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Quantification of the Incremental Cost of Nitrogen and Oxygen Removal at High-Btu Plants

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Typical Pipeline Quality Gas Specifications

Parameter	Pipeline A	Pipeline B	Pipeline C
Higher Heating Value (Btu/ft^3)	≥ 960	≥ 966	≥ 985
Hydrogen Sulfide (grains/100 ft^3)	≤ 0.25	≤ 0.25	≤ 0.25
Water Vapor (lbs/mmcf)	≤ 7	≤ 7	≤ 7
Oxygen (O_2)	≤ 0.25%	≤ 1%	≤ 0.2%
Nitrogen (N_2)		≤ 3%	
Carbon Dioxide (CO_2)	≤ 3%	≤ 3%	≤ 2%
$CO_2 + N_2 + O_2$	≤ 6%		≤ 3%

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Typical Landfill Gas Quality

Parameter	Tight Wellfield	Good Wellfield	Fair Wellfield	Poor Wellfield
Methane (CH_4)	55.1%	54.0%	52.0%	50.0%
Carbon Dioxide (CO_2)	43.5%	42.6%	40.3%	38.3%
Nitrogen (N_2)	1.2%	2.9%	6.8%	10.5%
Oxygen (O_2)	0.2%	0.5%	0.9%	1.2%
	100%	100%	100%	100%
Moisture	4% to 6%			
Hydrogen Sulfide	50 ppmv to 600 ppmv			

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Conventional Approach to High-Btu

- Rely on tight wellfield
- Remove moisture
- Remove hydrogen sulfide
- Remove carbon dioxide
- Current carbon dioxide removal technologies include:
  - Membrane separation
  - Pressure swing adsorption
  - Selexol

Typical Conventional High-Btu Plant

- Inlet blowers
- SulfaTreat
- Compression/chilling
- Temperature swing adsorption (TSA)
- Pressure swing adsorption (PSA)
- Thermal oxidizer
- Product gas compression (if required)

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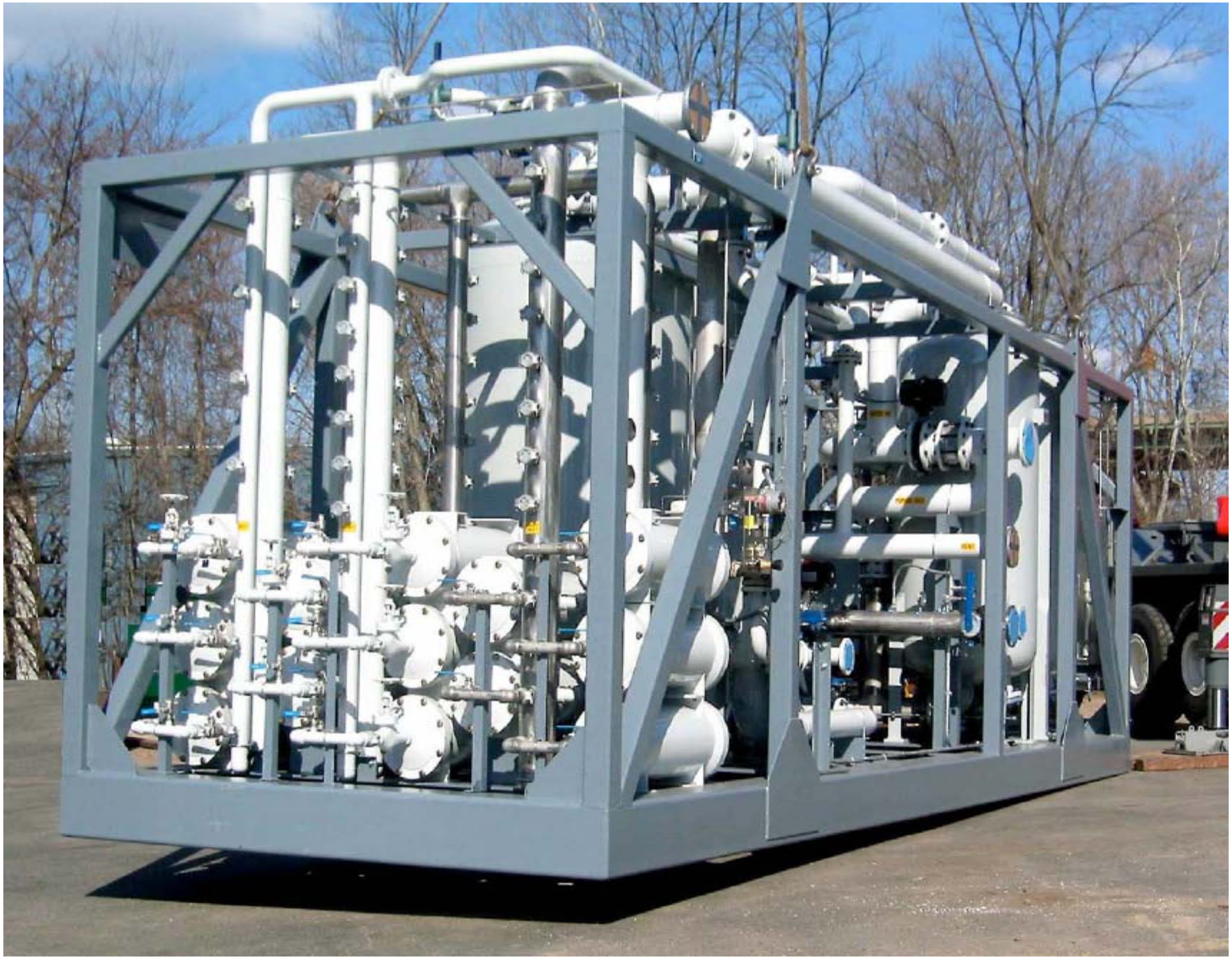

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Conventional High-Btu Plant on Tight Quality Landfill Gas

Parameter	Tight Wellfield	Membrane Product Gas	Pipeline B Specification
Methane (CH_4)	55.1%	97.07%	≥ 95.5%
Carbon Dioxide (CO_2)	43.1%	1.00%	≤ 3%
Nitrogen (N_2)	1.2%	1.82%	≤ 3%
Oxygen (O_2)	0.2%	0.11%	≤ 1%
HHV (Btu/ft^3)		982	≥ 966

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Conventional High-Btu Plant on Good Quality Landfill Gas

Parameter	Good Wellfield	Membrane Product Gas	Pipeline B Specification
Methane (CH_4)	54.0%	94.31%	≥ 95.5%
Carbon Dioxide (CO_2)	42.6%	1.00%	≤ 3%
Nitrogen (N_2)	2.9%	4.41%	≤ 3%
Oxygen (O_2)	0.5%	0.28%	≤ 1%
HHV (Btu/ft^3)		954	≥ 966

Conventional High-Btu Plant on Fair Quality Landfill Gas

Parameter	Fair Wellfield	Membrane Product Gas	Pipeline B Specification
Methane (CH_4)	52.0%	88.16%	≥ 95.5%
Carbon Dioxide (CO_2)	40.3%	1.00%	≤ 3%
Nitrogen (N_2)	6.8%	10.34%	≤ 3%
Oxygen (O_2)	0.9%	0.50	≤ 1%
HHV (Btu/ft^3)		892	≥ 966

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Conventional High-Btu Plant on Poor Quality Landfill Gas

Parameter	**Poor Wellfield**	**Membrane Product Gas**	**Pipeline B Specification**
Methane (CH_4)	50.0%	82.37%	≥ 95.5%
Carbon Dioxide (CO_2)	38.3%	1.00%	≤ 3%
Nitrogen (N_2)	10.5%	15.96%	≤ 3%
Oxygen (O_2)	1.2%	0.67%	≤ 1%
HHV (Btu/ft^3)		834	≥ 966

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Nitrogen Removal Technologies

- Commercially available equipment relies on PSA Technology
- PSA exploits the difference in size of nitrogen and methane molecules to achieve nitrogen removal from the methane
- Current equipment suppliers include:
  - Guild (Molecular Gate)
  - Xebec
  - ARC Technologies

Nitrogen Removal Technologies

- Xebec removes nitrogen and carbon dioxide concurrently in their carbon dioxide PSA – currently limited to four percent nitrogen in inlet LFG
- ARC removes nitrogen and carbon dioxide concurrently in their carbon dioxide PSA – currently limited to four percent nitrogen in inlet LFG
- Guild removes nitrogen in a PSA added to the end of a conventional high-Btu plant. Guild can remove varying levels of nitrogen, with 20 percent probably being a practical upper limit

Xebec PSA

ARC Technologies PSA

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Guild Molecular Gate PSA

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Oxygen Removal Technologies

- Some oxygen can be removed by membranes (concurrently with carbon dioxide)
- ARC can remove some oxygen (concurrently with carbon dioxide removal in their PSA)
- Oxygen can be removed from the product gas by the catalytic consumption of oxygen with methane ($CH_4 + O_2 = CO_2 + H_2O$)
- The catalytic reaction will consume a small amount of methane
- The water formed in this reaction must be removed from the gas. Removal of the water formed by the catalytic reaction can be accomplished in a TSA dryer

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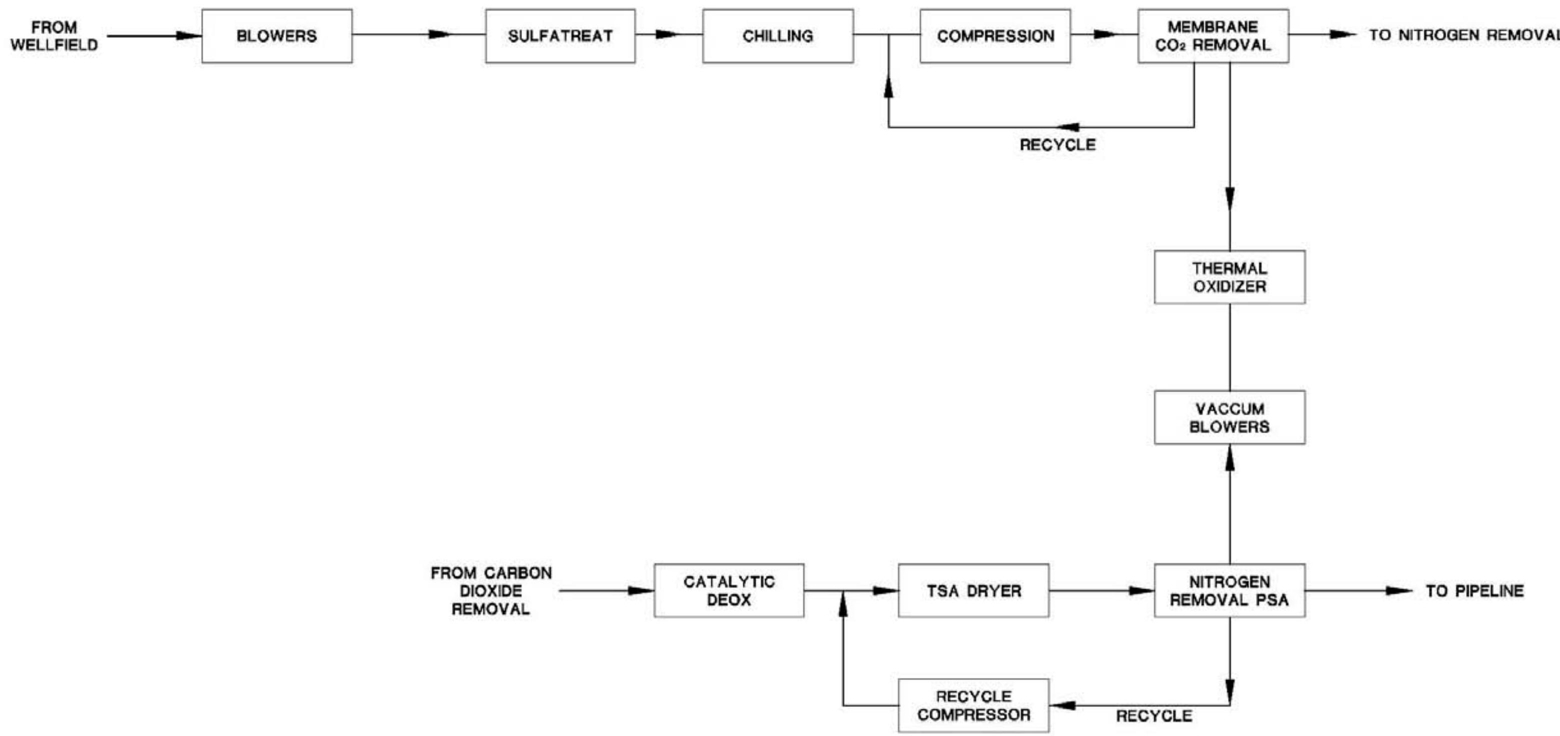
High-Btu Plant with Nitrogen and Oxygen Removal



High-Btu Plant with Nitrogen and Oxygen Removal

High-Btu Plant Performance with N_2 and O_2 Removal

Parameter	Landfill Gas	Membrane Plant Exit	Final Plant Exit
Methane (CH_4)	50.0%	82.37%	95.9%
Carbon Dioxide (CO_2)	38.3%	1.00%	0.0%
Nitrogen (N_2)	10.5%	15.96%	4.0%
Oxygen (O_2)	1.2%	0.67%	0.1%
HHV (Btu/ft^3)		834	971
% Methane Recovery Across CO_2 Removal = 90%			
% Methane Recovery Across N_2/O_2 Removal = 90.5%			
% Methane Recovery Across CO_2 + N_2 Removal = 81.5%			

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Comparison of 4,000 scfm Inlet Capacity Plant With and Without N_2 and O_2 Removal

Parameter	Inlet Nitrogen = 1.2%	Inlet Nitrogen = 10.5%
Capital Cost	$12.5 million	$17.0 million
Annual O&M Cost	$2.2 million	$2.6 million
Power Consumption (kW)	1,960	2,360
Percent Methane Recovery	90%	81.5%
Annual Product Gas (mmBtu)	1,022,000	841,000
Production Cost ($/mmBtu)	$4.14	$6.38

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Summary of Impacts at 4,000 scfm Associated with Inlet Nitrogen at 10.5% Versus 1.2%

Capital Cost	+ 4.5 million	+36%
Annual O&M Cost	+ 0.4 million	+18%
Power Consumption	+ 400 kW	+20%
Product Gas Loss		9.5%

Comments and Recommendations

- LFGE industry has limited experience with nitrogen removal, but nitrogen removal technology is a proven technology
- Nitrogen removal is expensive
- It is more cost-effective to minimize nitrogen entry into the wellfield than to remove nitrogen in the plant
- Money is better spent on wellfield upgrades and/or wellfield operational changes than on nitrogen removal equipment. The cost of nitrogen removal is proportional to the amount of nitrogen that must be removed