RENEWABLE NATURAL GAS

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PRESENTATION OVERVIEW

- Introduction
- Bio-Gas 101
- Landfill Gas Collection
- Bio-Gas Treatment
- US Bio-Gas Overview
- Renewable Identification Numbers (RINs)
- California Low Carbon Fuel Standard (LCFS)
- Case Studies
- Questions

INTRODUCTION

Municipal solid waste (MSW) landfills are one of the largest sources of human-related methane emissions in the United States. Other sources of bio-gas include wastewater treatment facilities and anaerobic digesters.

Methane which is lighter than air is a potent greenhouse gas 21 times more effective than CO_2 at trapping heat in the atmosphere.

BIO-GAS 101

- Landfill gas is formed as a by product of the decomposition of municipal solid waste
- Comprised of approximately 50% methane, 45% carbon dioxide, 3% nitrogen, 1% oxygen, 1% non methane organics
- Contains approximately $\frac{1}{2}$ of the heating value of natural gas or ~520 BTU/ft^3 **(natural gas ~ 1,020)**
- Most landfills will produce landfill gas for 15-20+ years

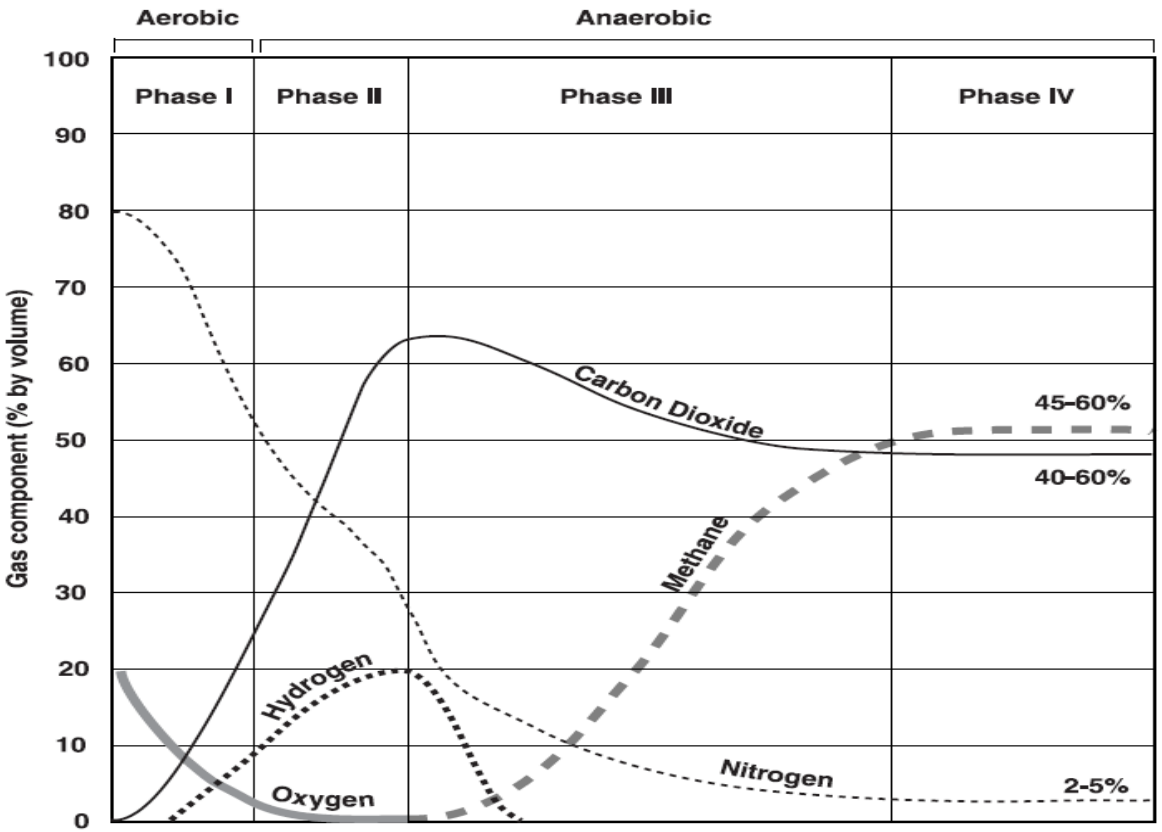
BIO-GAS 101

How is landfill gas produced?

Three processes—bacterial decomposition, volatilization, and chemical reactions—form landfill gas.

- ***Bacterial decomposition.*** Most landfill gas is produced by bacterial decomposition, which occurs when organic waste is broken down by bacteria naturally present in the waste and in the soil used to cover the landfill. Organic wastes include food, garden waste, street sweepings, textiles, and wood and paper products. Bacteria decompose organic waste in four phases, and the composition of the gas changes during each phase.
- ***Volatilization.*** Landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or a solid into a vapor. This process is known as volatilization. NMOCs in landfill gas may be the result of volatilization of certain chemicals disposed of in the landfill.
- ***Chemical reactions.*** Landfill gas, including NMOCs, can be created by the reactions of certain chemicals present in waste. For example, if chlorine bleach and ammonia come into contact with each other within the landfill, a harmful gas is produced.

BIO-GAS 101



Note: Phase duration time varies with landfill conditions

Source: EPA 1997

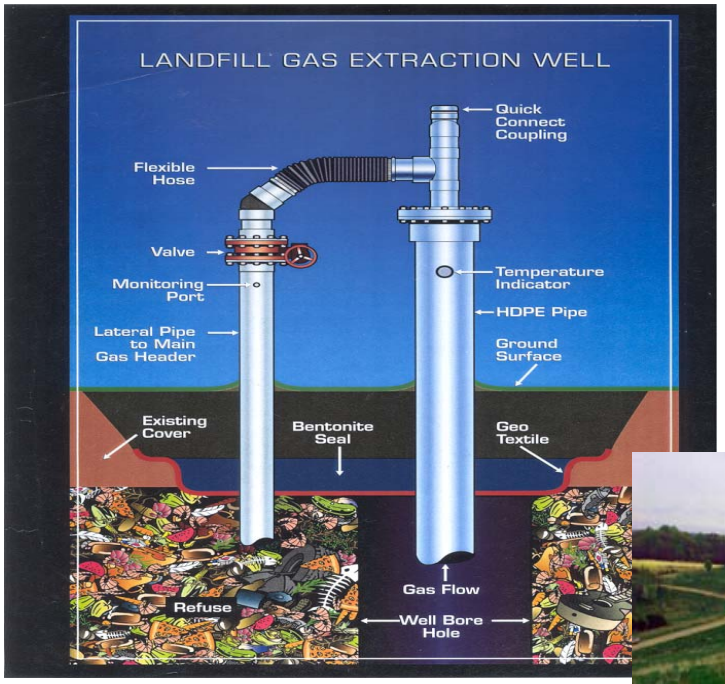
BIO-GAS 101

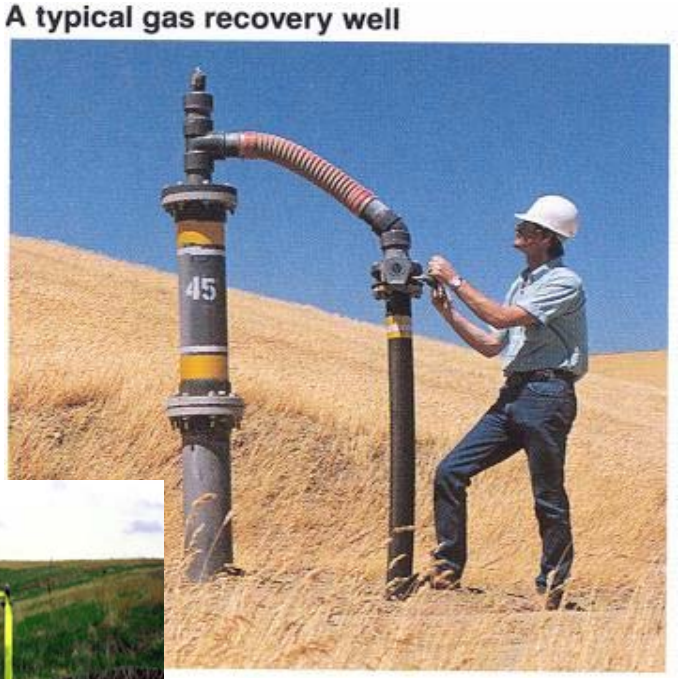
- Municipal wastewater treatment plants configured with anaerobic (vs. aerobic) treatment systems produce large quantities of bio-gas especially those taking in whey wastes. These facilities have historically seen limited beneficial recovery.

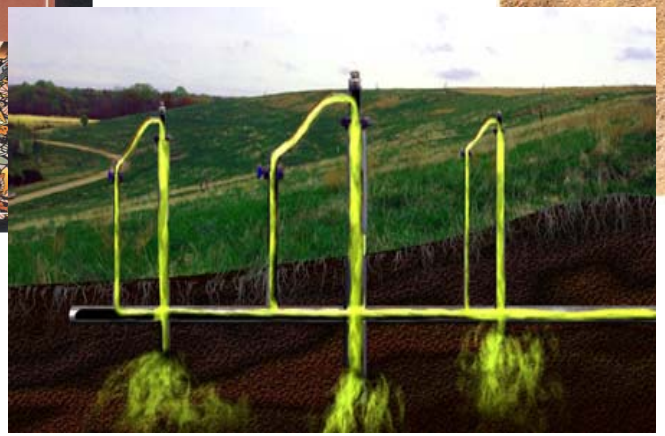
- Anaerobic digesters similar to WWTPs also produce large quantities of bio-gas and have historically almost all traditionally utilized the gas to produce electricity (and heat). Many of these facilities are co-located on dairy farms as manure provides an excellent substrate.

- Digester gas typically contains a higher methane content than landfill gas and also has less undesirable contents.

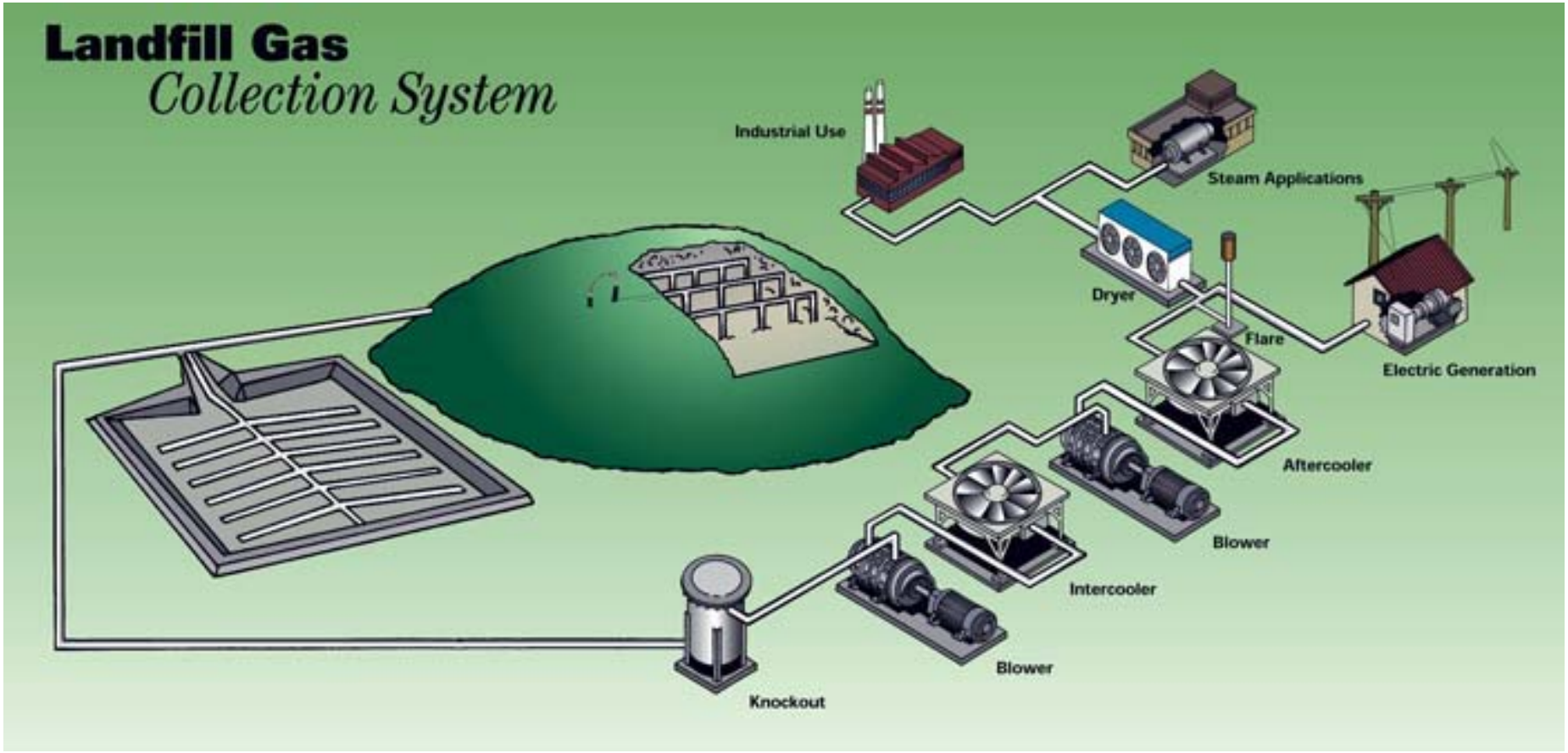
LANDFILL GAS COLLECTION







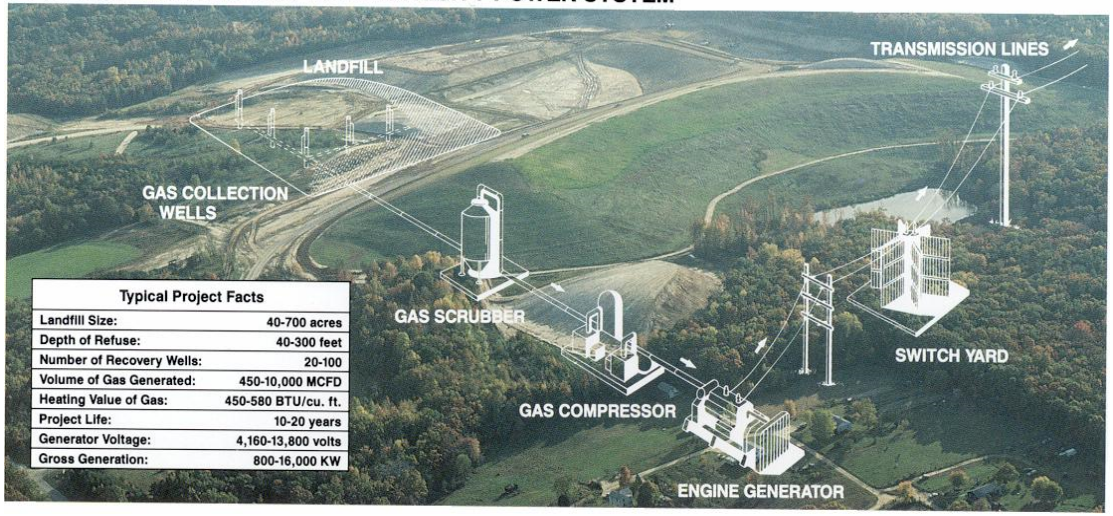
LANDFILL COLLECTION



LANDFILL GAS 101

- Landfill gas is an extremely effective and reliable fuel when used to produce electricity using turbines or reciprocating engines
- Landfill gas can also directly be used to fuel boilers or furnaces

A TYPICAL LANDFILL GAS-TO-ELECTRICITY POWER SYSTEM



Typical Project Facts	
Landfill Size:	40-700 acres
Depth of Refuse:	40-300 feet
Number of Recovery Wells:	20-100
Volume of Gas Generated:	450-10,000 MCFD
Heating Value of Gas:	450-580 BTU/cu. ft.
Project Life:	10-20 years
Generator Voltage:	4,160-13,800 volts
Gross Generation:	800-16,000 KW

INFLUENCING BIO-GAS FACTORS

- Waste Composition – organic waste is the main fuel
- Oxygen in the Landfill – not good for high quality gas
- Moisture Content – moisture encourages bacterial growth
- Temperature – warmer temperatures increase gas production
- Age of Refuse – more recently buried waste will produce more gas; peaks 5 -7 years after disposal; 20 -30 years following landfill closure

WM's Monroe Livingston Landfill (Scottsville, NY)- Placed on line in 1998

OTHER INFLUENCING FACTORS

❑ **Regulatory**

- Landfill owners are required under the Clean Air Act to capture and control landfill gas.
- States are beginning to ban food waste disposal into landfills (VT, MA, DE)….will NY be next?
- Compliance markets exist where air emission credits are actively traded

❑ **Corporate Responsibility**

- WalMart, Yahoo, Google, Amazon, etc. voluntary purchasing

❑ **Community Acceptance** (NIMBY, NIMROW, etc.)

❑ **Logistics**

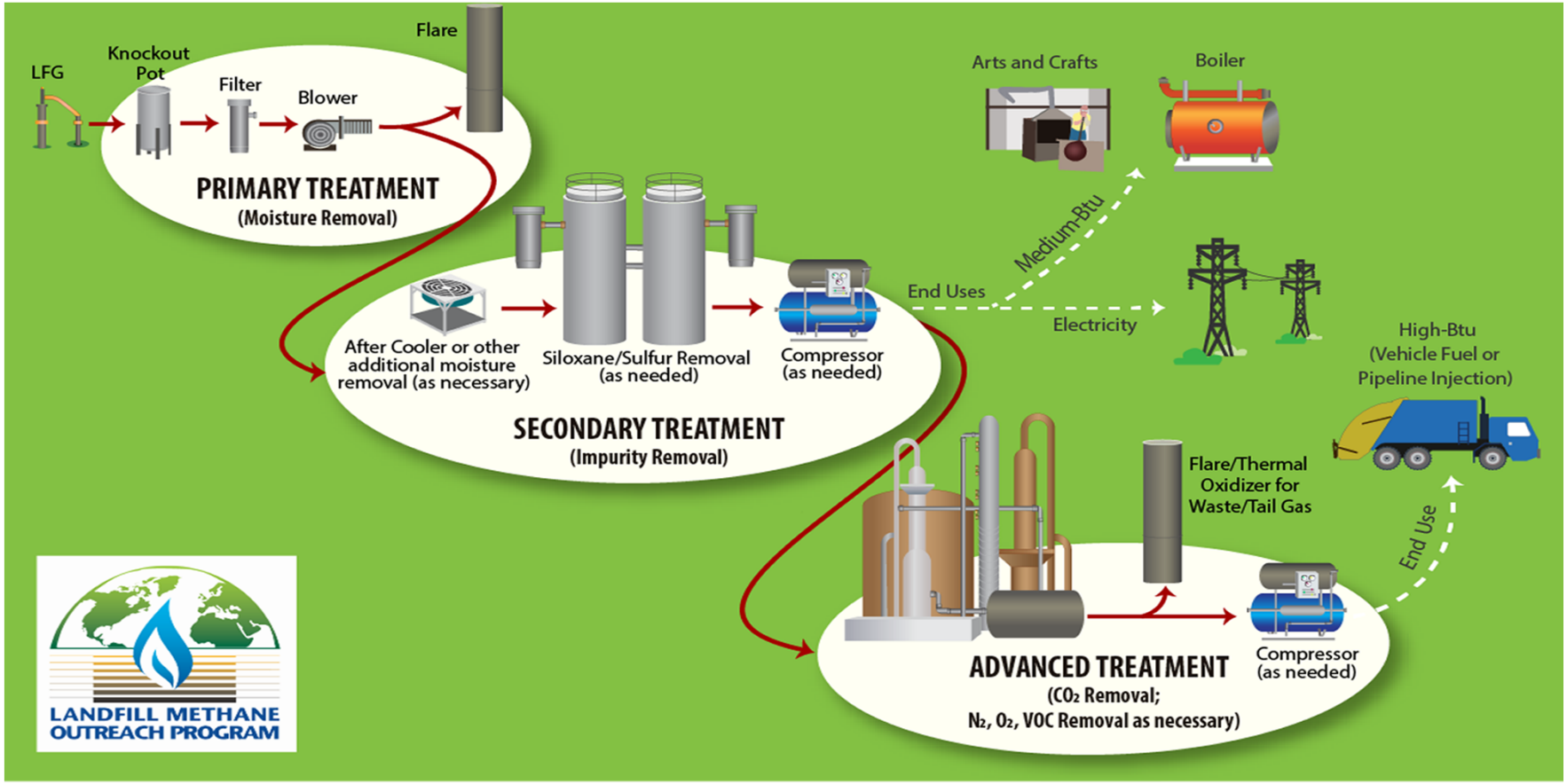
- Utility interconnections

BIO-GAS TREATMENT

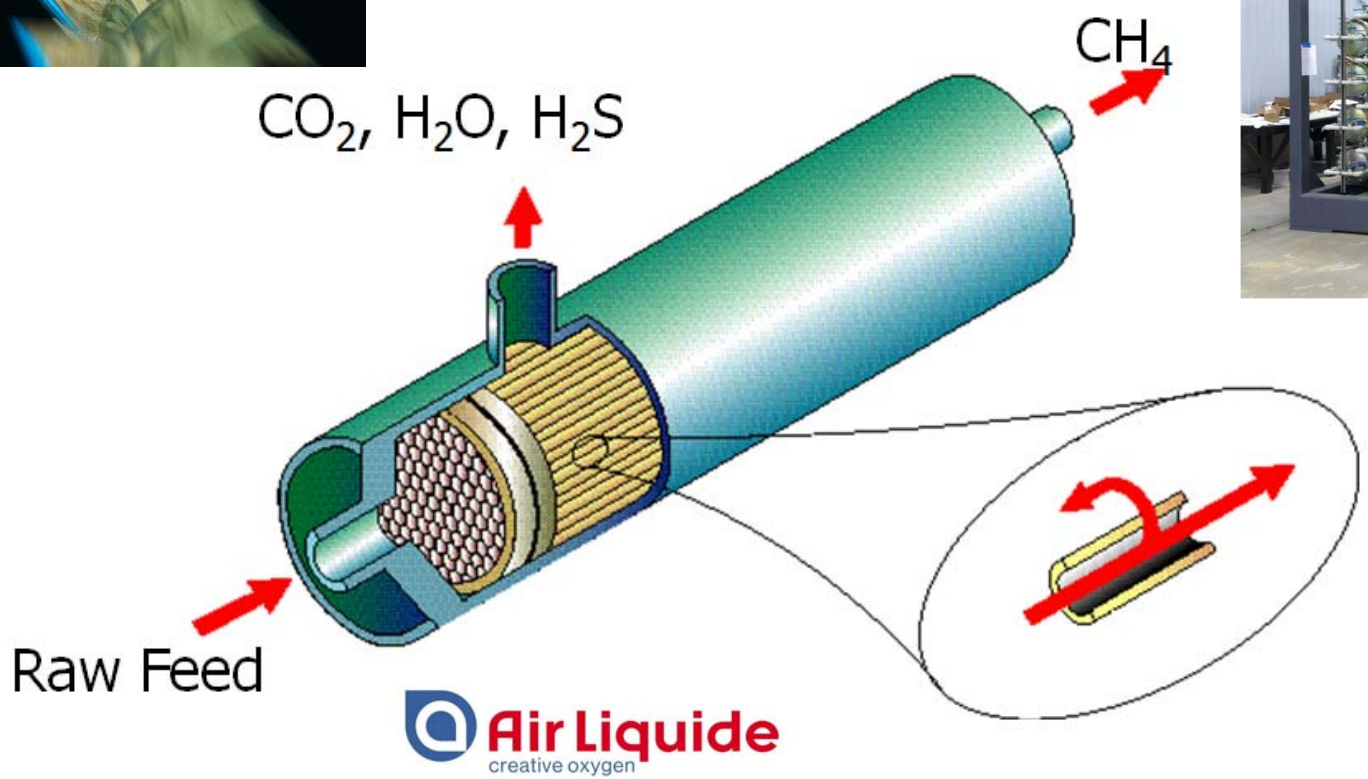
Upgrading landfill gas to high BTU gas requires the almost complete removal of all compounds other than methane. This requirement necessitates removal of the following components from a landfill gas stream:

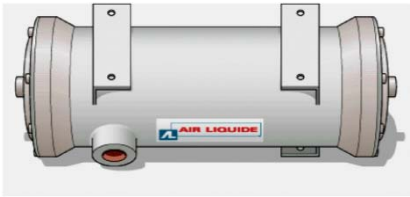
- Hydrogen Sulfide (H_2S)
- Carbon Dioxide (CO_2)
- NMOC (non methane organic hydrocarbons)
- Chlorinated Hydrocarbons
- Fluorinated Hydrocarbon
- Siloxanes **(from cosmetics, detergents, paper coatings, textiles)**
- Nitrogen (N_2)
- Oxygen (O_2)
- Moisture (H_2O)

BIO-GAS TREATMENT

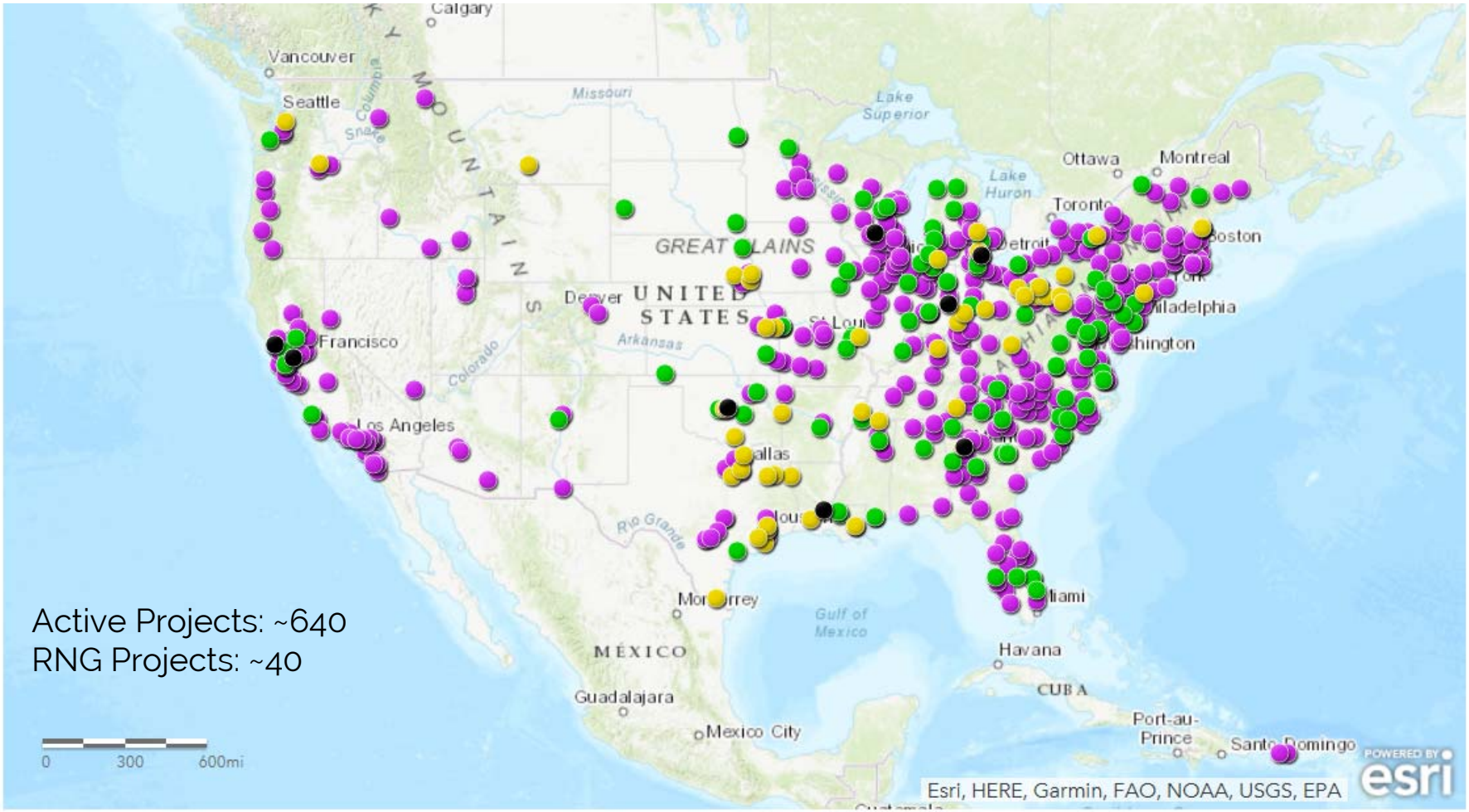


REMOVING CO_2 FROM BIO-GAS

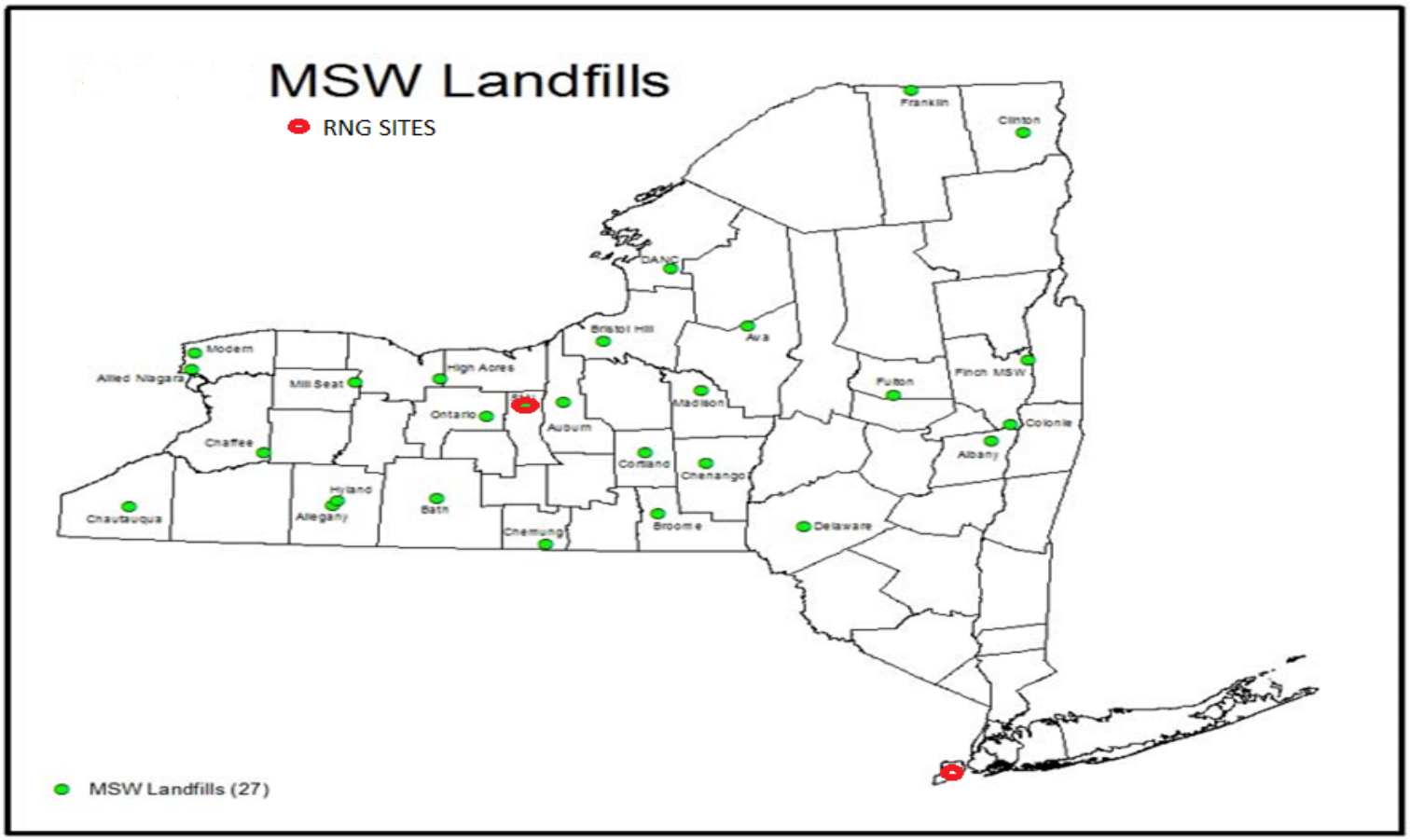




EXISTING US LFG PROJECTS



LANDFILLS IN NYS



EXISTING US WWTP PROJECTS

EXISTING US DIGESTER PROJECTS

US BIO-GAS MARKET POTENTIAL

- Nationwide there are over 2,400 Municipal Solid Waste (MSW) Landfills. The EPA states there is an additional 470 sites that are good candidates for LFG projects.

- Nationwide there are over 17,000 wastewater treatment facilities. Only ~1,200 wastewater treatment facilities have either anaerobic digesters onsite or send their waste to an alternate location for aggregation and digestion.

- Bio-gas recovery systems are technically feasible at over 8,000 large dairy and hog operations in the U.S. There are only ~275 agricultural operational anaerobic digesters on line.

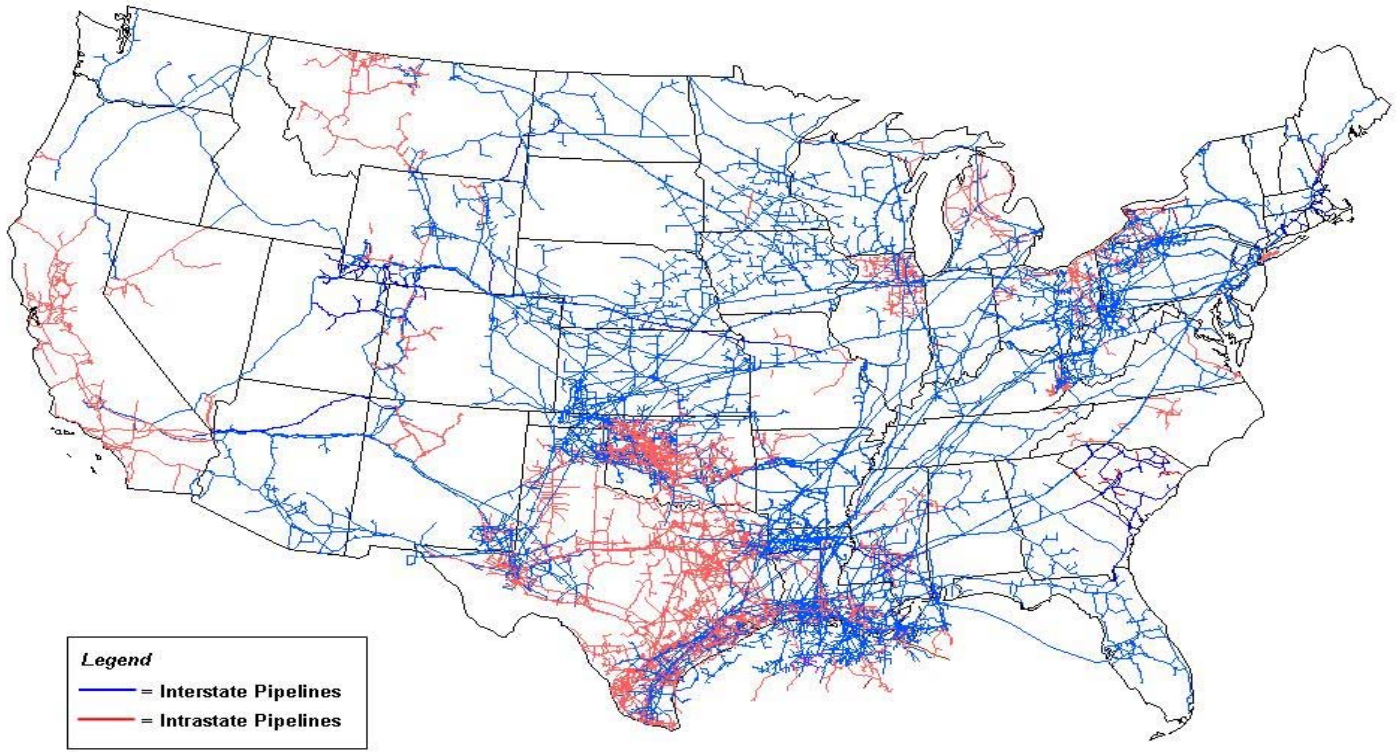
US BIO-GAS MARKET POTENTIAL

NREL Estimate of Anaerobic Digestion Biogas Potential

Source	Methane Potential (thousand tons/year)	Methane Potential (bcf/year)
Landfills	10,586	500.8
WWTP (wastewater treatment plant)	2,339	110.7
Animal Manure	1,905	90.1
IIC (industrial, institutional, and commercial) Organic Waste	1,158	54.8
Total	15,988	756.4

Source: NREL

US NATURAL GAS PIPELINES



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

RENEWABLE FUEL STANDARD

- Implemented in 2005 by the EPA to reduce greenhouse gas emissions, the Renewable Fuel Standard (RFS) requires transportation fuel to contain a minimum volume of renewable fuels. RFS mandates specific Renewable Volume obligations (RVOs) each year that must be blended into transport fuels.

- The EPA expanded the RFS in 2007 (RFS2) to 36 Billion gallons of renewable fuel annually by 2022.

- Compliance with the RFS can be accomplished with RINs that are generated from cellulosic biomass through the conversion of animal waste to energy are worth more (under what is known as a "D" rating system) than RNG produced from food waste. This is also the case with RNG produced from landfill gas.

- RNG from waste digesters qualifies as an advanced biofuel which is not as valuable as cellulosic biofuels (e.g., animal waste).

- The EPA has determined that each type of RIN must be compared to another through a comparison of its fuel value per unit volume to that of pure liquid ethanol fuel. Each gallon of ethanol has about 77,000 Btu (or 0.077 MMBTU), which is thus the definition of a RIN.

RENEWABLE IDENTIFICATION NUMBERS

- The premise behind RNG is that all natural gas regardless of its composition, emits the same amount of greenhouse gases (GHG) when combusted.

- Since the climate impact of methane is greater than that of carbon dioxide, reductions in waste related methane emissions yields a reduction in GHGs when the resulting bio-gas is combusted in place of natural gas wherein the bio-gas would otherwise be emitted or flared to the atmosphere.

- The RIN (Renewable Identification Numbers) system allows EPA to monitor compliance with the RFS and was created to track RFS compliance of obligated parties. A physical and contractual pathway are necessary in order to obtain EPA approval.

- A RIN is a 38-character number assigned to each physical gallon of renewable fuel produced or imported. Obligated parties that produce or own RINs must register with EPA and comply with RIN record and reporting guidelines.

RENEWABLE IDENTIFICATION NUMBERS

RINs are the "currency" of the RFS program

- Serial number attached to each gallon of renewable fuel
- Renewable fuel producers **generate** RINs
- Registered Market participants **trade** RINs
- **Obligated Parties obtain and retire** RINs for compliance (Refiners and Importers of gasoline/diesel are obligated parties)
- **EPA Moderated Transaction System (EMTS)** is the clearinghouse for RIN transactions registered with the EPA
- RINs are valued in $/Gallon*

There are several D Code RINs:

- D6 – Conventional RIN
- D5 – Advanced Biofuel RIN
- D4 - Biodiesel RIN
- D3 – Cellulosic RIN (Biogas)

*RIN Gallon to MMBtu Conversion:

$/Gallon X 11.727 = $/MMBtu
(1 MMBtu generates 11.727 RINs)

	Renewable Fuel	Advanced Biofuels	Biomass-based Biodiesel	Cellulosic Biofuels
RIN Code	D6	D5	D4	D3
Reduction in GHG Emissions	20%	50%	50%	60%
Feedstock sources	Corn-based Ethanol	Non-corn Feedstock	Biomass Feedstock inc. algae	Cellulose Hemicellulose Lignin

LOW CARBON FUEL STANDARD

- Originally adopted in 2009 and readapted in 2015, the Low Carbon Fuel Standard (LCFS) requires refineries and fuel suppliers in California to reduce the carbon intensity of its transportation fuels ten percent by 2020.

- Transportation fuels must meet an annual carbon intensity target that decreases each year. Refineries and fuel suppliers can meet these targets by mixing in fuels with lower carbon intensity (CI) values into their overall supply or by purchasing credits.

- The EPA resets the Renewable Volume Obligation (RVO) which establishes the number of RINs each obligated party must retire for the following calendar year.

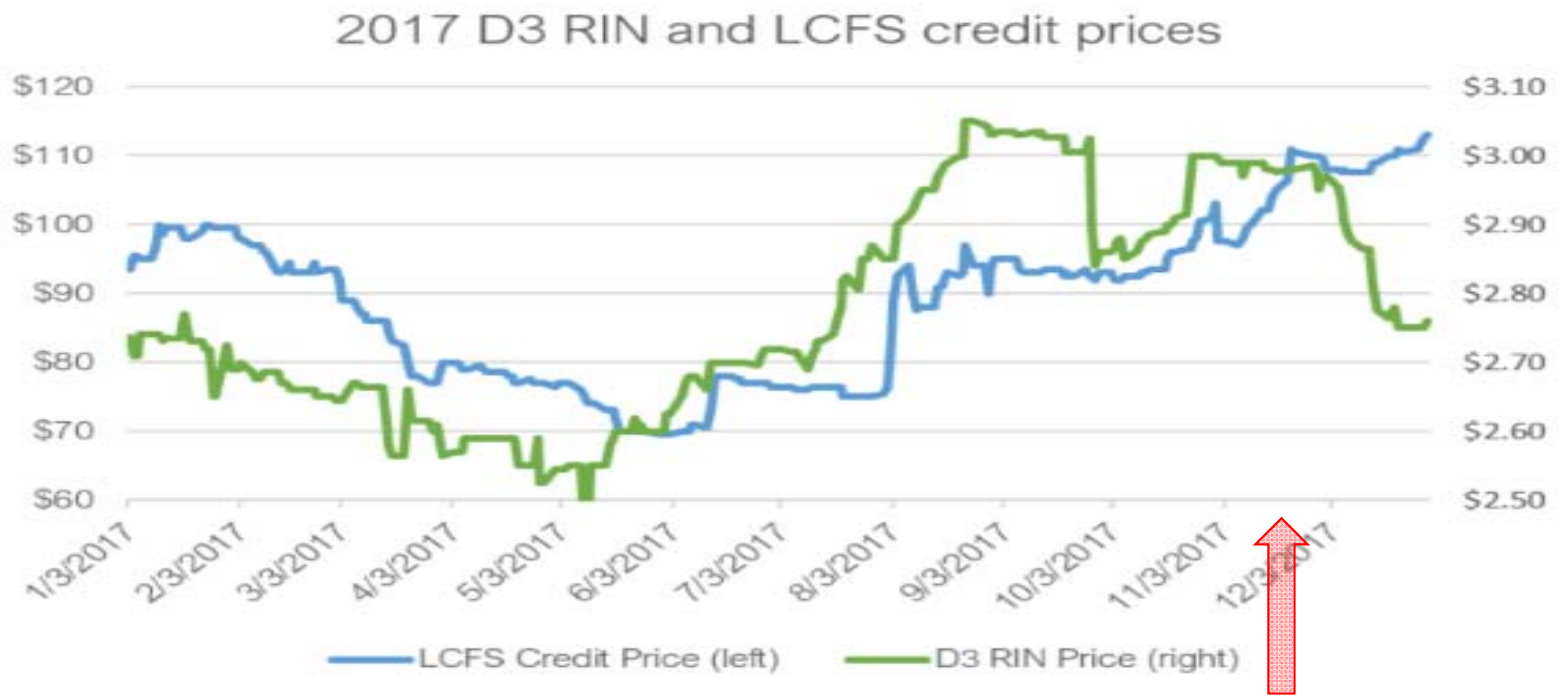
- Fuels with CI values below the target level (based on a lifecycle analysis) are able to generate credits. Under the rule, RNG is considered a low carbon fuel and can generate credits.

California LCFS Carbon Intensities

Gas Source	Carbon Intensity (g CO_2e/MJ)
California Natural Gas (Traditional)	78.37
Landfill Gas	46.42
Dairy Digester Gas	-276.24
Wastewater Treatment	19.34
Municipal Solid Waste (MSW)	-22.93

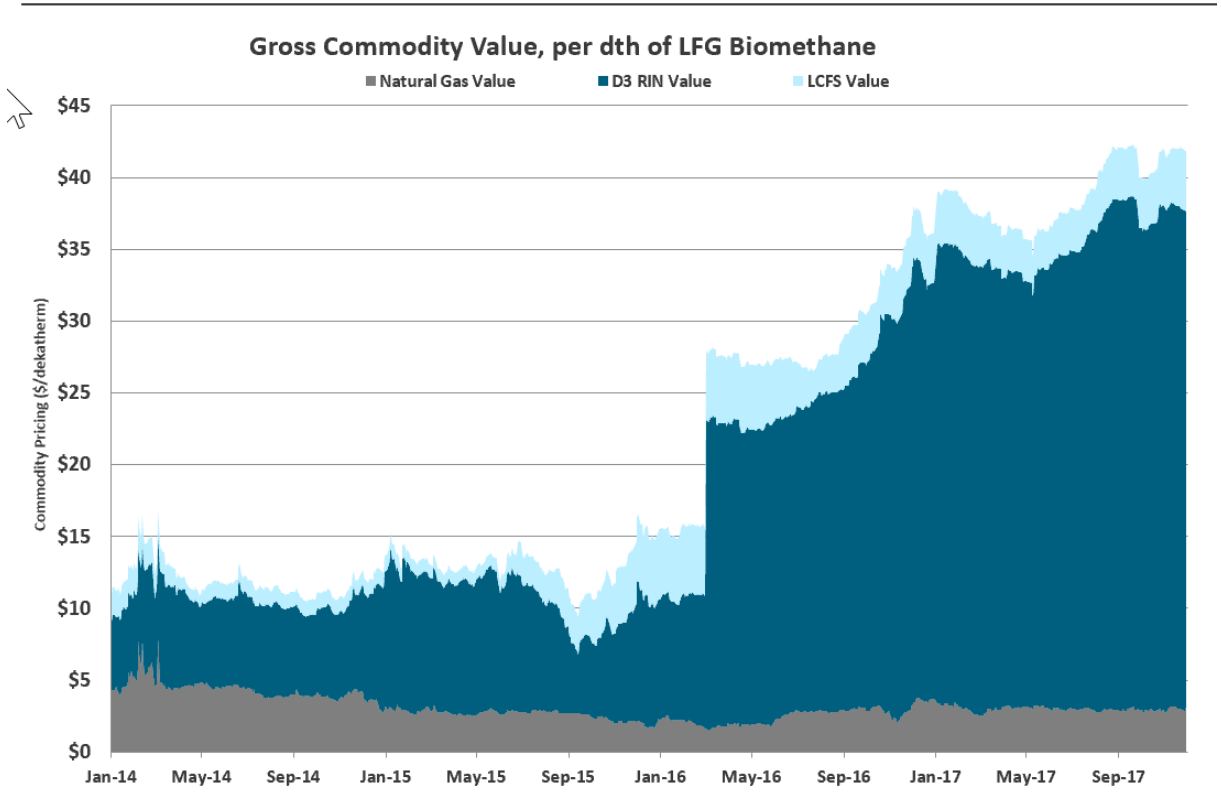
Source: California Air Resources Board

MARKET VOLATILITY



Trump Era Begins

VALUE OF RNG


Gross Commodity Value, per dth of LFG Biomethane
Natural Gas Value
D3 RIN Value
LCFS Value
Commodity Pricing ($/dekatherm)
$45
$40
$35
$30
$25
$20
$15
$10
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Jan-14
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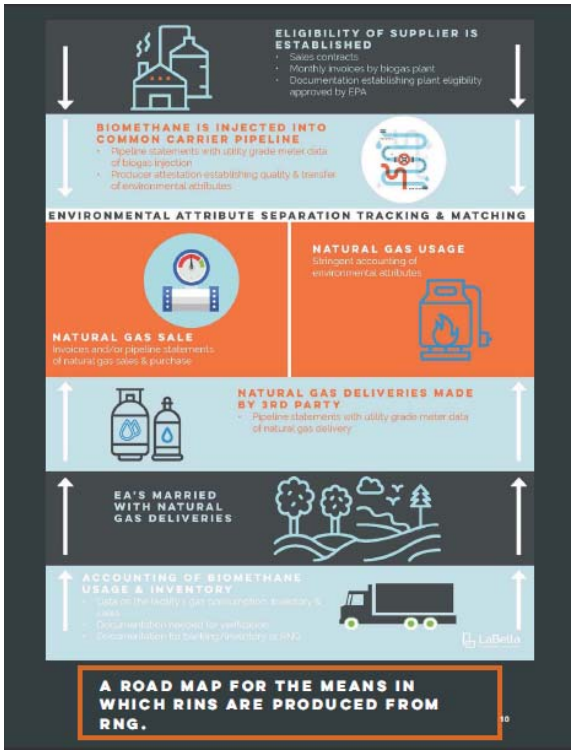
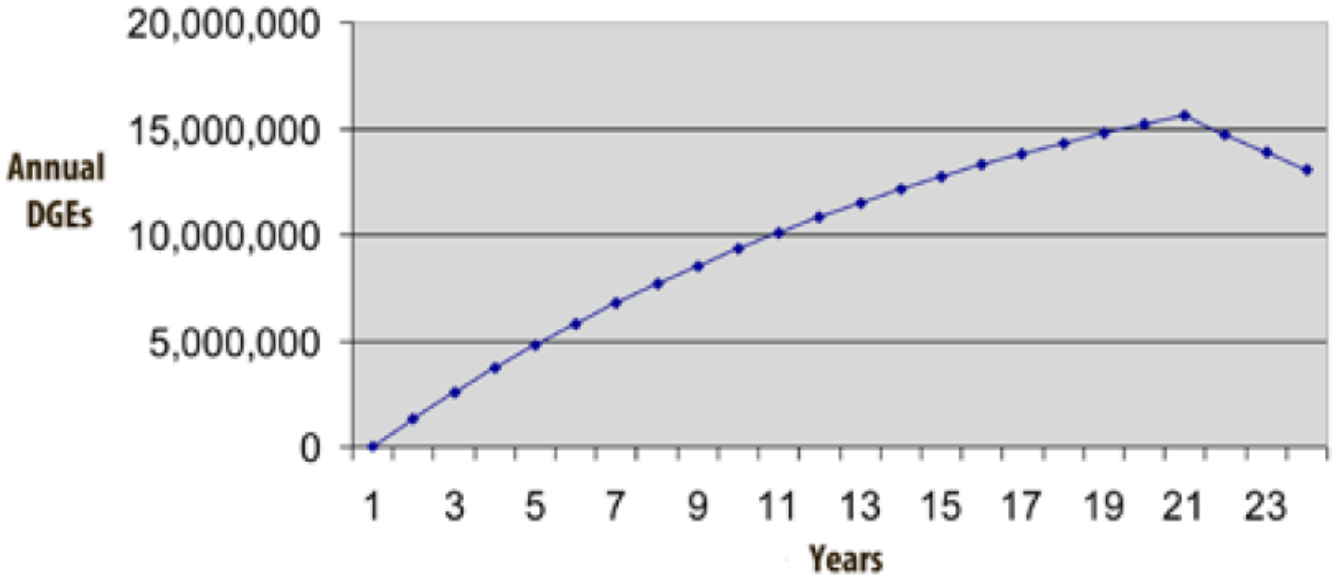

ELIGIBILITY OF SUPPLIER IS ESTABLISHED
Sales contracts
Monthly invoices by biogas plant
Documentation establishing plant eligibility approved by EPA
BIOMETHANE IS INJECTED INTO COMMON CARRIER PIPELINE
Pipeline statements with utility grade meter data of biogas injection
Producer attestation establishing quality & transfer of environmental attributes
ENVIRONMENTAL ATTRIBUTE SEPARATION TRACKING & MATCHING
NATURAL GAS USAGE
Stringent accounting of environmental attributes
NATURAL GAS SALE
Invoices and/or pipeline statements of natural gas sales & purchase
NATURAL GAS DELIVERIES MADE BY 3RD PARTY
Pipeline statements with utility grade meter data of natural gas delivery
EA'S MARRIED WITH NATURAL GAS DELIVERIES
ACCOUNTING OF BIOMETHANE USAGE & INVENTORY
A ROAD MAP FOR THE MEANS IN WHICH RINS ARE PRODUCED FROM RNG.

VALUE OF RNG

ENERGY VISION

How Much Fuel Could A Mid-size City Make from One Million Tons of Mixed Waste per Year?



RNG – PDH QUESTION #1

Q: What is compound is most prevalent in bio-gas?

A: methane (CH_4)

RNG – PDH QUESTION #2

Q: Which gas is more harmful to the environment, methane or carbon dioxide?

A: methane (21x more)

RNG – PDH QUESTION #3

Q: What compound in landfill gas is harmful to engines and boilers?

A: Hydrogen sulfide

CFI – PDH QUESTION #4

Q: What does RIN stand for?

A: Renewable Identification Number

SUMMARY

- RNG projects have grown significantly over the past 5 years
- Existing LFGTE bio-gas projects are being phased out
  - Low power prices in the absence of incentives
  - Ability to utilize more BTUs (LFGTE projects use ~38% of the gas)
- Methane is 21x more harmful of a greenhouse gas that CO_2
- California's Low Carbon Fuel Standard could be a template for other states
- Development involves navigation through a number of regulatory, political, economic and public affair hurdles
- Sizable undeveloped market in the US

CASE STUDIES

- Palmetto Landfill (Spartanburg, SC)
- Seneca Meadows Landfill (Waterloo, NY)
- Outer Loop Landfill (Louisville, KY)

BMW PROJECT

Palmetto Landfill – Spartanburg, SC

Landfill Gas- To-Hydrogen Project Complete At BMW

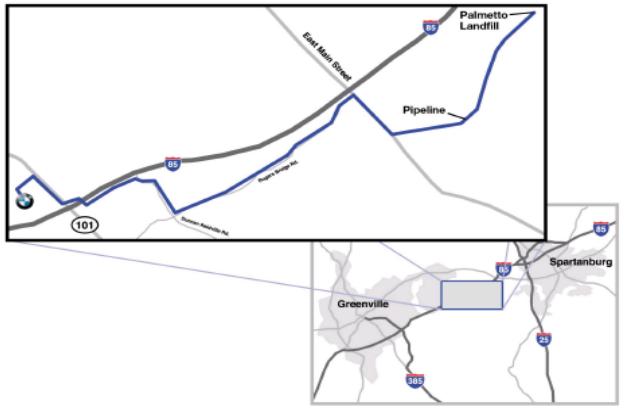
TOPICS: BMW Landfill Gas- To-Hydrogen SCRA

A BMW team member at the BMW Plant in Spartanburg, SC, drives a hydrogen-powered fuel cell material handling train. BMW Manufacturing announced on Wednesday, March 13, 2013 the successful expansion of the company's hydrogen fuel-cell material handling equipment across its 4. million square foot production facility.(File Photo/BMW Manufacturing via newscast)

POSTED BY: SCMFGMAG AUGUST 3, 2015

SCRA today announced the succes
which was conducted at the BMW
facility.

The U.S. Department of Energy (D
feasibility of converting landfill ga
vehicles, including material handl
more than 350 pieces of material h
production facility, all powered by



SENECA MEADOWS PROJECT

Seneca Meadows Landfill – Waterloo, NY

The second of only two facilities in NYS processes up to 6,000 standard cubic feet per minute (SCFM) of incoming landfill gas. This equates to about 2,500 mmbtu per day of RNG, or 50,000 diesel gallon equivalents (DGE) per day. The RNG is injected into Dominion's transmission pipeline and conveyed to California for sales under the LCFS program.

- Complements existing 17 MW LFGTE facility
- Initial localized gas quality issues downstream of the site

OUTER LOOP PROJECT

Outer Loop Landfill – Louisville, KY

The $30M facility processes up to 5,000 standard cubic feet per minute (SCFM) of incoming landfill gas. This equates to about 2,500 mmbtu per day of RNG, or 18,000 diesel gallon equivalents (DGE) per day, enough to fuel about 800 of the company's compressed natural gas (CNG) collection trucks.

- Required fleet upgrade and fueling stations
- Replaced a prior direct sale project

QUESTIONS?

REFERENCES

- *USEPA LMOP Database & Website*
- *USEPA AgStar Database & Website*
- *National Renewable Energy Laboratory Website*
- *American Biogas Council*
- *ATSDR – Landfill Gas Primer – Chapter 2: Landfill Gas Basics; 2001*
- *Energy Vision RNG Community Guide - TURNING WASTE INTO VEHICLE FUEL:*
- *RENEWABLE NATURAL GAS (RNG)*
- *M.J. Bradley & Associates: Renewable Natural Gas – The RNG Opportunity for Natural Gas Utilities, 2017*
- *BP: The Power of Waste – Opportunities for Renewable Natural Gas in NYC, 2018*