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Industrial / Pretreatment
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# Benefits of Digester Gas Scrubbing at the Dayton WWTP

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# Overview

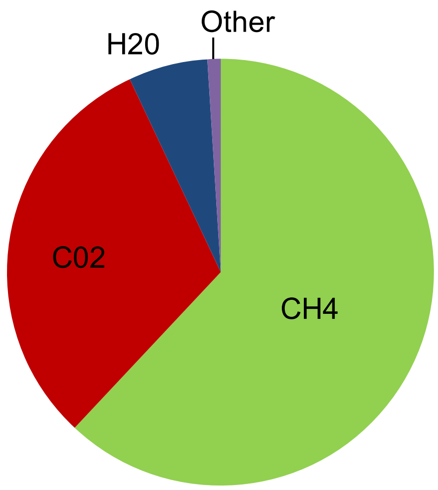
- Composition of Digester Gas
- Undesirable Components and Effects
- Gas Scrubbing Technologies
- Case Study at Dayton WWTP

# Digester Gas

- Gas produced during reduction of organic matter under anaerobic conditions in the Anaerobic Digesters.
- Composed primarily of methane and carbon dioxide.
- Fuel (heat) value of digester gas is typically 550 to 650 BTU/CF.
- Contains lesser quantities of other gases such as hydrogen sulfide, nitrogen, water vapor, and volatile organic compounds (mostly siloxanes).

# Composition of Digester Gas

- Methane, $CH_4$: 60 – 65%
- Carbon dioxide, $CO_2$: 35 – 40%
- Water Vapor, $H_2O$: 1 – 6%
- Nitrogen, $N_2$: <1%
- Hydrogen sulfide, $H_2S$: 100 to 3,000 ppm
- Siloxanes: 100 to 10,000 ppb

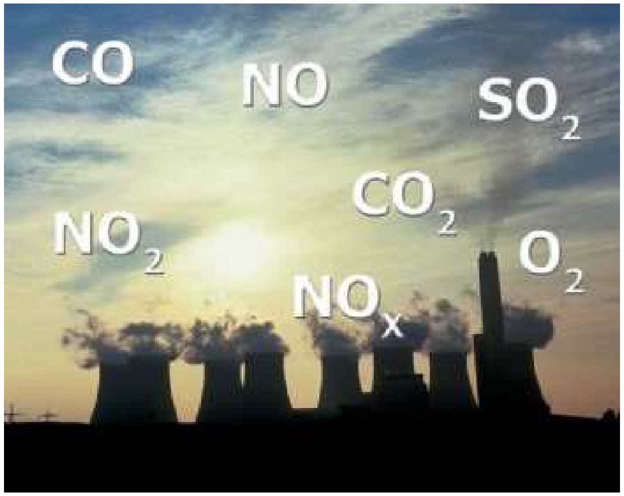



Heat value of methane is approximately 1,000 BTU/CF

# Undesirable Digester Gas Components

- Hydrogen Sulfide
- Siloxanes
- Particulates
- Water Vapor
- Carbon Dioxide
- Nitrogen

# Hydrogen Sulfide and Effects




- Hydrogen Sulfide ($H_2S$) gas when combined with water vapor produces a weak acid:

  *hydrosulfuric acid: $H_2S$ (aq)*

- Corrosive to metals
  - Combustion chamber
  - Intake and exhaust piping
- Produces sulfur compounds during combustion
- Target concentration in feed gas : <100 ppm

# Siloxanes – what are they?

- The word *siloxane* is derived from the words *silicon, oxygen*, and *alkane*.
- They belong to the wider class of organo-silicon volatile organic compounds (VOCs).
- Siloxanes can be found in products such as cosmetics, deordorants, defoamers, toothpaste, water repelling windshield coatings, lubricants, food additives, and soaps.




# Siloxane species

Typical species analyzed for are D3, D4, D5, D6, and total siloxanes.

**SELECTED CYCLIC AND LINEAR ORGANOSILOXANE PROPERTIES**

| Name | Formula | MW | Vapor Pressure mmHg 77° F | Abbreviations | Boiling Point ° F | Water Solubility (mg/l) 25° C |
|---|---|---|---|---|---|---|
| Hexamethylcyclotrisiloxane | $C_{12}H_{18}O_3Si_3$ | 222 | 10 | $D_3$ | 275 | 1.56 |
| Octamethylcyclotetrasiloxane | $C_8H_{24}O_4Si_4$ | 297 | 1.3 | $D_4$ | 348 | 0.056 |
| Decamethylcyclopentasiloxane | $C_{10}H_{30}O_5Si_5$ | 371 | 0.4 | $D_5$ | 412 | 0.017 |
| Dodecamethylcyclohexasiloxane | $C_{12}H_{36}O_6Si_6$ | 445 | 0.02 | $D_6$ | 473 | 0.005 |
| Hexamethyldisiloxane | $C_6H_{18}Si_2O$ | 162 | 31 | $L_2$, MM | 224 | 0.93 |
| Octamethyltrisiloxane | $C_8H_{24}Si_3O_2$ | 236 | 3.9 | $L_3$, MDM | | 0.035 |
| Decamethyltetrasiloxane | $C_{10}H_{30}Si_4O_3$ | 310 | 0.55 | $L_4$, $MD_2M$ | | |
| Dodecamethylpentasiloxane | $C_{12}H_{36}Si_5O_4$ | 384 | 0.07 | $L_5$, $MD_3M$ | | |

## Recommended total siloxane concentrations:

- Reciprocating engines and boilers <100 ppb
- Turbines / Microturbines < 50 ppb

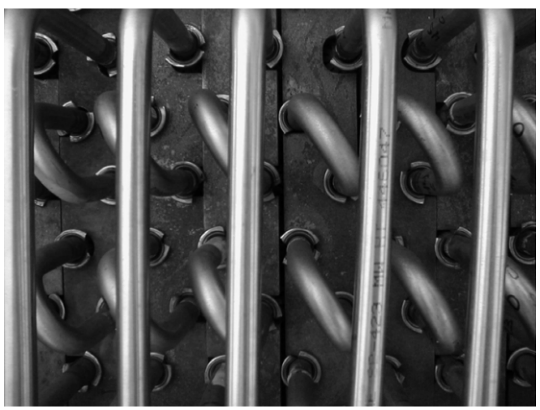
# Effect of Siloxanes

- Siloxanes degrade to silicates ($SiO_2$ & $SiO_3$) at high temperature and create impermeable glass particles. These particles bond onto hot metal surfaces.
  - Reciprocating piston engines – forms deposits and hot spots in the combustion chamber, valves, valve seats, piston crowns and cylinder walls.

Siloxane damage to upper cylinder area and piston

# Effect of Siloxanes

- Boilers – deposits a coating of silicate on boiler tubes that lowers heat transfer efficiency.
- Gas turbines – deposits on turbine blades leading to blade erosion and a significant drop in operating efficiency.


Clean boiler tubes


Siloxane deposits on tubes

# Other Gas Component Effects

- Particulates
  - Form deposits on engine  surfaces and boiler equipment
  - Impact / deposit on turbine blades
- Carbon Dioxide
  - Inert gas, lowers heat value of digester gas
- Water Vapor
  - “Wet” gas forms acids - corrosive to machinery
  - Lowers heat value

# Digester Gas Scrubbing

- Definition – Process of removing one or more undesirable components from a gas stream.
  - Typically targeted at removing hydrogen sulfide ($H_2S$), siloxanes, and particulates.
  - Optional removal of carbon dioxide and water vapor for specific applications.

# Reasons for Gas Scrubbing

- Decrease engine maintenance intervals
- Improve fuel (heat) value
- Improve engine performance – more power!
- Sell gas to utility (pipeline quality)
- Produce compressed natural gas (CNG) for City fleet use
- Happier maintenance staff! 

# Gas Scrubbing Technologies

- Conventional Unit Processes
  - Adsorption (Dry Scrubbing)
  - Wet Scrubbing
  - Refrigeration (a.k.a. Chilling, Dehydration)
- Pressure Swing Adsorption (PSA)
- Other less common methods
  - Cryogenic Separation
  - Membrane Separation

# Gas Scrubbing Technologies

- Relative Cost, Yield, and Purity of Various Methods

| Technique | Cost per CCF to perform ($) | Yield % | Purity % |
|---|---|---|---|
| Chemical Absorption | $1.09 | 90 | 98 |
| High Pressure Water Scrubbing | $0.59 | 94 | 98 |
| Pressure Swing Adsorption | $1.02 | 91 | 98 |
| Cryogenic separation | $1.56 | 98 | 91 |
| Membrane separation | $0.86 | 78 | 89 |

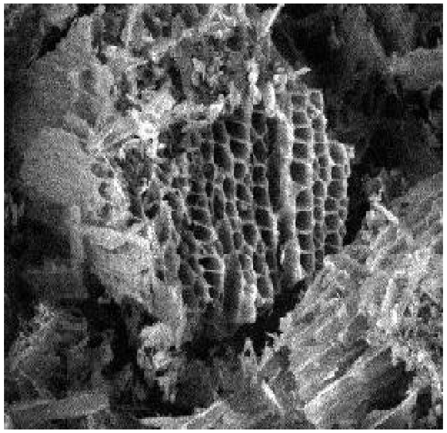
Eindhoven University of Technology, July 3, 2008
(cost converted at €1 = $1.38)

# Chemical Adsorption (Dry Scrubbing)

- Passing gas through adsorption media such as activated carbon, activated alumina, iron sponge, or synthetic resins.
  - Component is adsorbed onto media.
  - Media is either exhausted and replaced or regenerated

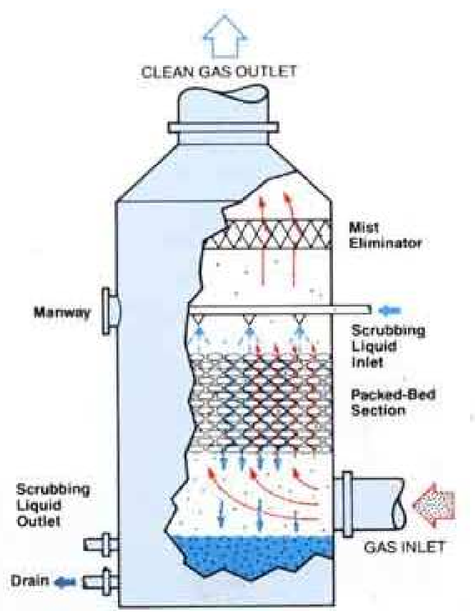
Activated alumina

- Examples:
  - Iron sponge (iron oxide on wood chips) for removing $H_2S$
  - Proprietary adsorbents, e.g. Sulfa-Treat, for $H_2S$
  - Activated carbon or activated alumina for siloxane removal



Activated carbon under electron microscope

# Wet Scrubbing




- A method of passing the gas through water or another liquid medium for the purpose of removing particulates or other gases.

Usage

- $CO_2$ removal – carbon dioxide is soluble in water.
- Particulate removal
- $H_2S$ removal

# Wet Scrubbing

- High-pressure wet scrubbing is the most frequently used method of $CO_2$ removal at WWTPs.
- Requires inlet gas pressure to be raised to 150 psi to 300 psi to increase $C0_2$ solubility.
- $H_2S$ is usually removed upstream to avoid compressor corrosion.
- Process can achieve 98% methane.

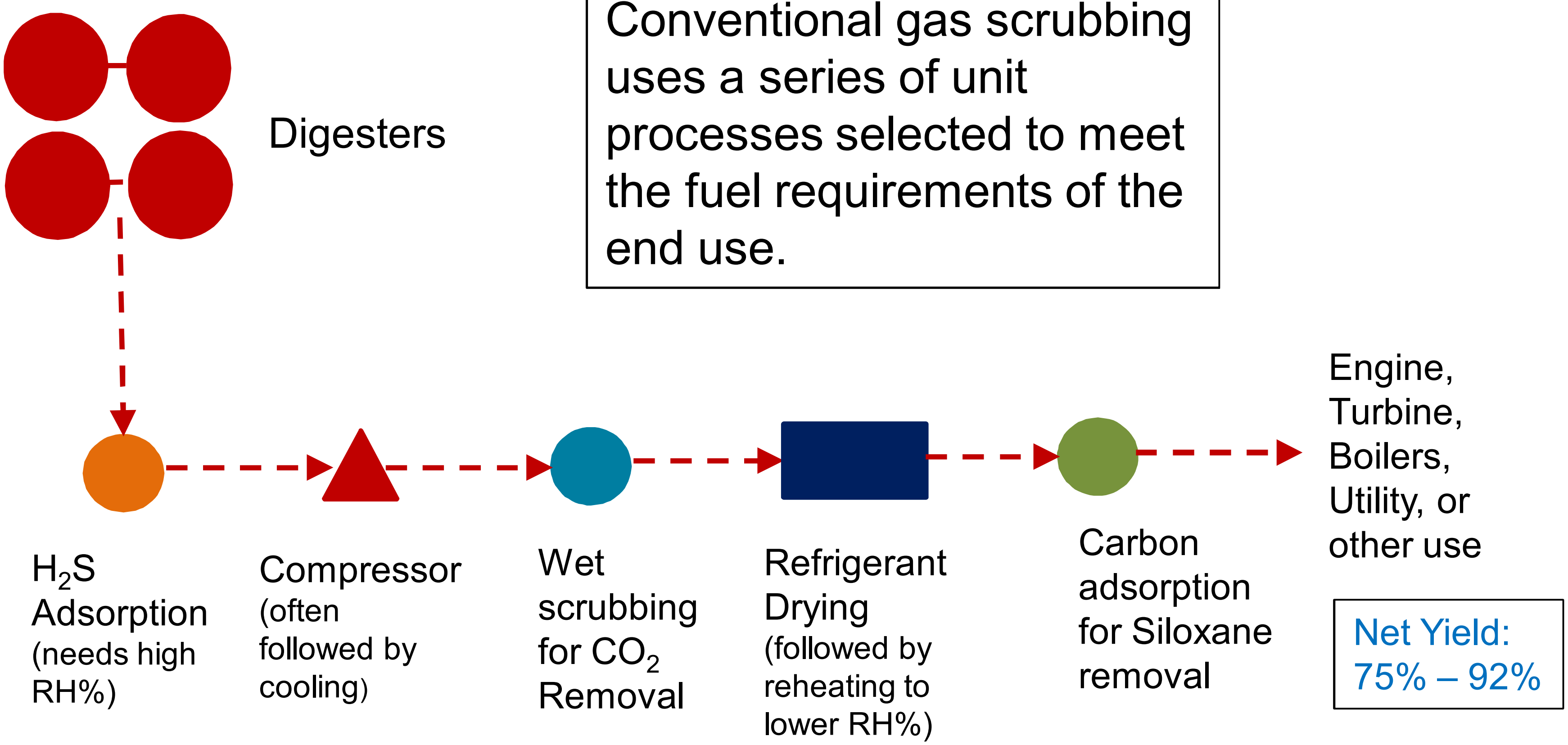
# Refrigeration (Chilling, Dehydration)

- Mechanical refrigeration that removes moisture by lowering the temperature of the gas to condense the water vapor. Other impurities also removed in condensate.

- Removes:
  - Moisture - dewpoint < 40ºF
  - 90 - 100% particulates
  - 70 - 80% siloxanes
  - 20 - 30% $H_2S$

# Typical Unit Process Flow Diagram

Conventional gas scrubbing uses a series of unit processes selected to meet the fuel requirements of the end use.



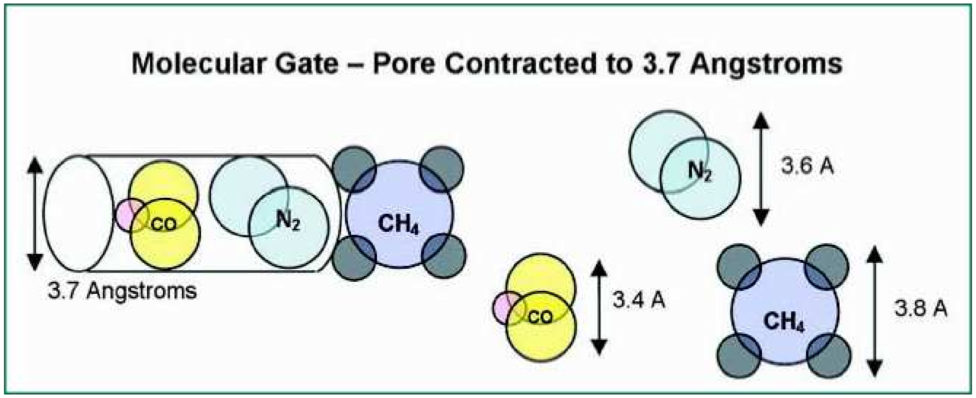
# Pressure Swing Adsorption (PSA)

- A mechanical pressure switching system that rapidly cycles from adsorption to regeneration.
- Regeneration is desorption of the adsorbed material under vacuum conditions.
- Uses molecular sieve media and other medias to allow the passage of methane but adsorb $CO_2$, $H_2S$, and siloxanes.

# Molecular Sieve Media

- Specialized media that traps smaller $CO_2$ and $N_2$ molecules while allowing methane to pass through media.
- Media is capable of rapid adsorption and desorption cycles.

Molecular Sieve Media – Pore Size at 3.7 Angstroms




*Angstrom – length equal to 1 x $10^{-10}$ meter*

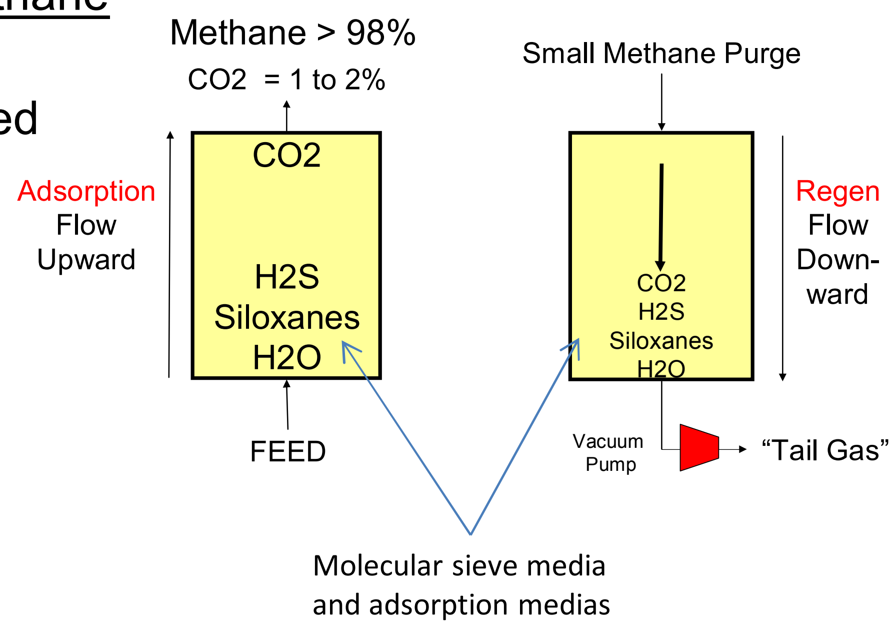
# PSA Cycle Diagram

## Pressure Phase – Adsorb

- Vessel is pressurized
- Feed gas flows upward thru media bed
- Target compounds adsorbed while <u>methane passes thru the bed</u>
- Over time the bed will become saturated

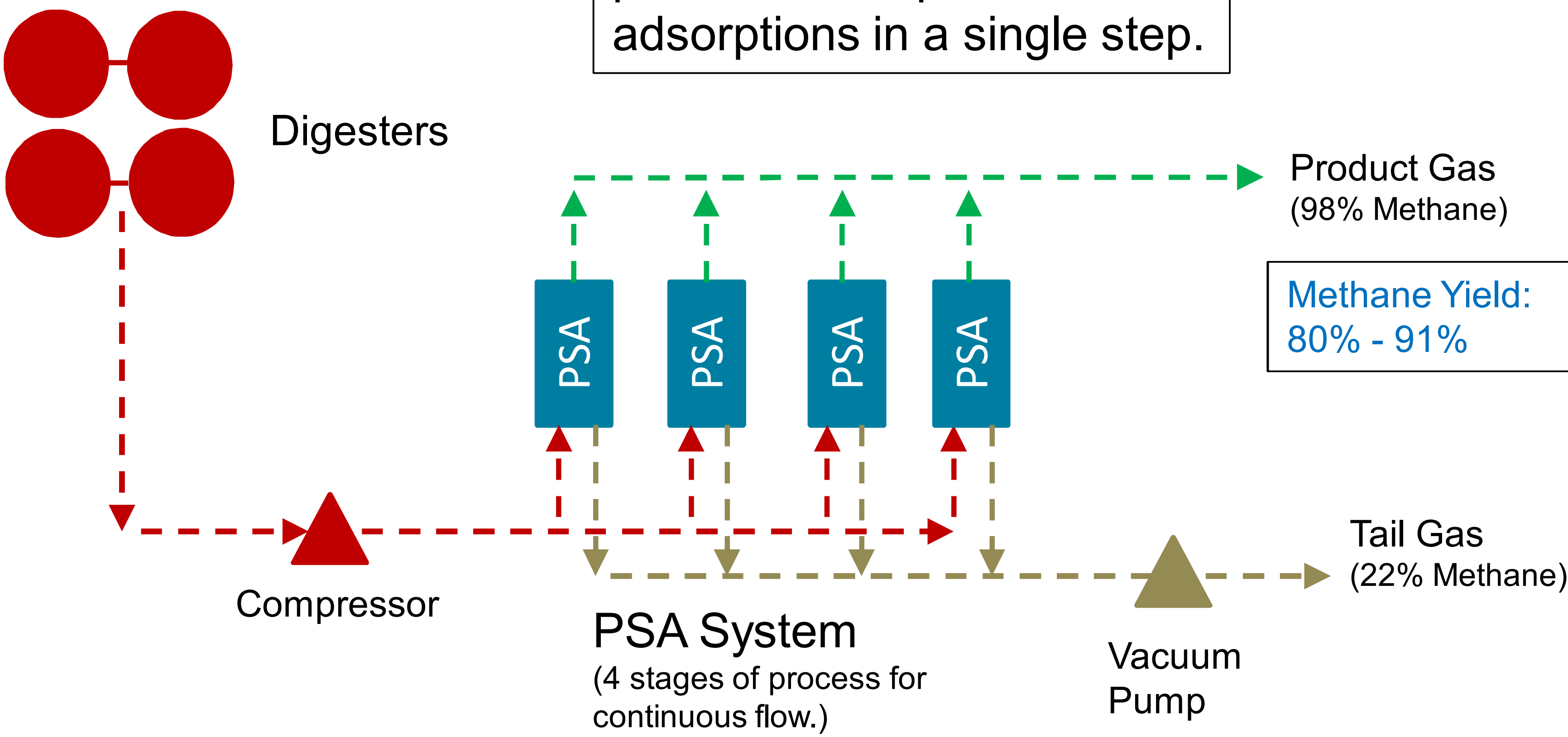
## Vacuum Phase – Regen and Purge

- Vacuum applied to bottom of adsorbent bed
- De-adsorbed compounds extracted as “Tail Gas”
- Methane purge gas applied from top



# Typical PSA Flow Diagram

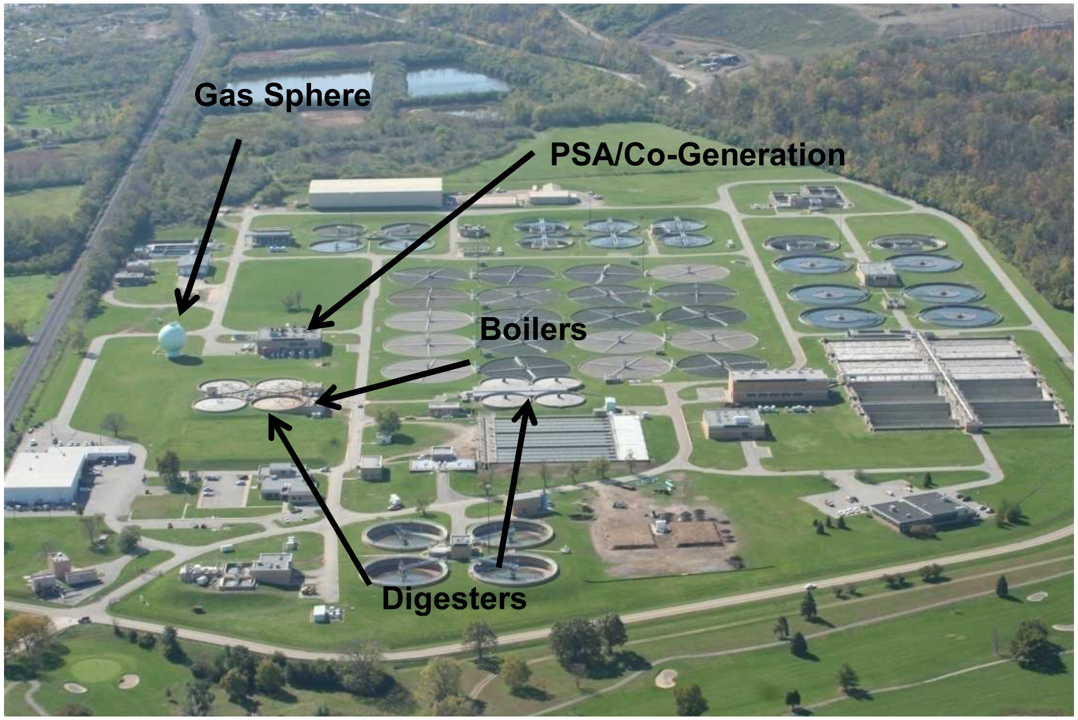
PSA gas scrubbing performs multiple chemical adsorptions in a single step.




Methane Yield: 80% - 91%

# City of Dayton WWTP – Case Study

- Dayton, Advanced Wastewater Treatment Facilities (AWTF) located at 2800 Guthrie Road, Dayton, OH.
- Rated at 72 MGD and peak 180 MGD
- Secondary (nitrification) plant with effluent filters and diffused post aeration
- Four 85-ft and four 90-ft diameter Anaerobic Digesters (1.2 & 1.6 MG)
- 52-ft diameter Gas Holding Sphere (300,000 CF at 50 psi)
- 800,000 CF/day gas generation
- Energy recovery facilities
- Additional information http://water.cityofdayton.org/Water/wwtp_main.asp



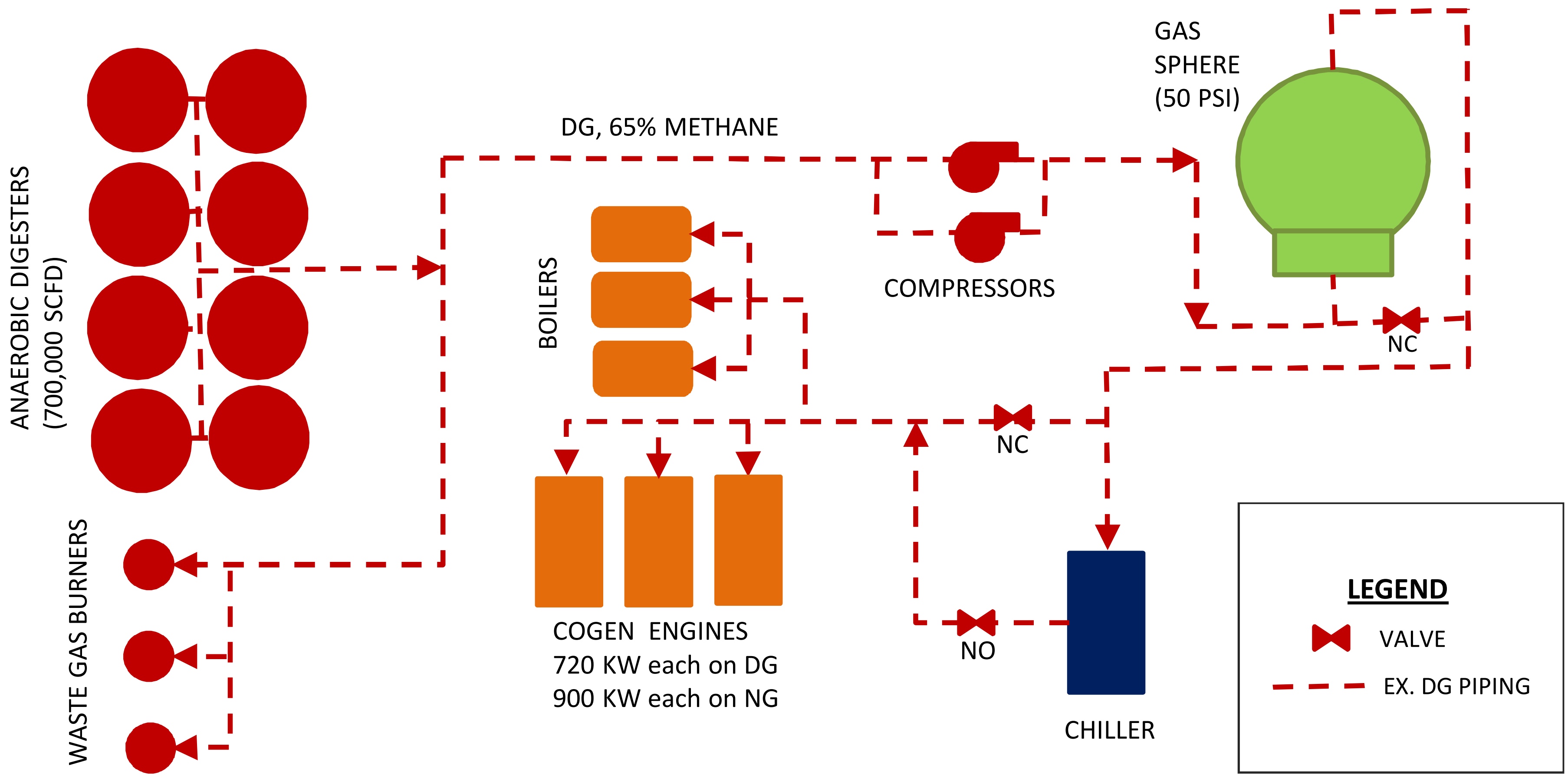
# Gas Utilizing Equipment

- Co-generation Engines
  - 3  Waukesha Engines
  - Dual fuel: Digester Gas and Natural Gas.
  - “Lean burn” engines
  - 720 kW each on digester gas
  - 900 kW each on NG or high-BTU (scrubbed) gas
- Present Strategy:
  - Peak-shave energy usage during high flow periods

# Gas Utilizing Equipment

- Boilers
  - 3 HURST Hot water boilers
  - 350 Horse Power
  - Design: 3-Pass Wet-Back
  - Burner Capacity: 14.7 Million BTU/Hour
  - Hot water Temperature: 180 °F

# Existing Digester Gas Schematic



# Selection Process

- Researched siloxane removal beginning in 1994.
- Found that refrigerated gas drying (chiller) was best method at time. Added chiller in 1995.
- Siloxane was not removed adequately and high maintenance intervals continued on engines.
- Learned about proprietary molecular sieve technology from Guild Associates (Dublin, OH) in 2009.
- Selected PSA for implementation at WWTP.

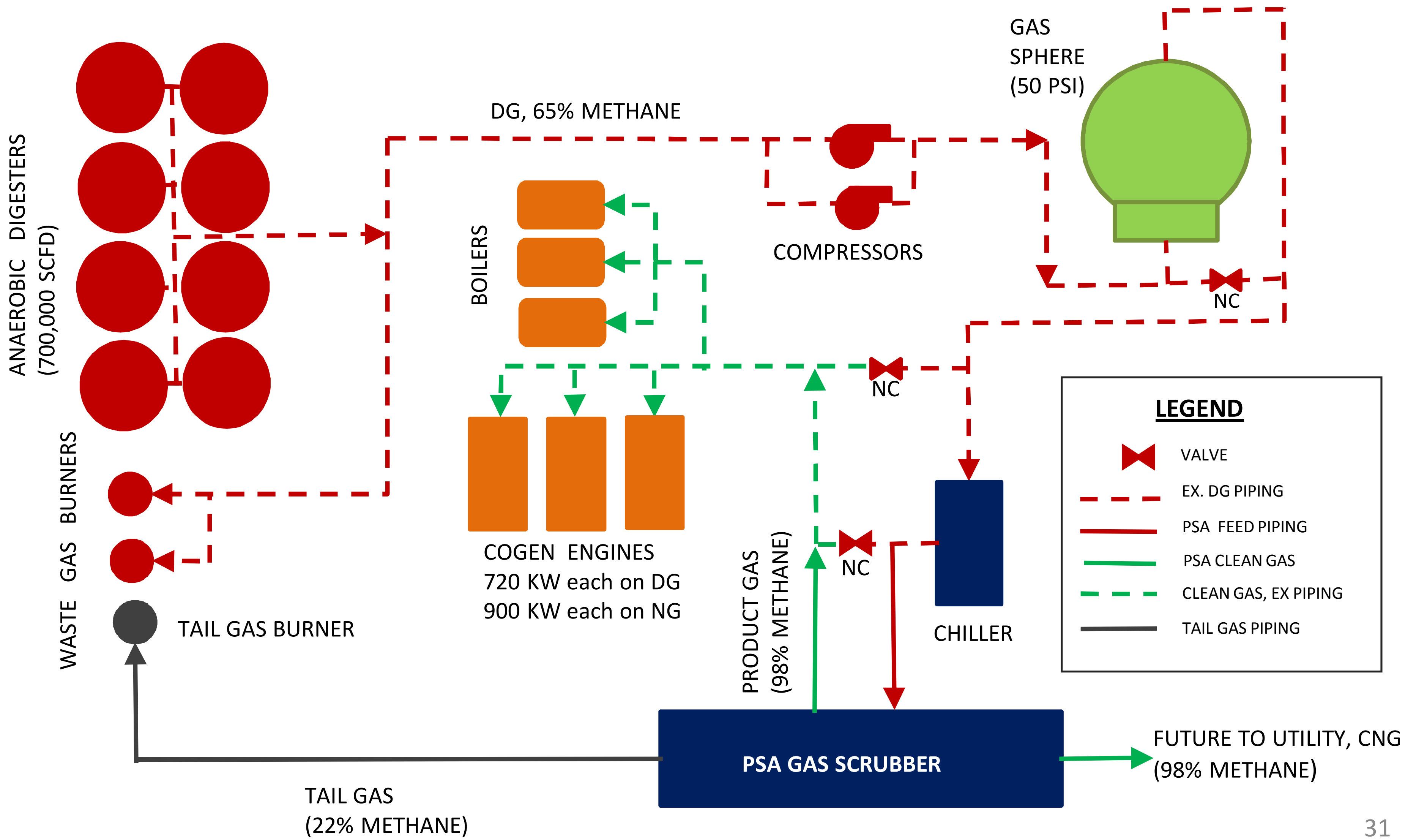
# PSA Gas Scrubber Specifications

- Designed Capacity: 1,000,000 SCFD
- Product gas
  - 524,000 SCFD
  - Methane: > 98%
  - $CO_2$: < 2%
  - Methane Yield: 85.6%
- Tail Gas
  - 476,000 SCFD
  - Methane: 22%

| Biogas Feed Properties | |
|---|---|
| | |
| Flow, SCFD | 1,000,000 |
| Pressure, psig | 40 - 50 |
| Temperature, F | 55-110 |
| Composition, Mol % | |
| CH4 | 61.9 |
| CO2 | 37.8 |
| H2S | 0.1 |
| Siloxanes | < 10 ppm |
| H2O | 0.2 |
| HHV BTU/FT3 | ~600 |

| Product Gas Properties | |
|---|---|
| | |
| Flow, SCFD | 524,000 |
| Pressure, psig | 90 |
| Temperature, F | < 120 |
| Composition, Mol% | |
| CH4 | 98.0 |
| CO2 | 2.0 |
| H2S | <4 ppm |
| Siloxanes | < 20 ppb |
| H2O | < 5 lb/MM SCF |

# Improved Digester Gas Schematic

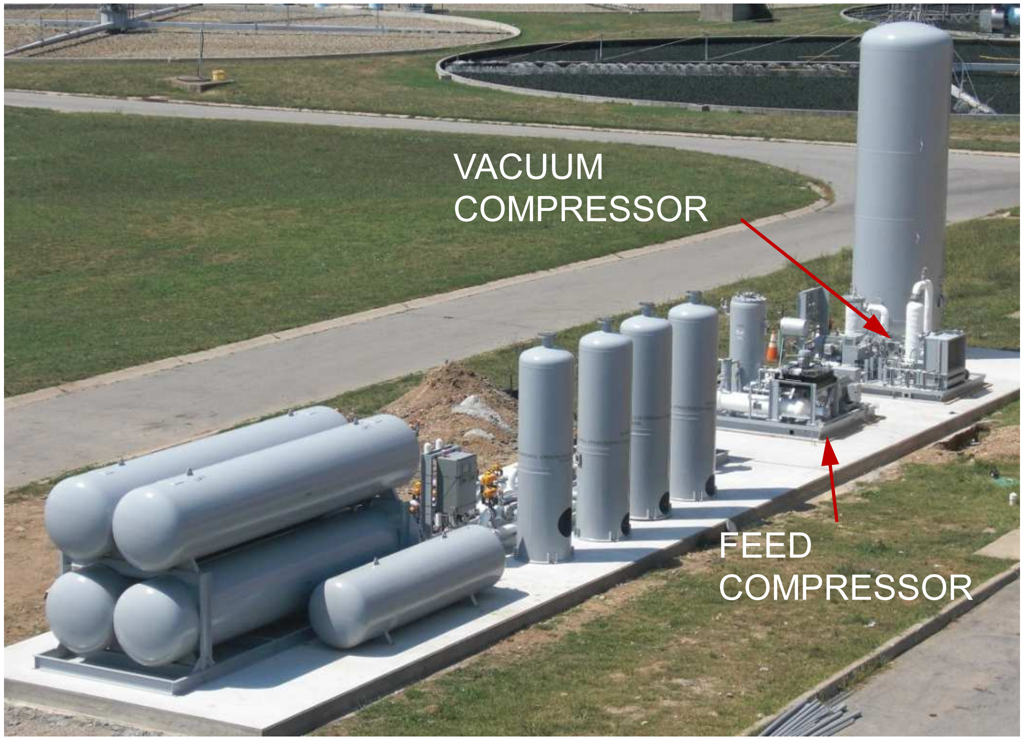


# Location of PSA Gas Scrubber

Location of PSA Gas Scrubber next to Co-generation Building

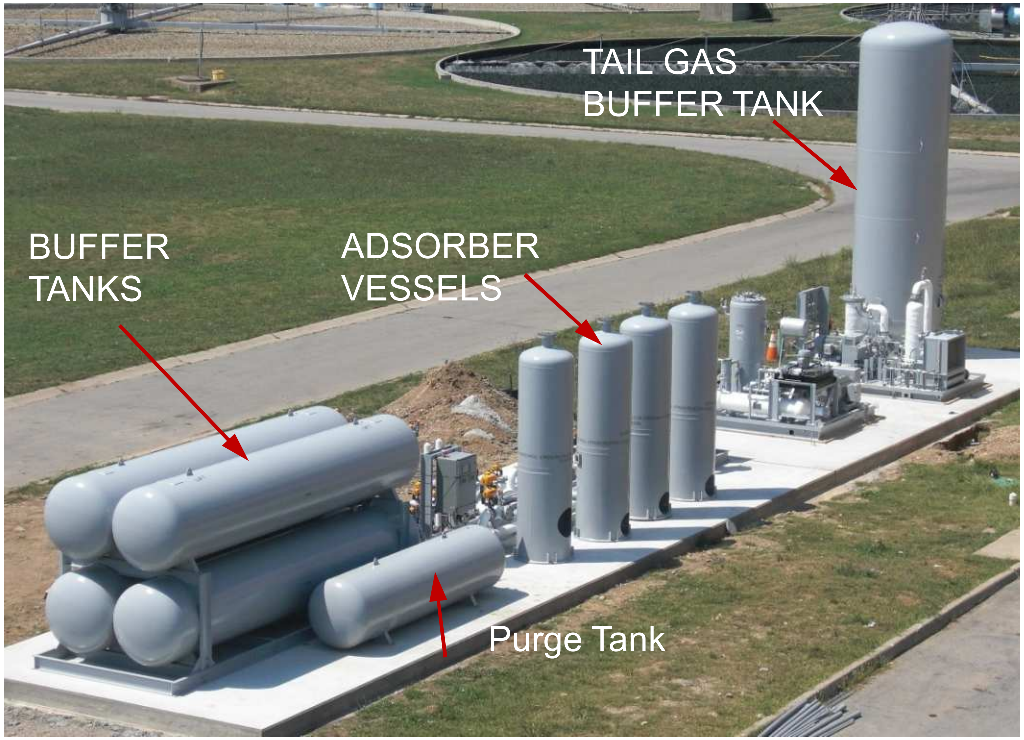
# Major Components of PSA Gas Scrubber

- Feed Compressor
  - Type: Reciprocating
  - Capacity: 1 Million SCFD
  - 60 HP Motor
  - Compresses from 40-50 to 105 PSIG
- Vacuum Compressor
  - Type: Liquid Ring
  - Capacity:0.5 Million SCFD
  - 150 HP Motor
  - Reduces from 3 in to 18 out PSIA



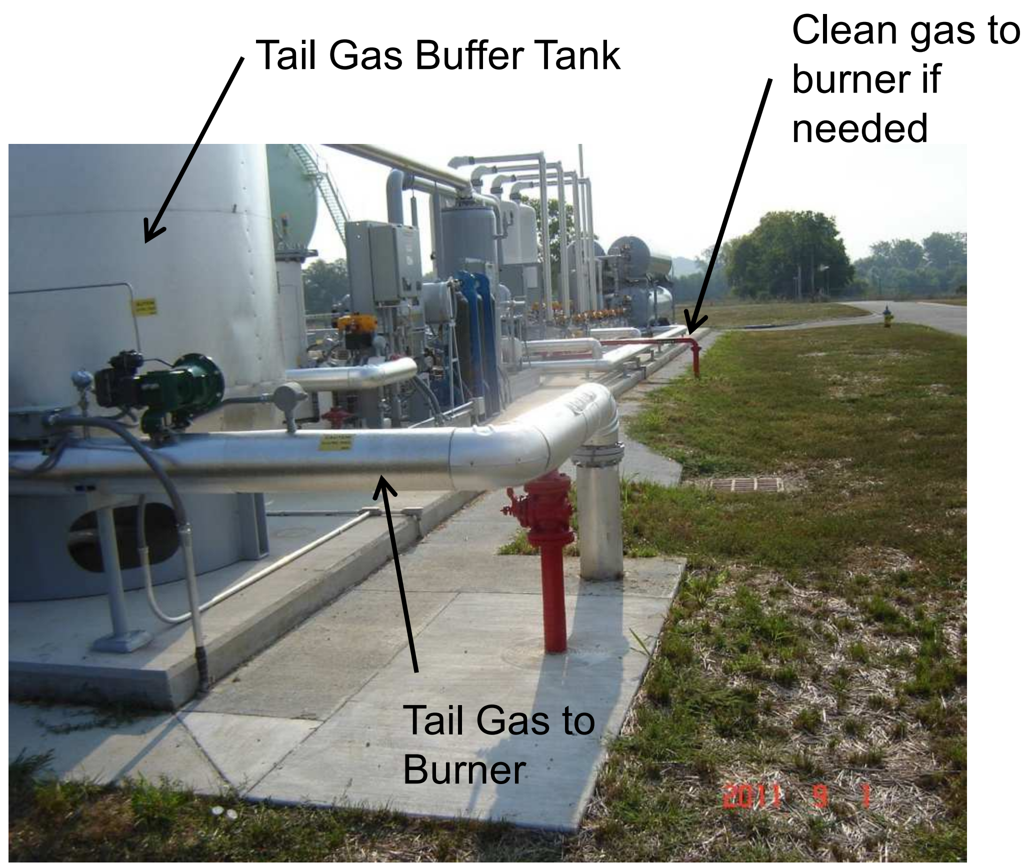
# Major Components of PSA Gas Scrubber

- 4 Adsorber Vessels that sequence these functions:
  - Pressurizing
  - On-line (adsorbing)
  - De-pressurizing
  - Purging
- 4 Buffer Tanks
  - Two Equalization
  - Two Repressurization
- Tail Gas Buffer Tank
- Purge Tank



# PSA Gas Scrubber

- This slide shows:
  - Connection to the tail gas burner from tail gas buffer tank.
  - Connection of clean gas to the tail gas burner in case we can not use the clean gas.



# PSA Gas Scrubber

- This slide shows:
  - Digester gas insulated piping to the PSA from Co-generation building Chiller.
  - Clean gas red piping to the Boiler and Co-generation Engines.

# Tail Gas Flare

- Tail Gas Burning obstacles:
  - Getting a new air permit from Regional Air Pollution Control Authority (RAPCA)
  - Existing flare would not work due to high (30%) methane requirement
  - Lead time on customized flare
  - Zeeco, Inc. designed lean burning flare tip for 22% methane combustibility

Modified Flare becomes Tail Gas Burner

# Advantages of PSA Scrubbing

- Lowers maintenance of engine equipment
- Single process versus multiple unit processes
- No consumables and PSA media has 5+ year life
- Lower O&M cost than conventional processes
- Less liquid discharge (compared to wet scrubbing for $CO_2$ removal)

# Scrubber Start-up

- Engine-Generator startup issues
  - Connect to the Natural Gas Line
  - Adjusted air/fuel ratio for the engines
  - Had to retune engines

- Boiler startup issues
  - Adjusted air/fuel ratio on two boilers

# Cost of the project

- PSA system cost $1.9M installed.
- Received American Recovery and Reinvestment Act (ARRA) grant money for the project.
- Pay back period will be between 5-10 years due to:
  - Reduction in maintenance cost of the engines and boilers.
  - Higher engine and boiler efficiency
  - Future plan to sell to local gas utility, or build a CNG station for City vehicles.

# Questions

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# THANK YOU

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