IC Engine Performance and Emissions Operating on Landfill Gas and Synthesis Gas

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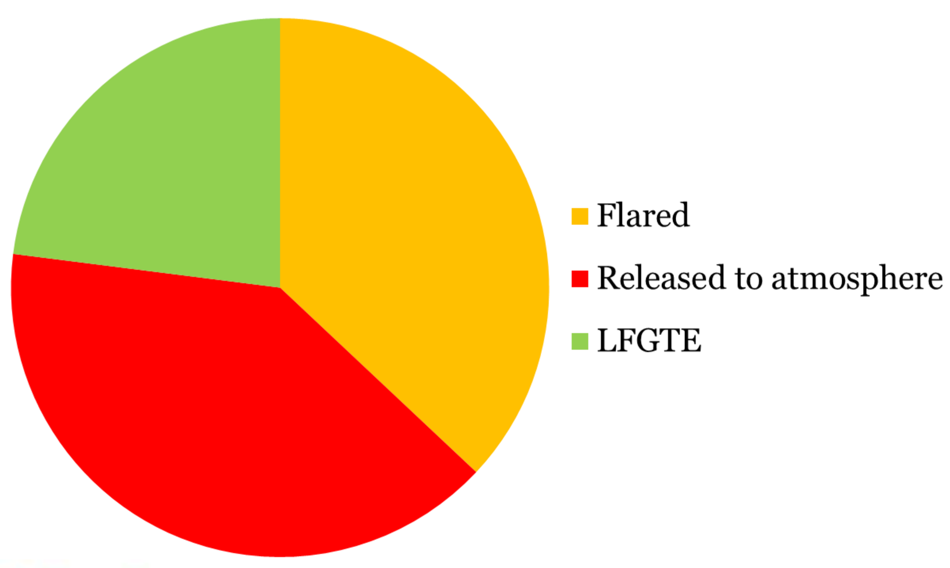
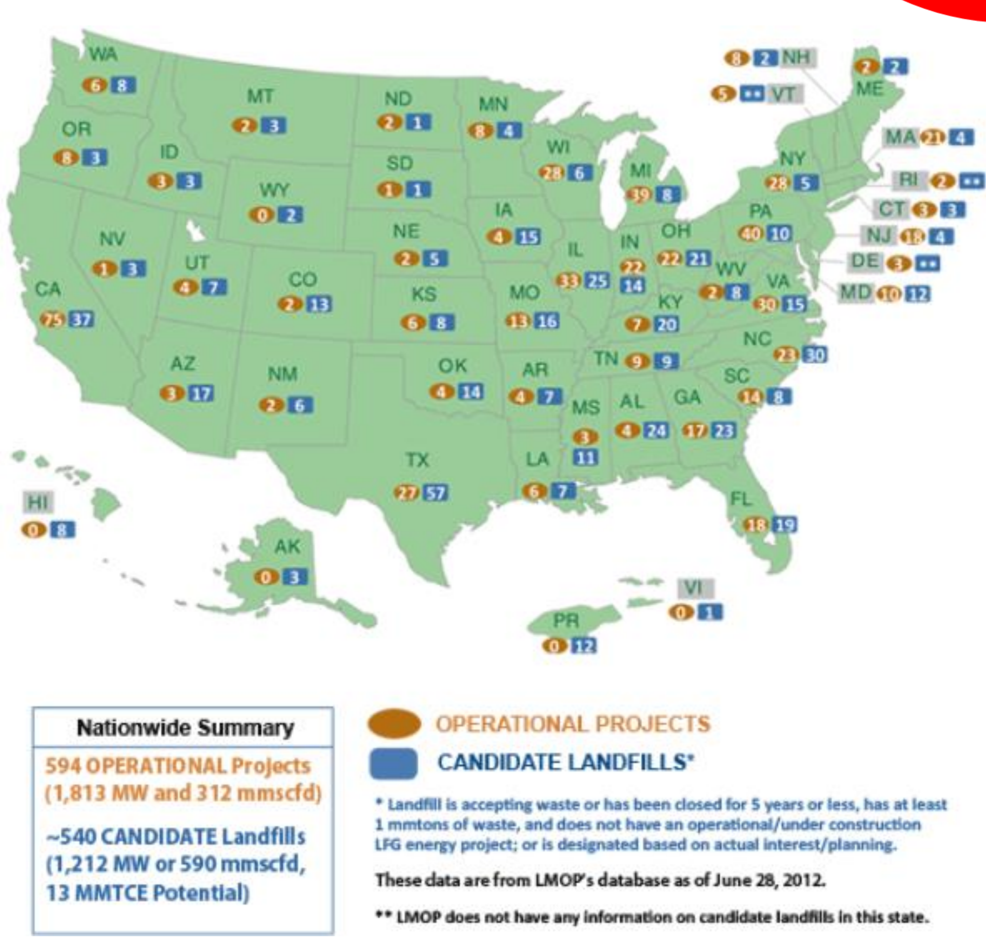
Motivation

- *Landfill gas* (*LFG*) is produced from the anaerobic decomposition of organic landfill waste and is approximately 50% (v.) CH_4 and 50% (v.) CO_2
- CH_4 (over 21 times as potent a greenhouse gas as CO_2) emitted from landfills accounts for 17% of anthropogenic CH_4 emissions and releases over 27.5 million metric tons per year of carbon equivalent into the atmosphere
- US landfills emit 7.2 billion m^3 of CH_4 annually = nearly 3.5% of total US natural gas consumption for electric power generation

Current handling methods of US landfill CH_4





As of June 2012, 23% of landfill CH_4 is utilized in over 590 operational landfill gas to energy plants across the US through the Landfill Methane Outreach Program (LMOP).

Image: http://www.epa.gov/lmop/projects-candidates/index.html#map-area

Research Goal:

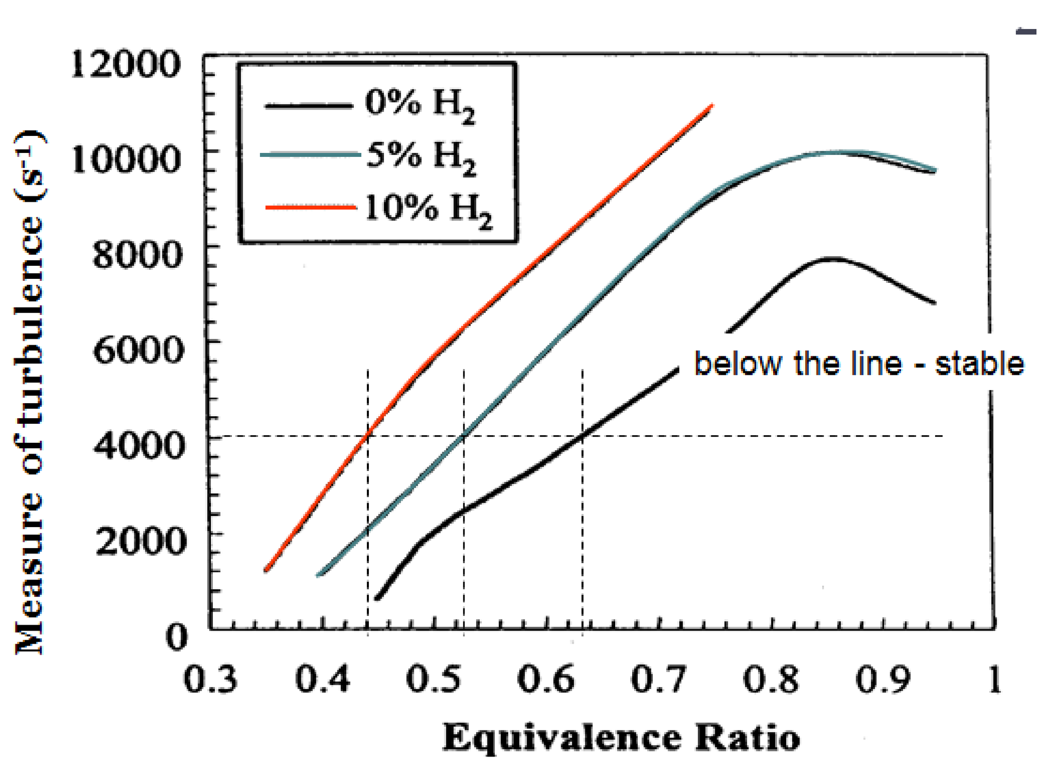
To utilize LFG as a fuel in internal combustion engines with minimal pollutant emissions and maximum engine efficiency.

Process Concept:

Stabilize BTU content of LFG and enhance LFG combustion in internal combustion engines by adding syngas (SG) in varying ratios of H_2/CO (2, 1, and 0.75).

Why SG?

CO_2 decreases flame temperature, burning rate, and flame stability. H_2 addition increases reactivity, extending stability/ blowout limits, while CO stabilizes the highly reactive H_2 and also contributes to the heating value of the fuel.

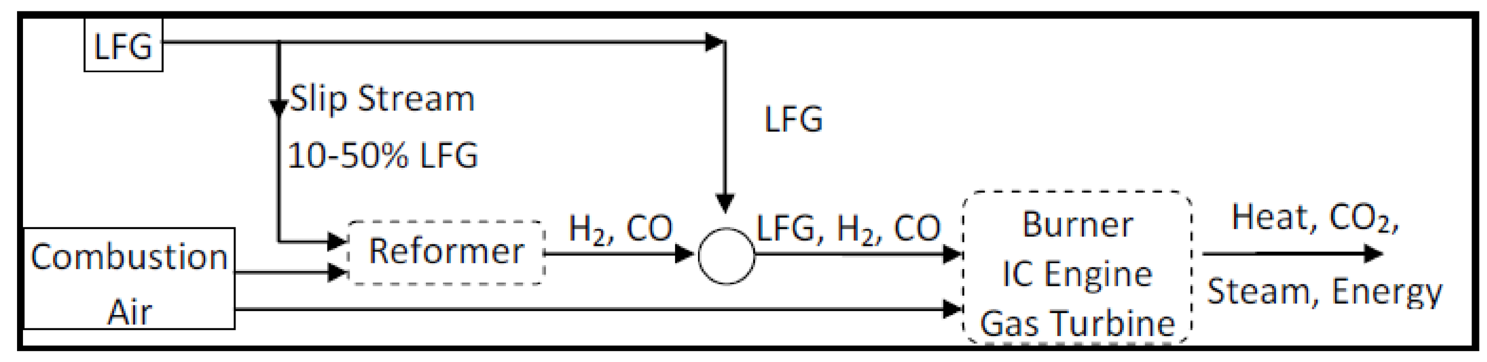


Calculation, GRI 2.1 mechanism for CH_4 @ 1 atm, 400 C inlet; Cong & Jackson (1999)

LHV (MJ/kg)	Fuel Component			
	CH_4	CO_2	H_2	CO
	50.0	0	120.9	10.1

LFG can be dry reformed (1) or steam reformed (2) to produce SG in-situ:

$$(1)\ CH_4 + CO_2 \rightarrow 2H_2 + 2CO$$
$$(2)\ CH_4 + H_2O \rightarrow 3H_2 + CO$$

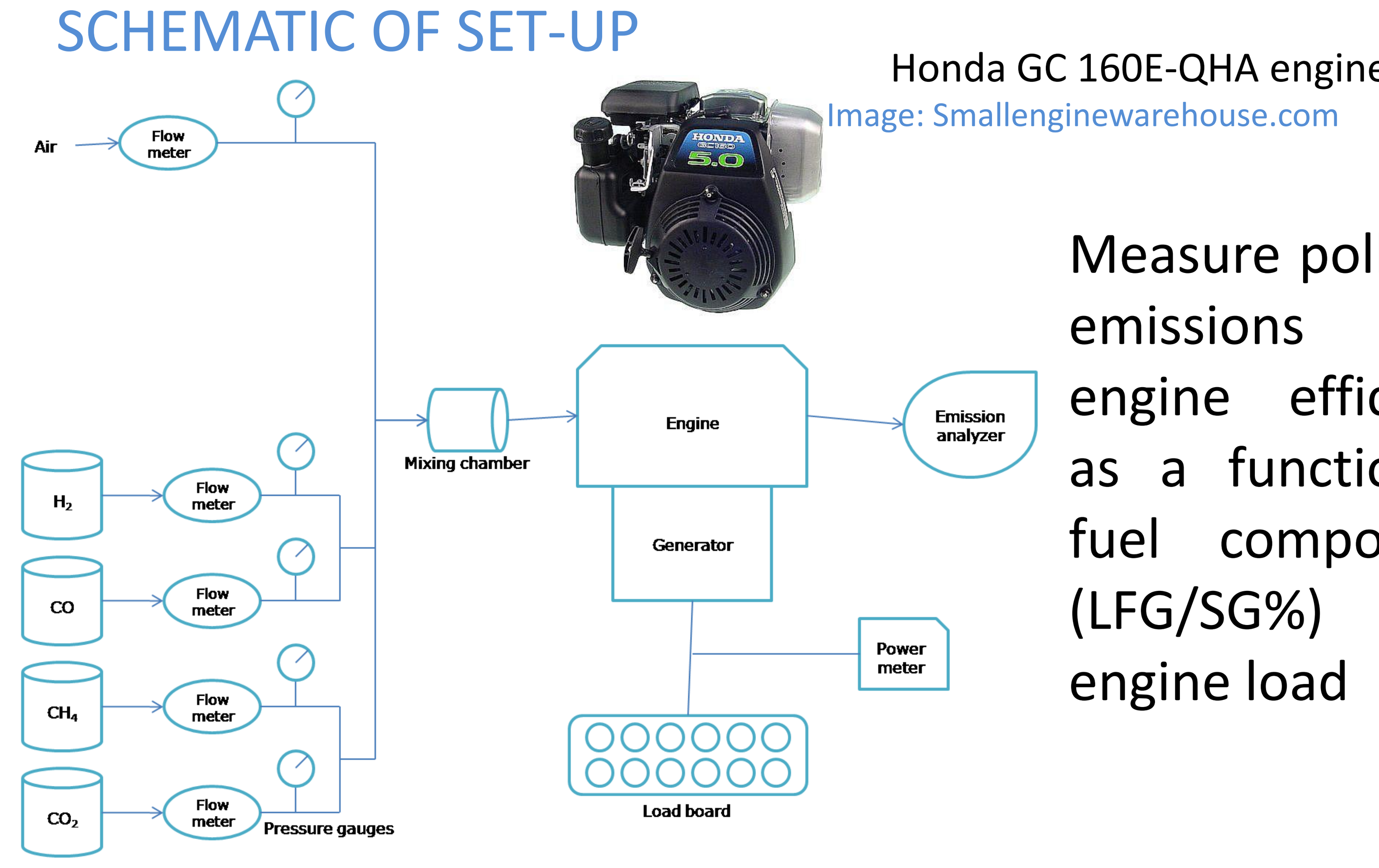


Schematic of in-situ LFG→SG reforming

Image: http://www.seas.columbia.edu/earth/wtert/sofos/lee_thesis.pdf

Experimental Methods

SCHEMATIC OF SET-UP



Measure pollutant emissions and engine efficiency as a function of fuel composition (LFG/SG%) and engine load

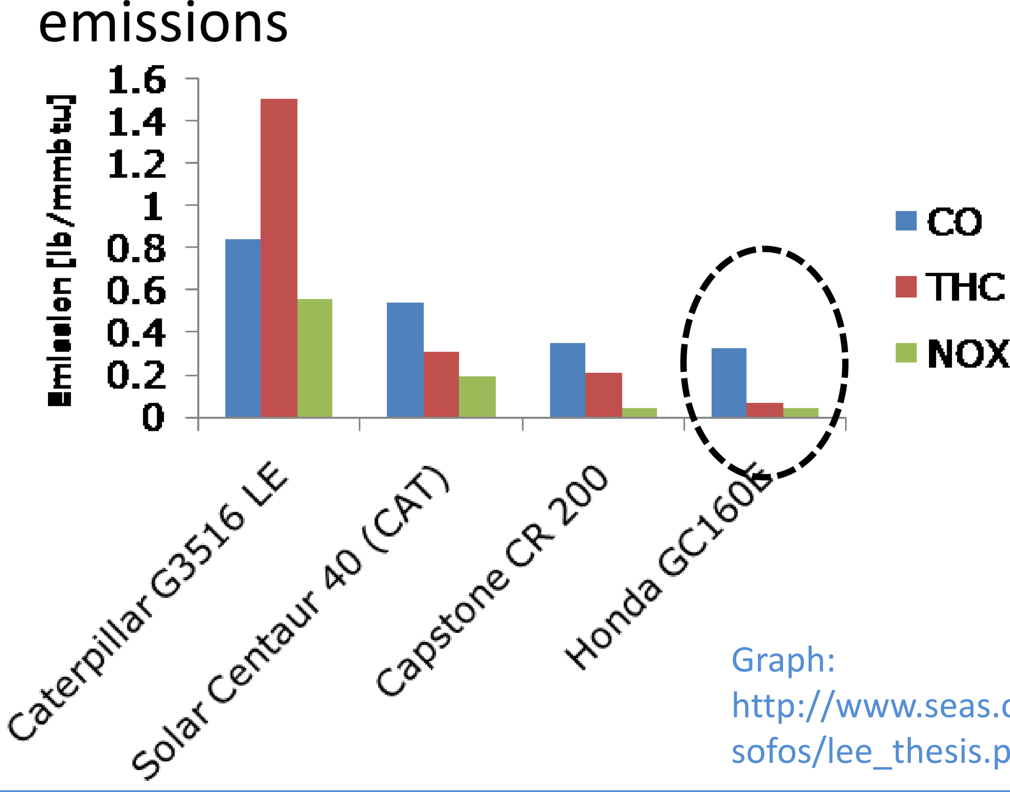
Image: http://www.seas.columbia.edu/earth/wtert/sofos/lee_thesis.pdf

Results and Conclusions

Fuel Type	Flow rate (L/min)	CO (PPM)	HC (PPM)	NO_x (PPM)	Adiabatic Flame Temp. (AFT) (K)
100% CH_4	6.9	158	31	24	1244
100% CH_4	7.3	159	32	34	1251
50% CH_4, 50% CO_2	6.9, 6.9	376	95	9	1206
75% CH_4, 25% CO_2	**7.1, 2.4**	**730**	**100**	**18**	-
50% CH_4, 50% CO_2, 5% SG*	6.6, 6.6, 0.7	320	30	10	-

*LFG %s are by volume, SG % is by enthalpy; H_2/CO ratio = 2; bolded data from Jechan Lee: http://www.seas.columbia.edu/earth/wtert/sofos/lee_thesis.pdf

- CO, HC emissions increase with increase in LFG CO_2 fraction
- NO_x emissions increase with increase in AFT—which generally correlates with a decrease in LFG CO_2 fraction
- H_2, CO in LFG stabilize flame, leading to more power output for a given fuel enthalpy flow and lower CO, HC, and NO_x emissions



Test data shows emissions from test unit at CCL is comparable to commercial units operating on LFG (without syngas)

Graph: http://www.seas.columbia.edu/earth/wtert/sofos/lee_thesis.pdf

Future Work

- Real systems (ie, MSW gasification) generate SG with H_2/CO ratios closer to 1 and 0.75: examine engine efficiency and pollutant emissions with these ratios
- Evaluate the limits of the system: max. power output of the engine with pure CH_4, LFG, and LFG/SG fuel compositions; max. SG addition before engine cuts out

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