Opportunities to Add Value Using Real-Time Data and Control Technology to Increase Methane Capture and Reduce Emissions

Peter Quigley, CEO and Chairman, LoCI Controls

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Maximum Methane Recovery & Emission Reduction

- Leveraging technology to enhance landfill methane capture can **generate greater financial returns compared to** any other investment by the MSW sector

- Increasing focus on methane emission reduction aligns MSW and bio-gas to energy producer goals to achieve maximum collection efficiency and minimize landfill gas emissions

Landfill Gas: An Overview

- **Composition**
  - LFG is generated in real-time from decomposing organic material found in landfills

- **Regulation**
  - NSPS regulations for Municipal Solid Waste landfills (NSPS 40 CFR Parts 51, 52, and 60) regulates the capture of landfill gas per the Clean Air Act and the March 1996 publication by the EPA "Standards of Performance"

- Since 1996, LFG collection operations have **not been driven to maximize methane recovery**
  - Landfill gas collection is undertaken to ensure compliance with federal and state regulations

Landfill Gas: By the Numbers

- 550 operational beneficial use projects at landfills — where LFG is used to generate electricity, RNG, medium btu, or direct use projects (source: EPA)
- Additional 480 large landfills that are candidates for beneficial use projects

- In Michigan, 56 large landfills report annually EPA GHG Reporting database
  - 41 have landfill gas to energy projects
  - 35 are operating landfill gas to electricity projects; 6 are operating RNG to pipeline projects
  - Additional conversions between landfill gas to electricity projects, to RNG projects may occur in Michigan depending on public policy – RFS, D3-RIN's, eRINs, LCFS Greet 4.0, etc.
- Average gas collection at MI's 56 largest landfills:
  - ~2,500 scfm landfill gas collection, 50% average methane concentration, or 12,000 metric tons/year of methane captured at average large landfill in Michigan

Federal Regulation: Landfill Gas Collection

Historically, federal regulations have driven both LFG collection system design *and* operations — virtually all MSW landfill gas collection systems are designed in accordance with and operated to meet regulatory requirements

System Design

- Collection well spacing — maximum 200 ft radius spacing
- Timelines required to expand collection system — 2 years after waste at final grade

System Operations

- Surface Emissions — system must operate to keep methane emissions below 500 ppm as measured once per quarter
- Individual collection well measurement/tuning once per month
- Must be under negative pressure at all times
- Below threshold landfill gas temp
- Below threshold O_2 concentration

Landfill Gas Collection: Current Performance

- Nationally, MSW landfill gas collection is ~58% and industry-estimated collection efficiency is 76% (per EPA and EPA GHG reporting database, respectively)

- Currently no direct measurement of LFG collection system efficiency — which requires a model for how much methane is generated — and no direct measurement of emissions
  - Landfill gas collection system efficiency and landfill methane emissions are subject to disagreement

- Direct measurement of methane emissions is emerging — emissions from landfills in the future will be measured, not estimated with LandGEM or other methane generation models

Current Performance (continued)

- Whether collection efficiency is assumed to be 58% or 76%, there is room for improvement
  - Increasing value for "bio-gas to energy" and the value/ton of CO_2e emission reduction

- **Bottom line: Gas Collection System design or operation to meet regulatory requirements does not equate to maximizing resource recovery and minimizing emissions from landfills**

Leveraging Technology to Improve LFG Collection

"The landfill gas to energy industry, especially RNG, has made significant investments in downstream processing of landfill gas, including real-time data and control technology to improve operations — but as an industry, we have made little investment to leverage technology and improve landfill gas collection..."

Steve Gabrielle
Partner, Energy Power Partners
2017 RNG Annual Conference
(paraphrased)

Emerging Value Proposition for the MSW and Landfill Gas to Energy Sector

Reducing methane emissions is the single most important near-term priority, in the U.S. and globally, to slow the rate of global warming

United Nations IPCC, June 2021

- Reducing methane emissions by 1/2 over the next 10 years is the #1 priority to slow the rate of global warming

Global Methane Pledge, November 2021

- Rapidly reducing methane emissions from energy, agriculture, and waste can achieve near-term gains in our efforts in this decade for decisive action and is regarded as the single most effective strategy to keep the goal of limiting warming to 1.5˚C within reach while yielding co-benefits including improving public health and agricultural productivity
- Since November 2021, **150 countries** have "pledged" to take voluntary actions to contribute to a collective effort to reduce global methane emissions by at least 30% from 2020 levels by 2030, which could eliminate over 0.2˚C warming by 2050

Maximizing Methane Capture & Reducing Emissions

- A shift from regulatory drivers to maximum resource recovery and emission reduction
  - Aligns with MSW brands and values
  - Supports stakeholder goals
  - Is consistent with financial market drivers: ESG
  - Creates significant new sources of value and compelling financial returns
  - Maximizes returns to both landfills and landfill gas to energy owners/operators from "downstream" landfill gas to energy projects.

- Leveraging real-time data and new control technology — the critical next step

Financial Impact of Current LFG Collection System Efficiency — Michigan Landfill Gas to Energy Industry

- 41 operational projects, 56 large MSW landfills in MI
  - Average MMBTU methane captured per landfill = 1,820 MMBTU/day
  - Average MMBTU captured at largest 56 landfills = 37.2 million MMBTU/year
  - Value to MSW and LFGE sector at $20/MMBTU assumed (D3 RINs, LCFS, eRINs, etc.) = $745M/year
  - **Value of lost revenue from landfill collection system efficiency of 58–75% = $235M–$540M/year**

- Estimated emissions from 56 largest MI MSW landfills:
  - Average methane captured/year = 12,000 metric tons/project
  - Estimated tons of methane emissions/landfill = 3,400—7,800 tons/year, per project

- Based on CO_2 equivalent (CO_2e) emissions over 100-year global warming potential (GWP) of methane
  - 95,000–220,000 metric tons of CO_2e/project = 5.3—12.6 million tons/year CO_2e
  - Estimated CO_2e emissions over 20-year GWP = 16–37 million tons/year

Financial Impact of Current LFG Collection System Efficiency — Michigan Landfill Gas to Energy Industry

- Financial opportunity in MI to reduce landfill emissions = $265M–$1.8B/year
  - $51/ton assumed "price" on CO_2e emission reduction
    - (U.S. Federal Government = $51/ton; CA LCFS = $65/ton or LCFS = $120/ton; Voluntary Carbon Credit market = $10/ton)

- **Value of increasing methane capture and emission reduction will exceed total value of LFG to Energy industry**

- The solution? **Shift paradigm from gas collection to meet regulatory standards, to gas collection to maximize methane capture and emission reduction**

Paradigm Shift

Leveraging data and technology to enhance methane recovery

Liquid Management

- Real-time data on liquid levels in collection wells
- Improved performance/reliability of sub-surface pumps — liquids lifting
- Timely and complete removal of leachate from collection system
- Evaporation to compliment leachate disposal

Sub-Surface Characterization

- To optimize collection well placement
- Down-space collectors from regulatory required 200 ft. radius spacing

Paradigm Shift (continued)

Installation Speed

- Drilling/completing collection wells as soon as possible
- Not waiting until 2 years for landfill to be at final grade, which is currently permissible by regulations

Operational Speed

- Improving landfill cover integrity to reduce surface permeability

Real-Time Response

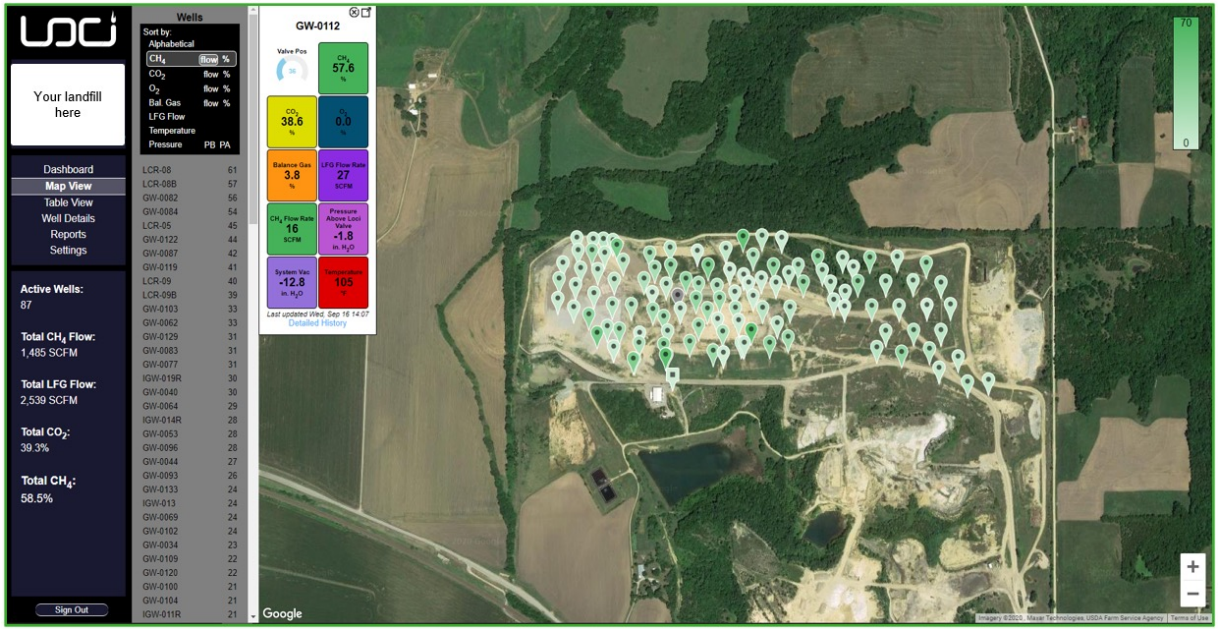
- Measure landfill methane emissions in real-time and at required resolution
- Results in rapid response by landfill gas control and collection operations

Real-Time Data & Control System

WellWatcher® Platform

Cloud-connected online platform and user interface displays live data from each well and allows users to access historical data

Actionable insights with trending tools, spatial visualizations, and on-demand response and project support from anywhere through its online real-time accessibility



Features include:

- 24/7/365 remote visibility on LFG operations
- Accessible via desktop, laptop, and tablet
- Visual trending
- Proprietary algorithms

Benefits for Landfills

- Increased safety, with fewer manhours spent in wellfield
  - Fewer environmental, health, and safety risks for on-site technicians and surrounding communities
- More empowered and effective on-site personnel
  - Rapid troubleshooting of gas collection system challenges
- Greater insight into well and infrastructure health
  - Helps streamline maintenance and improvement planning
- Reduced emissions and emissions exceedances
- Reduced risk of sub-surface thermal events (third-party study)

Monetizing Emission Reduction: Using Real-Time Data & Control Technology at Regulated Landfills

Voluntary Carbon Credits Overview

- LoCI worked with the American Carbon Registry (ACR) from 2019–2021 to create a new, first of its kind carbon credit standard to generate Voluntary Carbon Credits (VCC) at regulated landfills
  - Based on emission reduction results from leveraging LoCI's real-time data and control system
  - Learn more via ACR: Landfill Gas Destruction and Beneficial Use Projects
- Developed a peer reviewed methodology to calculate emission reduction benefits from LoCI's system
- Before LoCI began operations, three years of data was used to establish historical performance of the gas collection system at landfills
  - Leveraged public data in the EPA Greenhouse Gas reporting system

LoCI's Recent VCC Projects & Looking Ahead

- LoCI's first two VCC projects have been validated; carbon credits were verified for the first six months of operation
- Projects saw a 20% and 13% increase in gas collection with LoCI, per the ACR standard, over the first six months of operation
- VCCs are estimated to be worth $10/metric ton CO_2e in the current market
  - Demand is expected to increase in the future, especially for projects that reduce methane emissions

Annualized value for these two projects = $750,000 per year of new revenue linked directly to emission reduction through use of real-time data and control technology

What's Next for the Solid Waste to Energy Industry?

- Leverage real-time data and control technology to maximize resource recovery and reduce emissions from landfills
- Add value to downstream landfill gas to energy projects
- Increase safety, reduce risks, and add value to landfill gas collection operations

Thank you!

PETER QUIGLEY
CEO/Chairman
Phone: (508) 728-4426
Email: peter@locicontrols.com

LOCI CONTROLS
Corporate Office
14 Kendrick Rd, Suite 2
Wareham, MA 02571
Email: sales@locicontrols.com

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