Best Practices to Select Internal Combustion Engines and Maximize the Success of Methane to Electricity Projects

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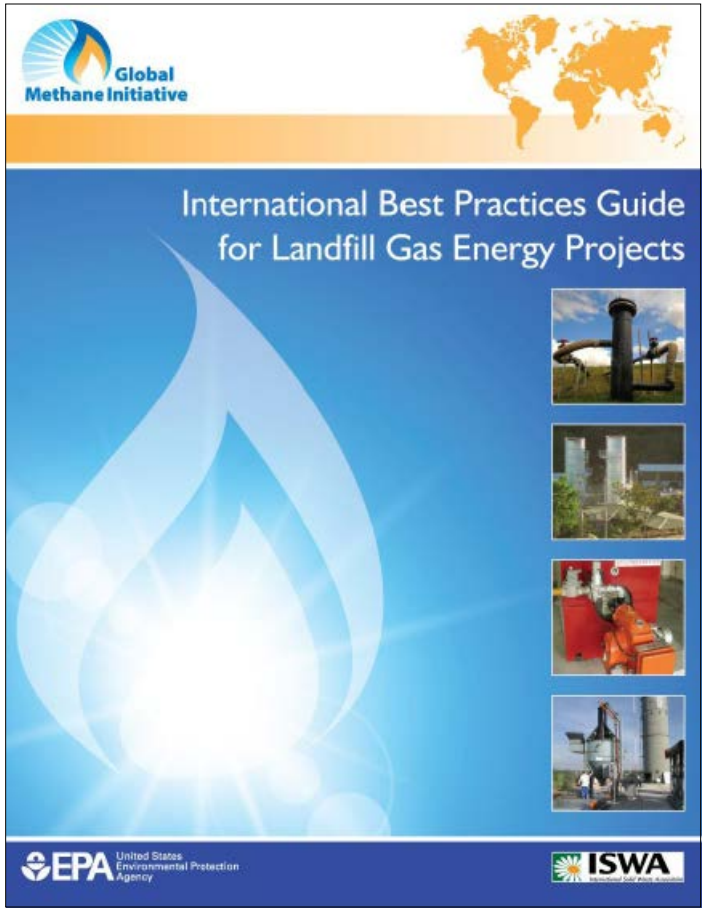
Objective



- This presentation is an add-on companion to GMI's Best Practices.
- Provides four additional practices for better decisions in methane to electricity projects.
- Applies to all segments (Ag, Waste Water, etc.)

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Agenda

1. Engine Technology

2. Gas Contamination

3. Engine Installation

4. Engine Maintenance & Operations (M&O) Costs.

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1. Engine Technology

High Efficiency v. High Robustness

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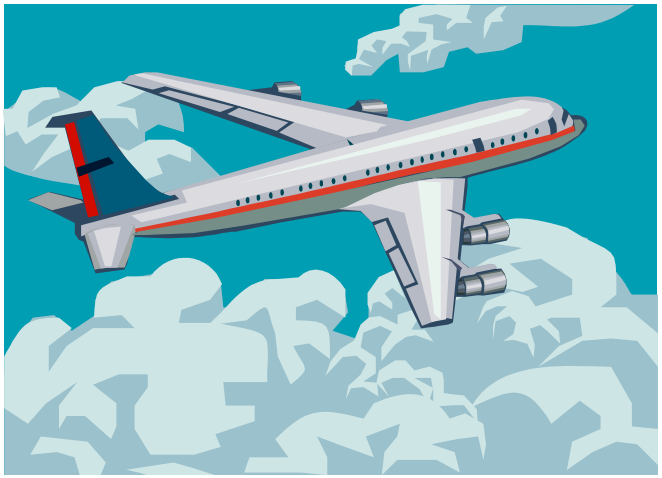
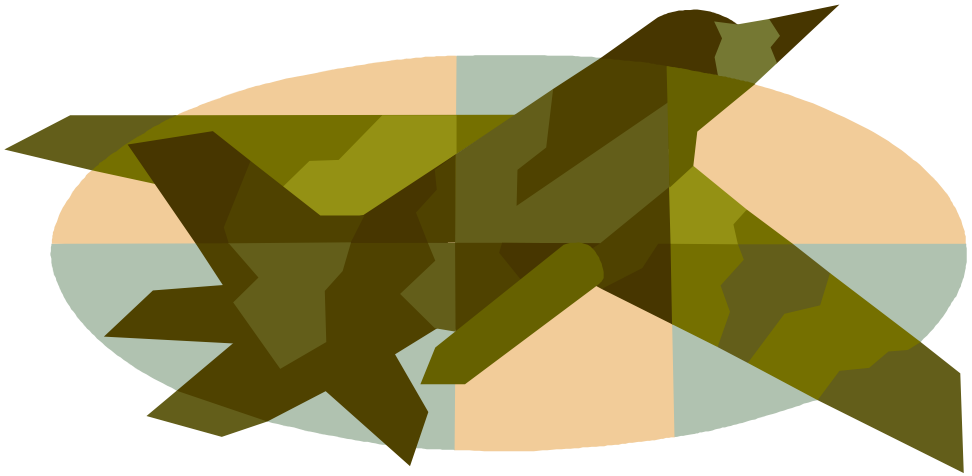
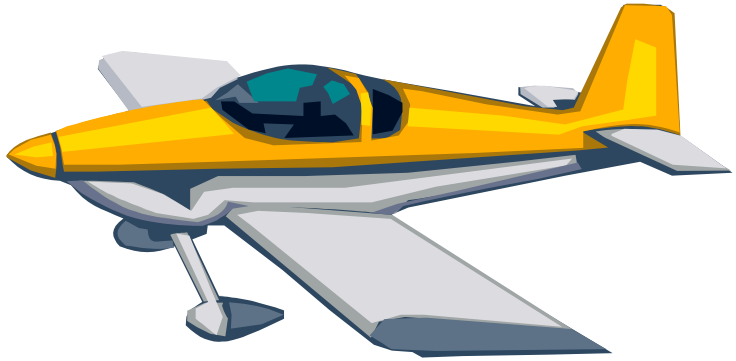
Internal Combustion Engine

- Invented by N. Otto, 1876
  - Traditional four-stroke cycle
- Improved by R. Miller, 1957
  - Changes valve timing, fuel mixture ‘supercharged’
  - Manages higher pressure inside the cylinders
  - Inherently more efficient
  - Requires closer control of air inlet temperature, fuel contamination, tolerances.

Which Technical Design Is Better?







It depends ….

Engine Design Trade-Off

High Robustness Engines

(Traditional *Otto, non-Miller*)

CAPEX ↓ OPEX ↑

- Accept higher siloxane and H2S contamination
- Efficiency below 40%
- Dirty gas forces more oil changes, higher M&O cost
- Excellent for: ‘dirty’ gas, worst-case ambient swings & quicker load response

High Efficiency Engines

(*Miller* Cycle)

CAPEX ↑ OPEX ↓

- Usually require costly siloxane & H2S removal
- Efficiency above 40%
- Lower M&O costs due to cleaner gas
- Excellent for: ‘clean’ gas, controlled environments, average load demands

Engine Technology Best Practice

- Run two separate economic evaluations of your methane to electricity project:
  - Scenario A: high efficiency engine (Miller)
  - Scenario B: high robustness engine (non-Miller)

- Include in your evaluation:
  - CAPEX: cost of siloxane and H2S removal equipment required by high efficiency engine
  - OPEX: additional M&O for siloxane/H2S removal units
  - Risk Factors: if cleaning equipment fails or under-perform, high efficiency engine will be quickly damaged

2. Gas Contamination

Removing Siloxanes and H2S

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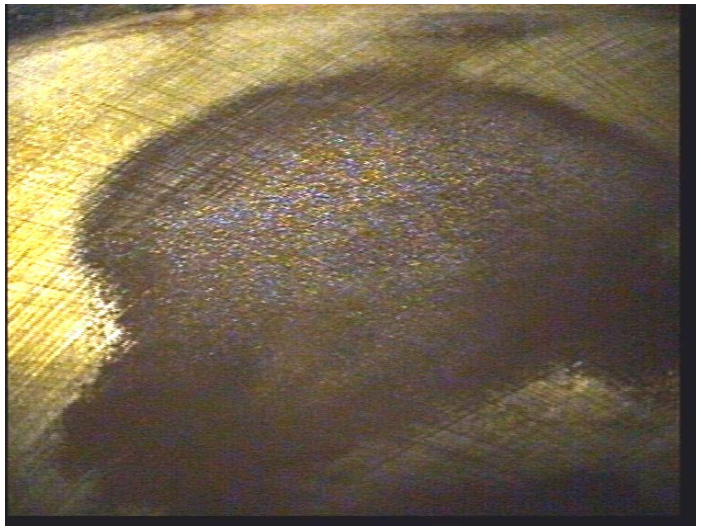
Why Siloxane and H2S?

- Siloxanes
  - Present in cosmetics, shampoo, detergents
  - Transform during combustion to SiO2. Sand in the engine!
- H2S (Hydrogen Sulphide)
  - Combusts to SO2 and H2O. Further transform to sulphurous/sulphuric acid.
  - Corrosion



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Fuel Specification Guidelines

- All Manufacturers have guidelines for maximum fuel contamination. Warranty depends on compliance.
- Miller engine users strongly advised to stay within the limits of the 'clean biogas' definition

Sample Recommendation for Optimal Engine Application *Based on 500 Btu/scf Fuel

	Non-Miller Engine		Miller Engine	
Fuel Contaminant	**µg/Btu of Fuel**	**Approx. PPM***	**µg/Btu of Fuel**	**Approx. PPM***
Halides (as Cl)	20	230	0.55	7
Sulfur (as H_2S)	60	730	12.2	155
Siloxanes (as Si)	0.6	9.0	0.11	1.6
Ammonia	2.96	72	0.17	4

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Economics of Siloxane Removal

- Recent 12MW LFGE project (6 engines)
  - Siloxane removal unit added 25% extra cost
- Recent 1-2MW quotes
  – 50-100% added cost.
- 1 MW and below
  – Siloxane removal costs as much as the engine!
- Cost becomes manageable if project is very large

3. Engine Installation Options

Building v. Container

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Container

Building

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Engine Installation Trade-Off

Building Installation

- Ample space for service personnel, cranes for safe lifting of heavy parts, controls & storage rooms
- Economies of scale for multi-engine buildings
- Easier to manage dust contamination and air inlet temperatures

Container Installation

- Restricted access and work space, more time & money on service steps
- Fast deployment, easier to quickly add or remove units
- Easier to obtain bank loans
- High reliability: complex systems integrated by engine manufacturer

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4. Better Estimation of M&O Costs

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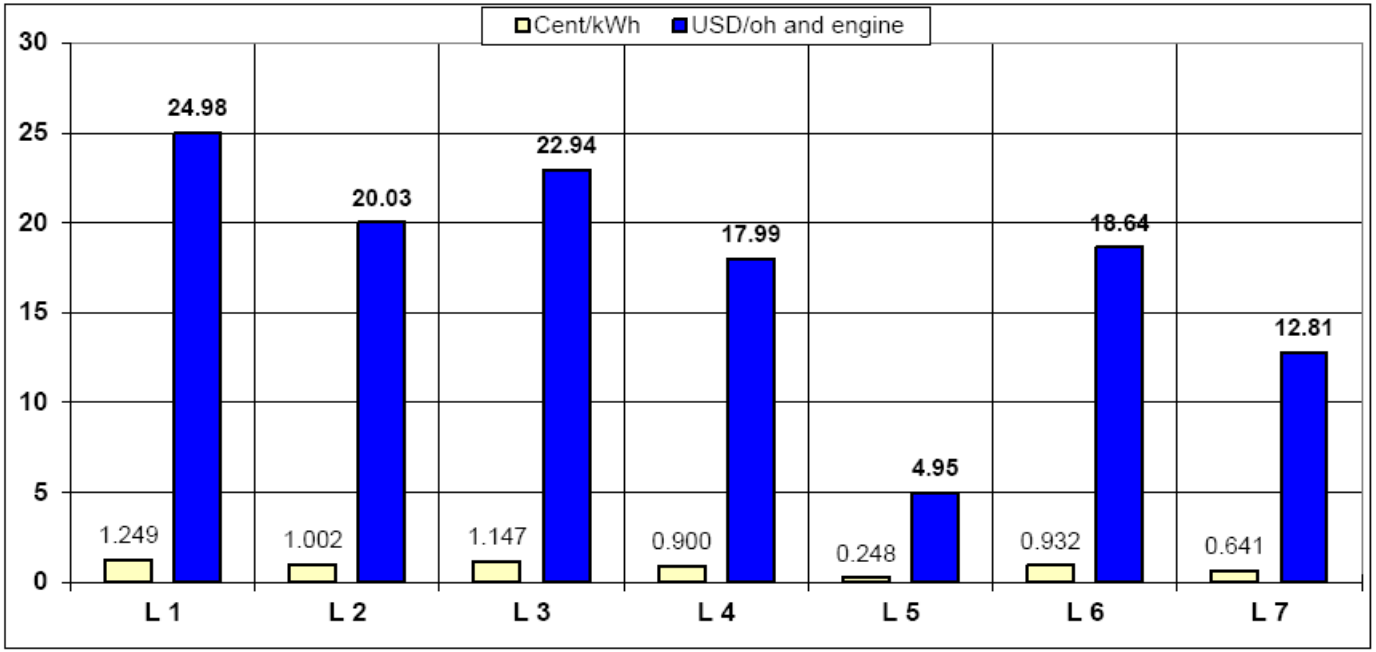
Estimating Maintenance & Operation Costs

- Most financial evaluation tools use just one number for the M&O cost of a generator set
- Comparison of costs may not be appropriate without knowing the different elements that went into the M&O number
- Potential customers need to request separate estimates for different combinations of service
  - Window of time used for calculations is critical
  - Gas type used for calculations also critical

Cost per kWh, Cost per Running Hour

	Customer
	System
2	Gas type
1	Number of engines
2,000 kW	El. power per engine

	Engine type
8,000 Bh/oh	Running time per engine and yea
0 Bh/oh	Start of calculation
64,000 Bh/oh	End of calculation
8	years



- L1-L7 are lists of different service alternatives

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Need to Break Down O&M Elements

Service list	(L1 - L7)	L 1	L 2	L 3	L 4	L 5	L 6	L 7
Engine	4 x E10	☒	☒	☒	☒		☒	☒
	16 x E30	☒	☒	☒	☒		☒	☒
	12 x E40	☒	☒	☒	☒		☒	☒
	2 x E50	☒	☒	☒	☒		☒	☒
	1 x E60	☒	☒	☒	☒		☒	☒
	1 x E70	☒		☒		☒	☒	
	4 x TC01	☒	☒	☒	☒		☒	☒
	1 x TC02	☒	☒	☒	☒		☒	☒
	0 x Z01							
Var. unsch. spare parts per engine and year:		☒	☒	☒	☒		☒	
unscheduled assignments (wage)		☒	☒	☒	☒		☒	
Exhaust Heat Exchanger	inspection	☒	☒					
	EGHE repairs	☒	☒					
Silencer	inspection	☒	☒					
	repairs	☒	☒					
Oxicat	inspection	☒	☒					
	renewing	☒	☒					
Cooling water pump	inspection	☒	☒					
	repairs	☒	☒					
PHE, cooler	inspection	☒	☒					
	repairs	☒	☒					
Batteries	inspection	☒	☒	☒	☒		☒	☒
	repairs	☒	☒	☒	☒		☒	☒
Gas control line	inspection	☒	☒	☒	☒		☒	☒
	repairs	☒	☒	☒	☒		☒	☒
TEM, Switching system	inspection	☒	☒	☒	☒		☒	☒
	repairs	☒	☒	☒	☒		☒	☒
Generator	inspection	☒	☒	☒	☒		☒	☒
	repairs	☒	☒	☒	☒		☒	☒
Pneumatics	Inspection	☒	☒	☒	☒		☒	☒
Lube oil per engine		☒	☒	☒	☒			

Included in cost?

- Lube oil?
- Major Overhaul?
- Electrical Items?
- Unscheduled Maintenance?
- System Auxiliaries?

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Thank You For Your Attention!

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