pits
- Waste dumped wherever possible

First “Modern” Landfill (1937)

- The Fresno Sanitary Landfill is the oldest "true" sanitary landfill in the United States, and the oldest compartmentalized municipal landfill in the western United States.
- On the National Register of Historic Places

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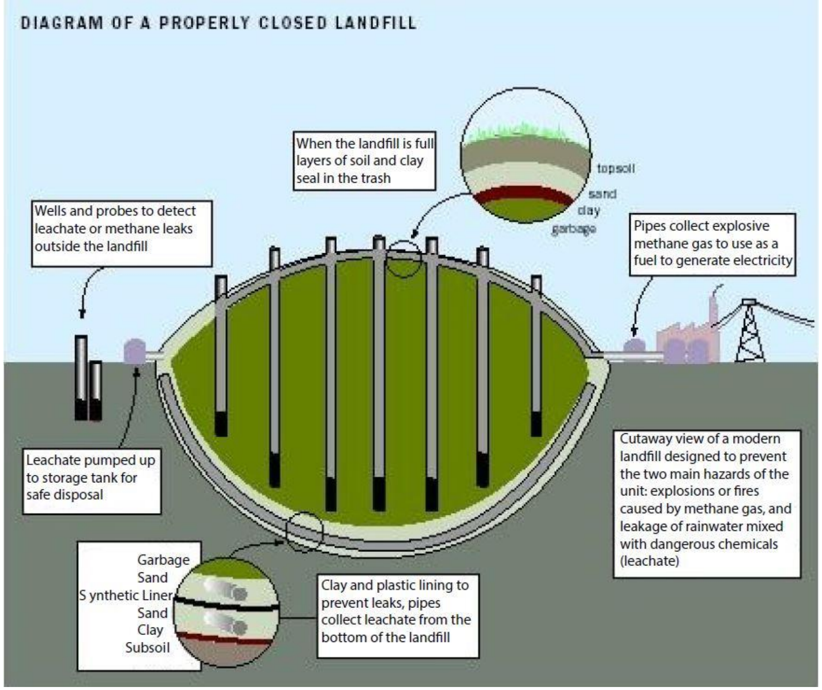
US Major Landfill Legislation

- **1965** | The Solid Waste Disposal Act was passed, authorizing government research on resource recovery and landfill research.
- **1976** | The Resource Conservation and Recovery Act was created to plan for recycling, conservation and waste management. The Resource Conservation and Recovery Act of 1976 (RCRA), is the defining legislation for MSWM practice in America today.

Subtitle D Regulations

- In the RCRA 1984 Hazardous and Solid Waste Amendments, Congress finally granted EPA regulatory authority over landfills and directed the preparation of landfill criteria.
- In October 2009, EPA issued a rule (40 CFR Part 98) that required the reporting of greenhouse gas (GHG) emissions from large sources and suppliers in the United States intended to collect accurate and timely emissions data

The Subtitle D "Dry Tomb" Landfill

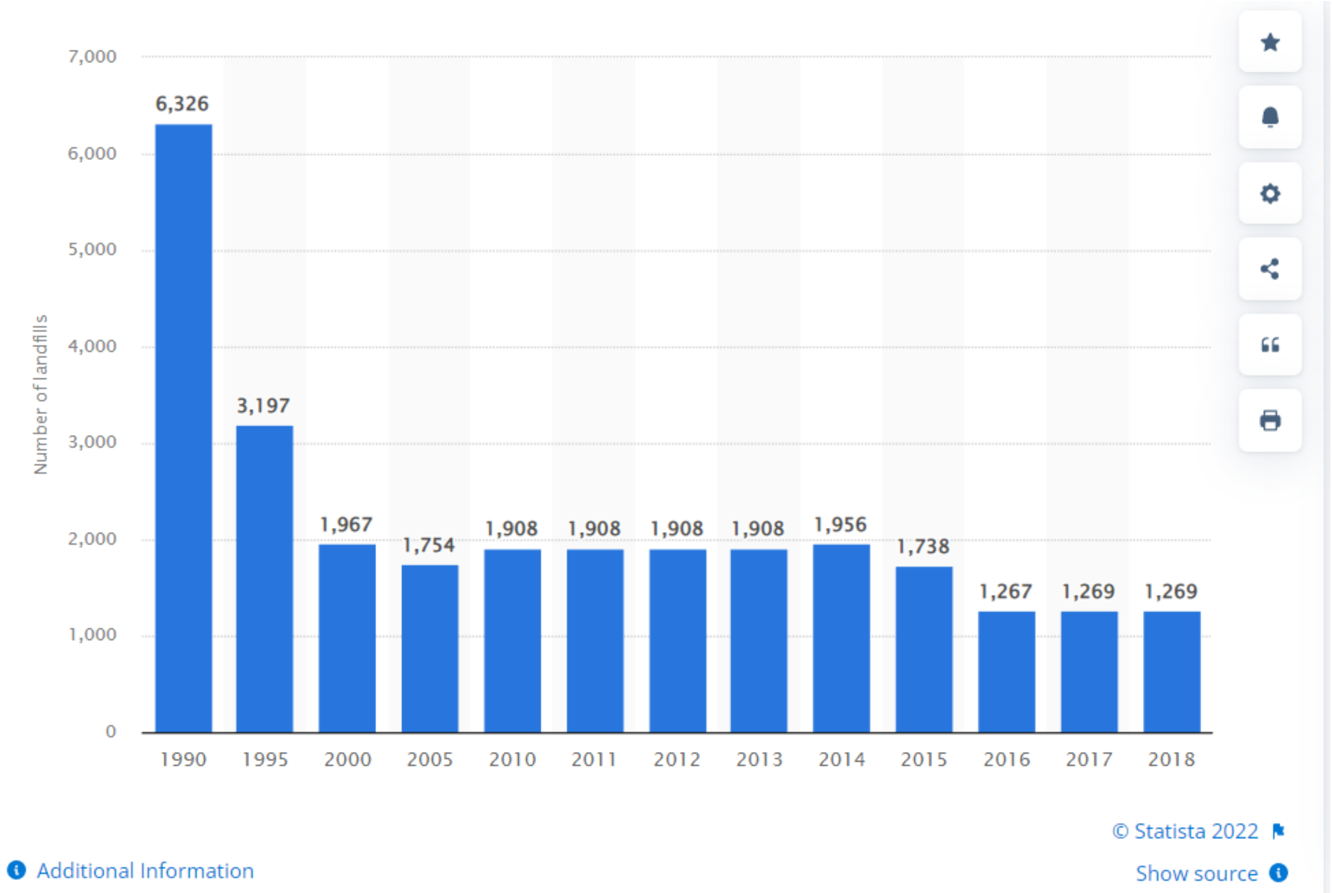


The “Model” Landfill (1970s)

The Orange County, Florida Landfill received USEPA funds to demonstrate construction of a landfill for the recovery of wetlands


A CENTURY OF AMERICAN GARBAGE
LANDFILLS OVER TIME, BY SIZE AND CURRENT STATUS
1911
LANDFILL STATUS
Open
Closed
Source: https://www3.epa.gov/lmop/projects-candidates/

The Number of Landfills 1990 - 2018



William Rathje - Garbologist

Tucson Garbage Project

1945-2012

- In 1992, William Rathje published the book The Archaeology of Garbage. In the book, he shared many unexpected findings.
- In 1973, Rathje and his students studied waste at a landfill in Tucson and found at least 10% of the rubbish thrown away was food. During a **beef shortage**, people started buying in bulk,
- Contrary to much of public opinion, fast-food packaging made up only one-third of 1% of the total volume of trash landfilled between 1980 and 1989, while expanded **polystyrene** foam accounted for no more than 1%.
- Even **disposable diapers** averaged out at only 1% by weight of the total **solid waste** contents (1.4% by volume).

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Bioreactor Landfills

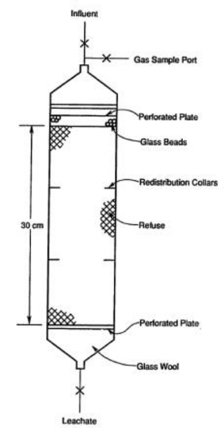
1970s: Laboratory/Pilot studies

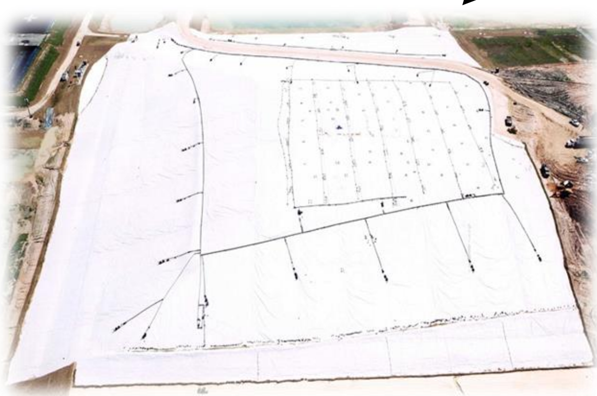
1980s: First generation full-scale application

1990s: Second generation full-scale application

2000s: Technology Implementation

2020s: Sustainable Landfilling





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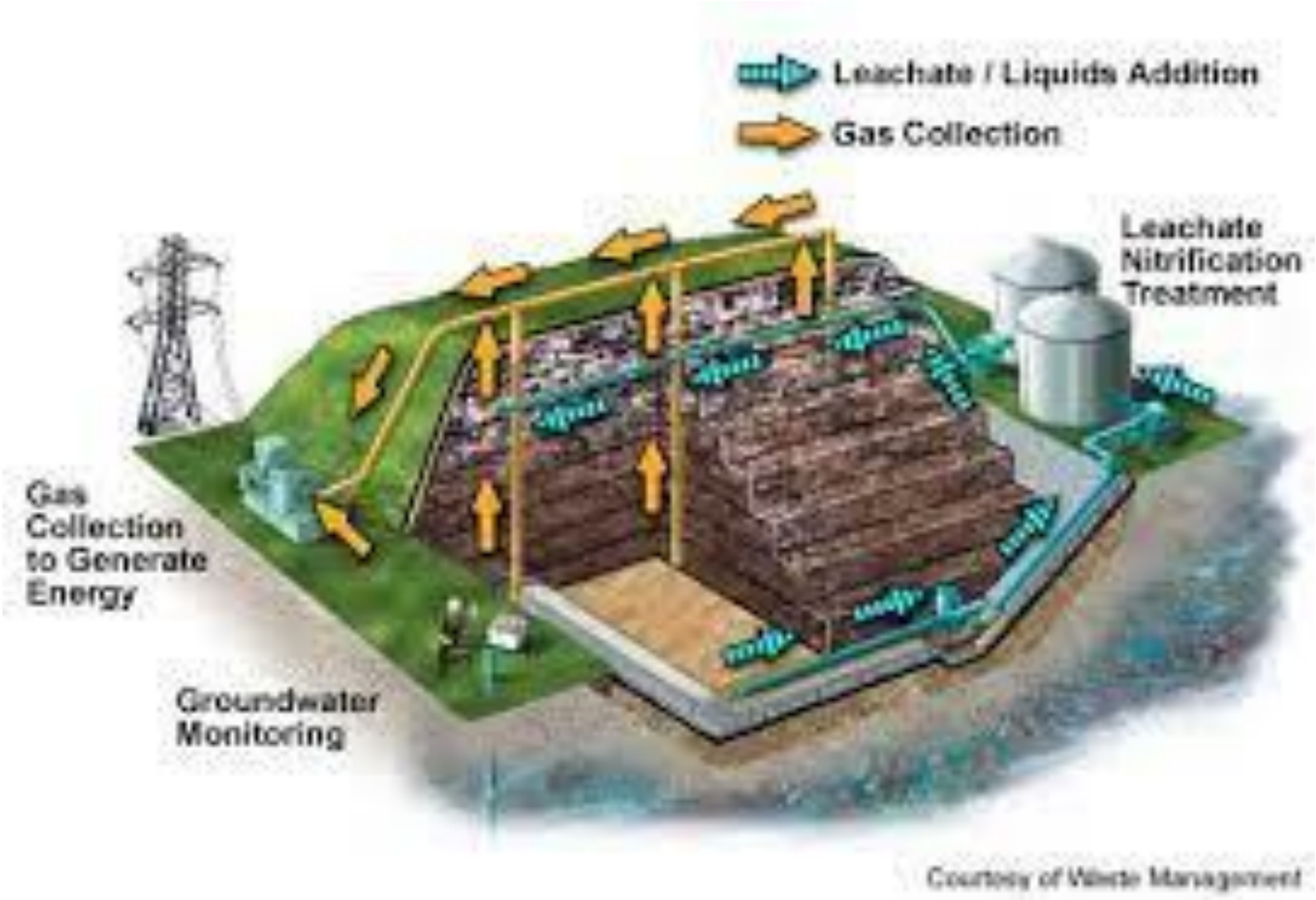
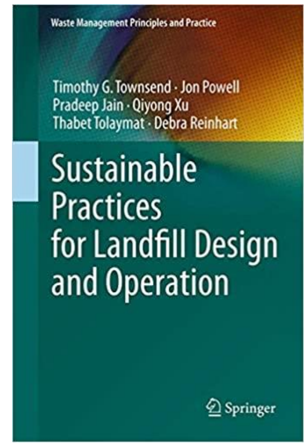
Leachate Recirculation

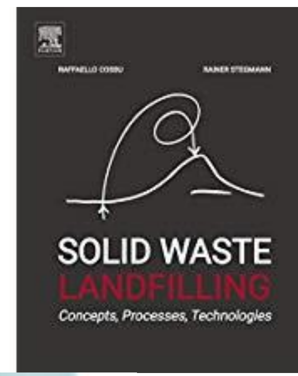
The Bioreactor Landfill



Excavated - Fall 1998
Test Cell #1
Test Cell #2
Chicken Leg
Chicken Leg

Body of Knowledge: Experience has Generated Liquids Addition Best Practices





Landfill Treatment and Sequestration of Organics

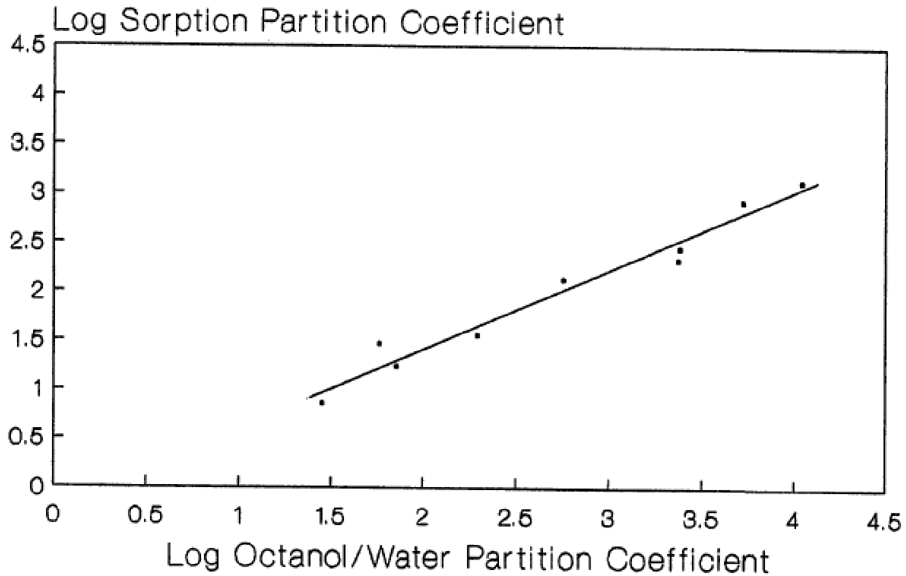
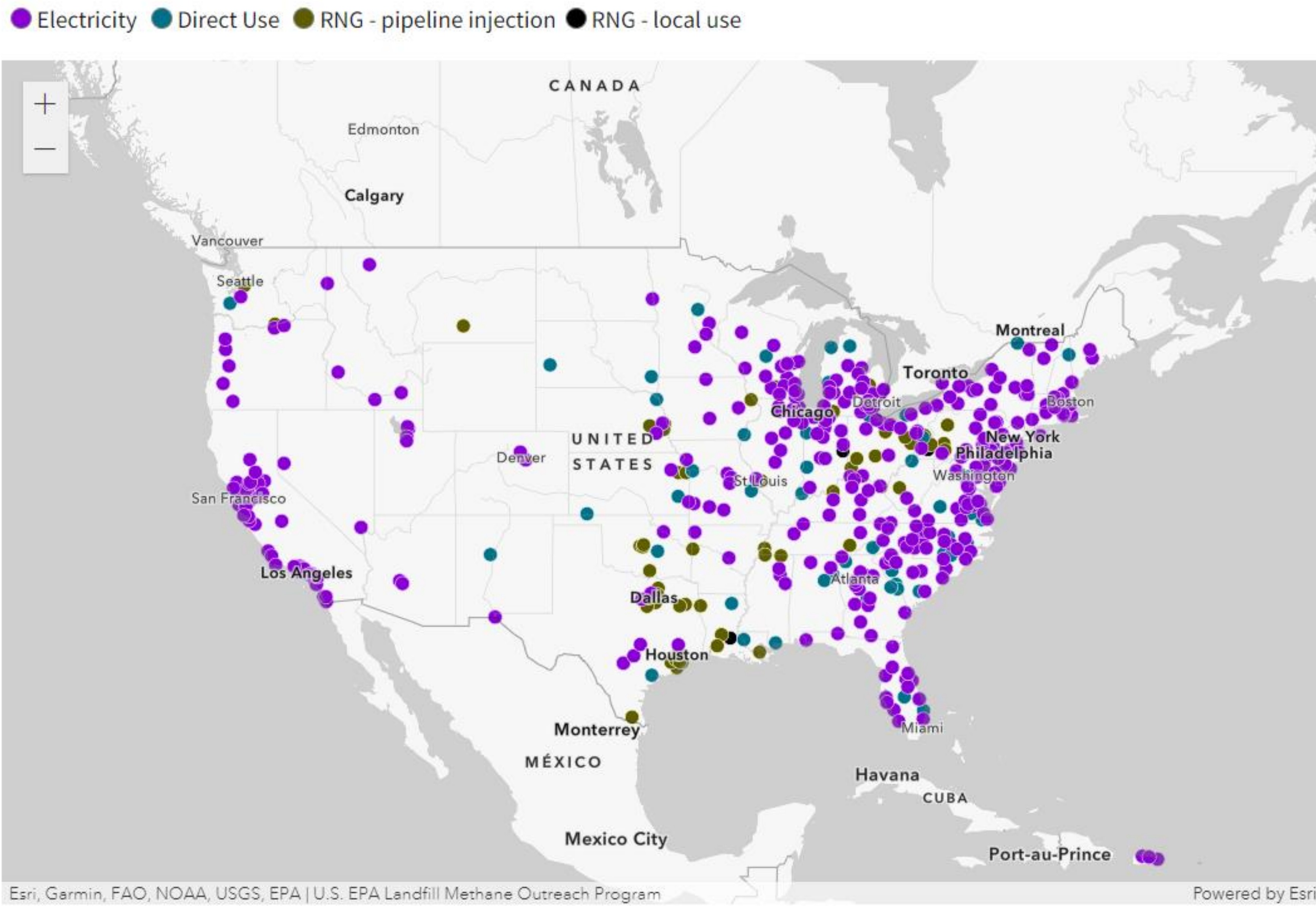
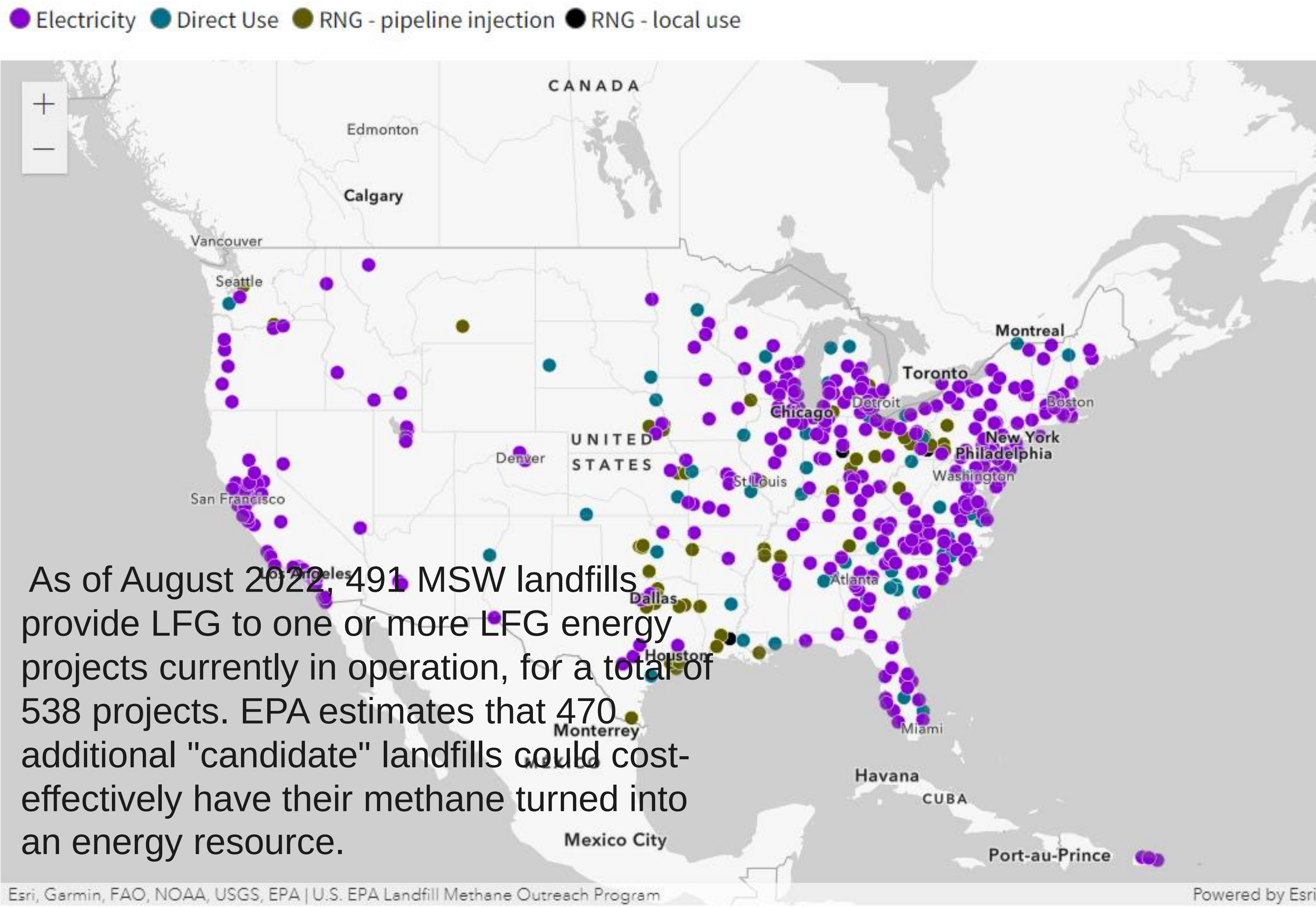


Figure 4.7 Relationship of Log Sorption Partition Coefficient and Log Octanol/Water Partition Coefficient for Test Organic Compounds Sorbed on Refuse

- Organic pollutants
- PFAS
- Lignin and lignocellulosic wastes


Electricity
Direct Use
RNG - pipeline injection
RNG - local use
CANADA
Edmonton
Calgary
Vancouver
Seattle
UNITED STATES
Denver
San Francisco
Los Angeles
Dallas
Houston
Monterrey
MÉXICO
Mexico City
Chicago
Detroit
St Louis
Atlanta
Miami
Havana
CUBA
Port-au-Prince
Toronto
Montreal
Boston
New York
Philadelphia
Washington
Esri, Garmin, FAO, NOAA, USGS, EPA | U.S. EPA Landfill Methane Outreach Program
Powered by Esri



As of August 2022, 491 MSW landfills provide LFG to one or more LFG energy projects currently in operation, for a total of 538 projects. EPA estimates that 470 additional "candidate" landfills could cost-effectively have their methane turned into an energy resource.

EU Landfill Directives

- Directive 1999/31/EC on the landfill of waste **aims to prevent, or reduce as much as possible, any negative impact from landfill on surface water, groundwater, soil, air or human health**.
- It does so by introducing stringent technical requirements including a requirement that waste must be treated before being landfilled
- In 2014 a plan called for Europeans to recycle 70% of municipal waste and 80% of packaging waste by 2030, and bans the landfilling of recyclable material by 2025
- By 2030, no more than 10% of municipal waste should go to landfill in the EU. In addition to this binding target, the new laws would include a total ban on the landfilling of waste which has already been separated and sorted for recycling.

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ICLRS 2014

Challenges

- **Long-term management of landfills** dictated by the continued presence of ammonia-nitrogen, dissolved metals, recalcitrant organic matter, and gas potential,
- **Co-treatment of wastewater and leachate** due to the presence of recalcitrant organic matter that passes through conventional treatment processes,
- **Emerging contaminants** that have yet to be identified in landfill leachates and may be present due to the vast number of complex consumer products being manufactured and ending up at a landfill at the end of their useful life,
- **Inefficient capture of methane from landfills**

Engineering Solutions

- Development of **advanced analytical techniques** to identify and characterize emerging containment in complex environmental matrices,
- Appropriate and sustainable treatment processes for **leachate treatment**,
- **Heat management** in landfills,
- Improved process **emissions monitoring**,
- Regulation of **organic waste landfilling**

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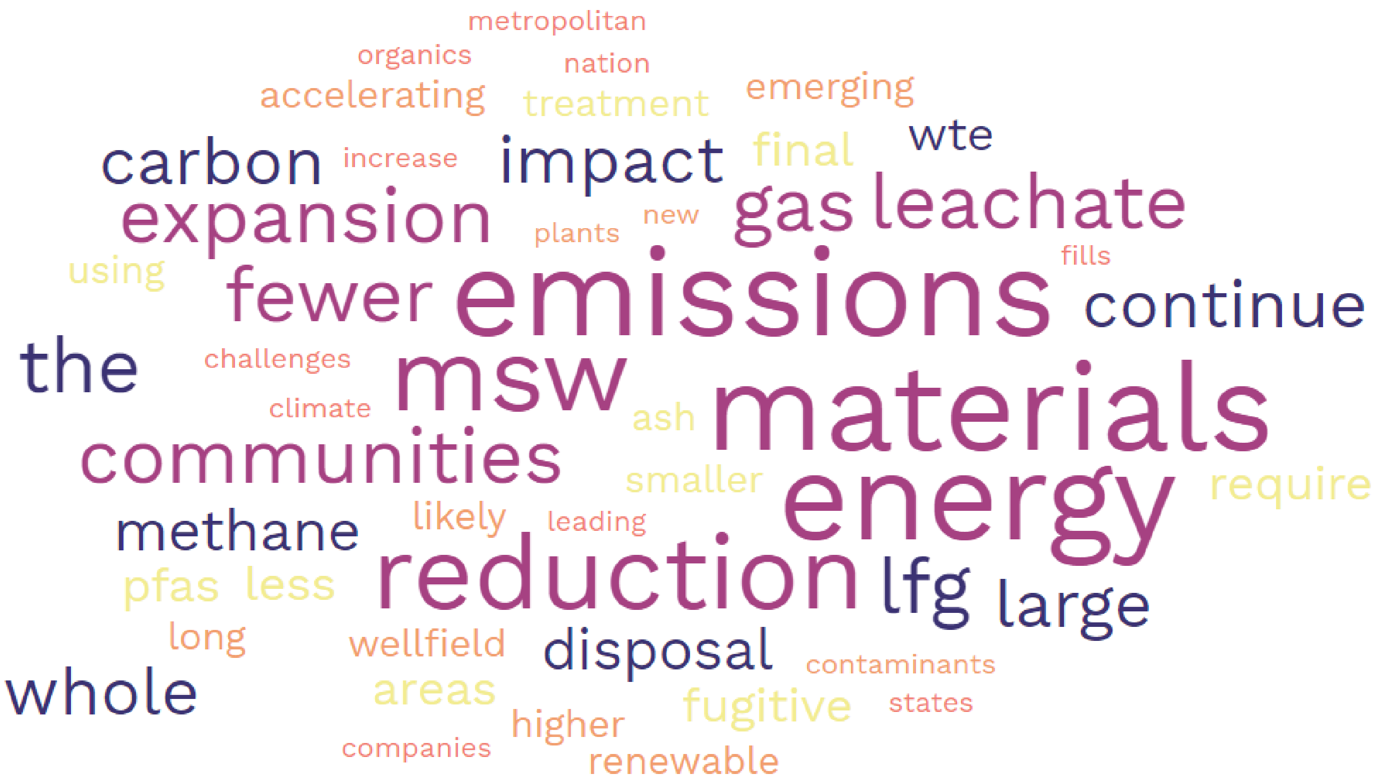
The Future


metropolitan
organics
nation
accelerating
treatment
emerging
carbon
increase
impact
final
wte
expansion
plants
new
gas
leachate
fills
using
fewer
emissions
continue
the
challenges
msw
climate
ash
materials
communities
smaller
energy
require
methane
likely
leading
reduction
lfg
large
pfas
less
long
wellfield
disposal
contaminants
whole
areas
fugitive
states
higher
companies
renewable

Emissions

- Quantifying emissions
  - More can be done to reduce emissions even if hard to quantify the benefits.
  - Private landfill owning companies will be evaluated based on their ability to control landfill emissions
  - Routine (continuous and/or semi-continuous) monitoring of landfill emissions will be commonplace\More comprehensive fugitive gas emissions understanding through more measurements/more sophisticated measurement techniques and interpolation of data over the cadence of measurements.
  - More measurements/more sophisticated measurement techniques and interpolation of data.

Emissions, Continued

- Landfill gas to energy systems may be implemented more widely to:
  - create revenue,
  - offset other costs (e.g., using gas to fuel trucks),
  - demonstrate increased sustainability,
  - improve public relations, or
  - avoid bad PR
- However, as large as US fugitive emissions are, they are likely worse in countries where there is no gas collection requirement

Landfill Gas

- Focus on RNG plants, electricity projects, medium BTU and expansion of powering fleet with LFG
- Landfill gas production will slowly but incrementally increase as average global temperatures rise,
- Expanded LFG wellfield density and accelerated LFG wellfield installation
- More “inert or residuals” landfills where LFG and nuisance odors are less prevalent
- Better appreciation for the best mix of waste and the feasibility of “good” gas for projects.

Carbon and Climate Change

- Biodegradable Organics
  - Divert from landfills to eliminate methane emissions and put these materials to better use.
  - Due to pressure from environmental groups, organics diversion projects will increase.
  - Will require new investment in anerobic digesters along with chemical upcycling plants for plastics
  - As a result, waste composition to landfills will continue to evolve.
- Landfills will continue to be under scrutiny (regulatory): emissions, odor and release of other contaminants.
- Implications of landfills on climate (methane) will continue to be brought into focus.
- Public perception of landfills as a non-circular/unsustainable solution will grow
- With climate change, there will be significant impact on landfills

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Energy

- Wider usage of waste to energy because
  - future generations are not having to manage the gas and leachate from our waste for multiple decades,
  - much smaller footprint is needed than what is used for landfills,
  - much less carbon impact on the environment and better recovery of metals from the ash; and
  - better energy recovery from waste thru burning than burying.
- CO_2 sequestration by pumping CO_2 from the flare and gas-to-energy plant into ground.
- Expansion of renewable energy as a whole,
- As energy prices increase, we will move toward energy recovery using thermal processes and away from landfills

Leachate

- Partnerships between POTWs and LFs
  - Technologies that can address biosolids that benefit both entities.
- Shift from off-site to on-site leachate treatment
  - Driven by POTWs having to meet more stringent regulations
  - Approaches and treatment to achieve direct discharge or water reuse requirements will become more prevalent.
- Leachate treatment technology advancements
  - LFs may act as centralized waste treatment and destruction of PFAS residuals
  - Requires mindset shift and advanced technical capabilities by owners.
- Deep well injection will continue to be a more common option for smaller landfills.

Future generations may not have to manage the gas and leachate from our waste for multiple decades

Communities

- Clarify recovery of materials that makes sense for all communities – rural regions are very different than urban/suburban communities.
- Environmental justice and related topics (e.g., health impacts from close long-term proximity to landfills) will be a significant focus
- Use landfills as a community resource to promote understanding that landfills are assets for the company
- Apply EPA community case studies to better communicate what strategies will best mange materials and minimize discards

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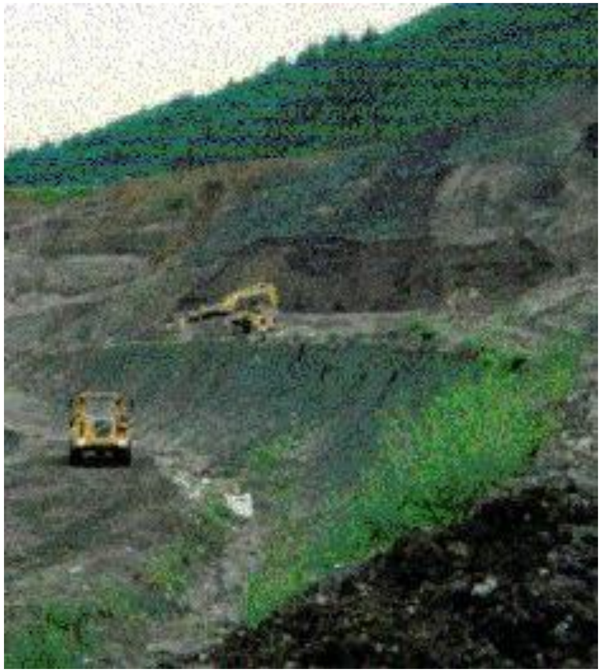
Materials

- Materials can only be reused a certain number of cycles before they become waste
- The more complex products with multiple materials are difficult to reuse.
- All products will become waste one day.
- Landfills will receive only those materials that cannot be repurposed, reused, recycled, upcycled and residuals that have no value.
- Increasingly landfilled waste is likely to be inorganic materials.
- Over time, less and less paper in MSW and higher food waste fractions

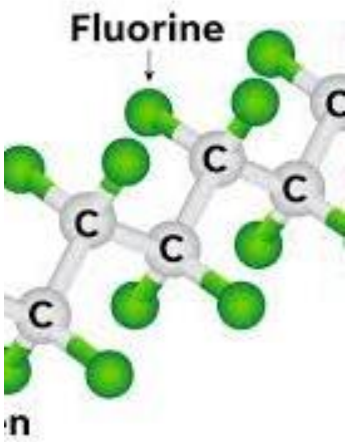
Landfill Mining

- Landfill mining to extract metals and plastics would start in distant future as value of such materials skyrockets.
- Challenges with siting new landfills (NIMBY, political etc.) will make landfill mining more attractive
- An example today is the excavation of old coal ash landfills to reclaim coal ash for use in concrete because coal ash has become more difficult to source, and more expensive.
- Landfill mining may become more viable if resources become scarce enough to make the proposition economically viable



Emerging Contaminants

- All landfills will require on-site leachate treatment plants to meet the discharge regulations for emerging contaminants
- PFAS:
  - Modern LFs are secure and heavily regulated and offer a safe disposal option for emerging contaminants such as PFAS
  - LFs may be ideal candidates for centralized waste treatment and destruction of PFAS residuals.
  - The majority of WWTP sludge will be landfilled rather than land applied
- Tip fees will be adjusted to reflect the cost of managing emerging contaminants
- Management of emerging contaminants in gas and leachate emission will continue to be a focus
- Operate separate cells to separately manage diverse stream of "MSW" such as WWTP sludges, PFAS impacted soils, sediments, and other solids.
- Likely problem contaminants already in landfills but not been identified as a problem yet



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In General

- As long as landfills are the least cost landfills will be used given limited other options.
- The industry may benefit from additional positive information sharing with the public for an improved image.
- In the US, the only way a major shift away from landfills will occur is:
    - the implementation of a landfill tax (as in Europe)
    - a carbon tax or
    - the economics of WTE change, perhaps because electricity prices triple; as such a focus on reducing CH4 emissions from landfills is appropriate
- Disaster debris will always have a major need for disposal, and may all go to landfills
- Building new landfills is getting more difficult and as such existing landfills are getting bigger and bigger

In General, Continued

- A final sink is needed for all residuals, e.g., safe landfills with high standards in “eternal” leachate avoidance
- The permitted capacity will continue to grow more concentrated and owned by a handful of large companies.
- Long range landfills for large metro areas.
- More highly instrumented facilities providing real-time feedback to its operator of its performance and status.

Final Comment

"As the economy becomes more circular, landfills will become more and more of a repository for items that cannot be successfully circularized or for items that have finite circularity. The extent to which this is possible, and what that would do to the public perception of landfills, **is hard to predict."**

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