PRODUCER GAS ENGINE

Combustion, Gasification & Propulsion Laboratory
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Background

- **Scenario in 1995 - 96**
  - **Spiraling crude oil resulted in dual-fuel operation to be expensive**
  - **Forced technologists to adapt 100% gas engines**
  - **No gas engines commercially available for producer gas**
  - **No engine manufacturer was favorable for producer gas**
    - **Market potential not clearly defined**
    - **Issue of gas contaminants a major one**
  - **Research & development was initiated at this laboratory**

Major Milestone

- Phase I (1996 – 1998) – Basic research on a three cylinder, hi comp. ratio gas engine (20 kW) converted from a diesel engine; satisfactory 100 hours test.

- Phase II (1999 – 2001) – Adapted Greaves bio-gas engine (250 kW); Gas carburetor developed; Cumulative experience of 100 hours in the lab.

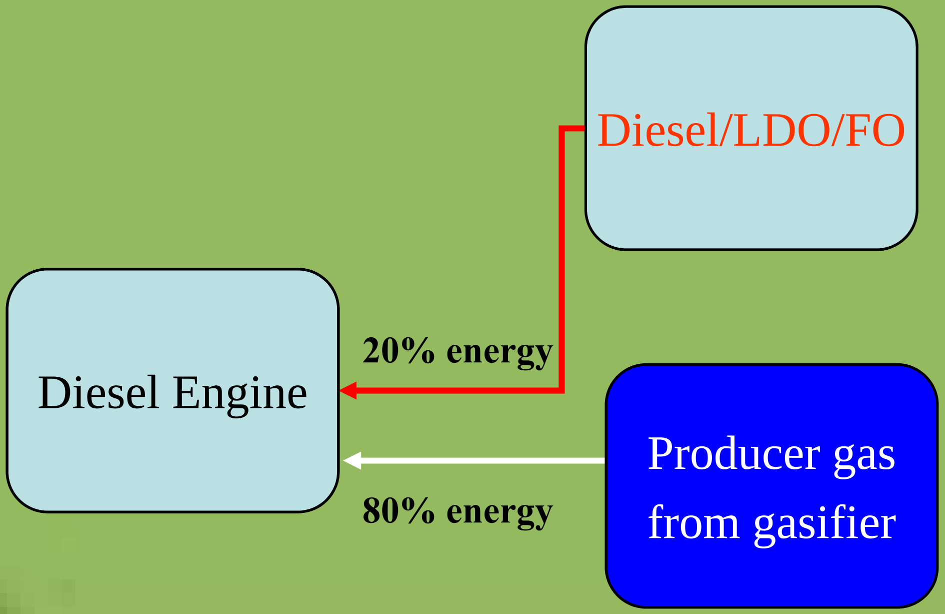
- Phase III (2002 onwards) – Adapted Cummins NG engines; Lab testing of two engine models along with Cummins; long duration trials - 75 hrs test; 3.0 MW installed in field, joint monitoring in progress; 25 kW engine for village project being tested.

Power generation using producer gas

Using R/C engines

- **Dual – Fuel Engine**
  80% gas & 20% diesel
- **Gas Engine**
  100% gas

What is dual – fuel operation?



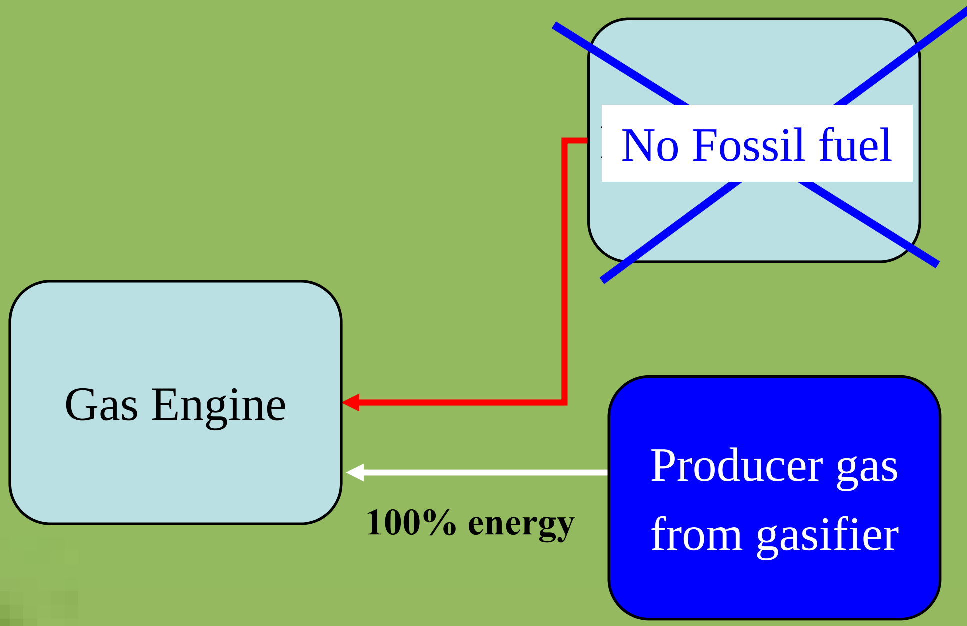
<u>Merits</u>

- Easy for retrofitting with existing diesel engine without any modifications
- Plant availability higher – utility will not suffer due to non-availability of gasifier
- Economical compared to fossil fuel – diesel

<u>De-Merits</u>

- Expensive can't compete with State grid electricity

Gas Engine option



<u>Merits</u>

- Economical and can compete with State grid electricity
- Plant availability reasonably high – provided correct operation practice are adhered to!
- Environmental friendly – emission meets pollution norms

<u>De-Merits</u>

- Start-up power required where grid is not available
- Not suitable if gas quality is poor (energy content – low & contaminants – high)

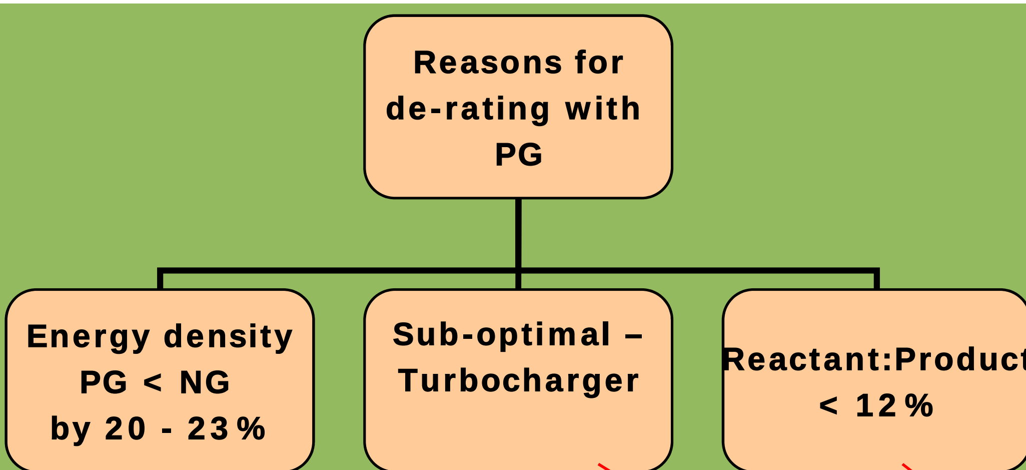
The Approach

- Basic Research – Experimental & Modeling
- Development of gas carburetion system
- Reliability tests - Long duration trails
- Collaborative work with Cummins India
  - Adaptation of Natural gas engines
  - Laboratory trails & Field monitoring
- Open for collaborative work with other engine manufacturers

How is PG different from NG engine?

- The air-to-fuel ratio of PG is 1.3:1, whereas for NG it is 17:1 – this calls for a different carburetor
- PG has higher octane rating, therefore can be used in engines with higher Compression ratio
- The flame speed of PG is higher ~ 20%; calls for a different ignition timing setting
- The energy density of PG is lower ~ 20%, this causes de-rating of the engine power
- The flame temperature is lower by about 300 K, implies different operating condition in the engine cylinder and turbocharger

Analysis of Producer Gas Engine



Properties of Gaseous Fuel

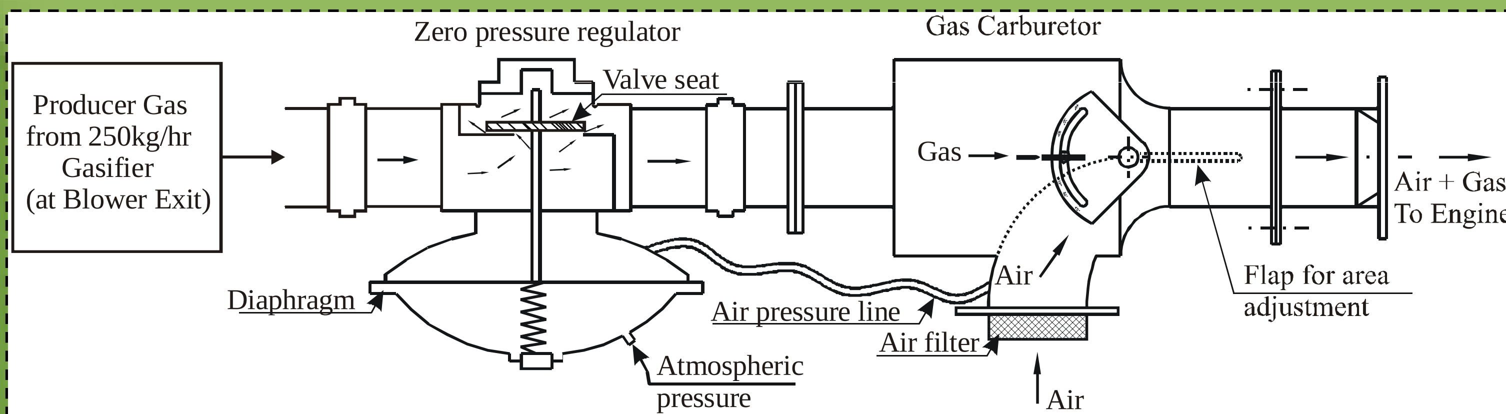
Fuel + Air	Fuel LCV, MJ/kg	Air/Fuel @ (Φ =1)	Mixture, MJ/kg	Φ, Limit		S_L (Limit), cm/s		S_L Φ =1, cm/s	Peak Flame Temp, K	Product/ Reactant Mole Ratio
				Lean	Rich	Lean	Rich			
H_2	121	34.4	3.41	0.01	7.17	65	75	270	2400	0.67
CO	10.2	2.46	2.92	0.34	6.80	12	23	45	2400	0.67
CH_4	50.2	17.2	2.76	0.54	1.69	2.5	14	35	2210	1.00
C_3H_8	46.5	15.6	2.80	0.52	2.26	-	-	44	2250	1.17
C_4H_{10}	45.5	15.4	2.77	0.59	2.63	-	-	44	2250	1.20
PG	5.00	1.35	2.12	0.47 a	1.60 b	10.3	12	50 c	1800 d	0.87

Results of Basic Research

- **Operation of gas engine with PG is possible without any limitation due to knock, this implies:**
  - **higher compression ratio (CR) can be adapted**
  - **Efficiency > 30%**
  - **Higher power for a given engine volume size**
- **Maximum de-rating of 16% at 17 CR, 26% at 11 CR**
- **Optimum ignition timing for NG different from NG**
- **The peak cylinder pressure is found to be lower compared to a diesel engine at comparable power level; this implies less wear and tear**
- **Emission friendly; low NOx & CO level**

Why need for a different Gas Carburetor ?

1. The air-to-fuel of NG is about 17:1(mass basis), whereas for PG it is about 1.3:1
2. NG carburetor requires gas under pressure ~ 1 bar, whereas PG is available at low pressure

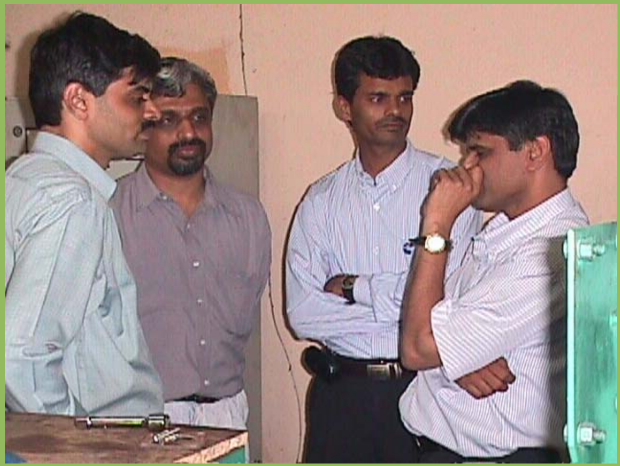


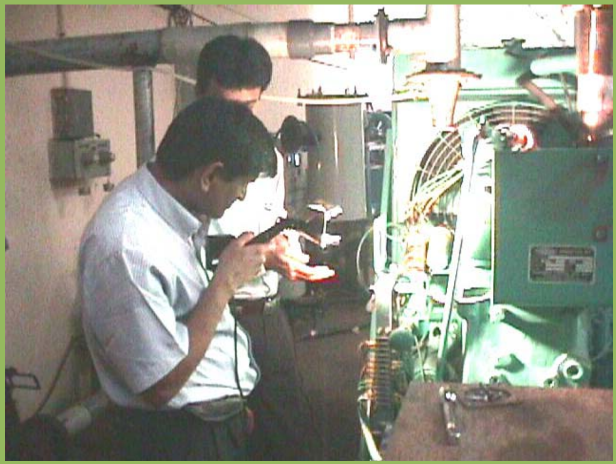
Designed to meet variable load operation

Collaborative work with Cummins

- It was hard to convince Cummins to offer their NG engine for PG
- Cummins laid a condition that engine needs to qualified on PG
- Two models of engines were tested at the laboratory
- Tested for 75 hours at the laboratory; two 24 hour run – active participation from Cummins
- Systematic trail conducted – energy input, power output and emissions were measured
- Condition of engine components were checked prior to and after the trail

Trails at the Lab …





Engine Components

Time T=0 Hours	T = 24 Hours
	
	
	

24 hour run

All engine components – throttle, manifold and valve were clean

Outcome of the collaborative work

- The laboratory trails very encouraging for Cummins; impressed with the gas quality & overall performance
- Initially 2 Engines were offered for commercial operations with close monitoring jointly by Cummins & IISc
- One engine has satisfactorily undergone this monitoring
- Today there are more than 12 installations with an installed capacity of over 3.0 MWe.
- Currently qualifying a 25 kWe engine for rural electrification package

Typical Applications

Application	Requirement
Rural Electrification	•Short duration ~ 4 – 6 hour/day, low PLF •High plant availability > 95% •Load reasonably constant
Industrial - Captive	•Continuous operation – 24 hr x 6/7 day a week •High plant availability > 90% •Large load fluctuations
Independent Power Producer – grid lined	•Continuous operation – 24 hr x 7 day a week •High plant availability > 90% •Large load fluctuations

Producer gas engine can meet each of the above applications

Energy Service Company - ESCO

Bagavathi Bio-Power @ Metupalyam, TN, India

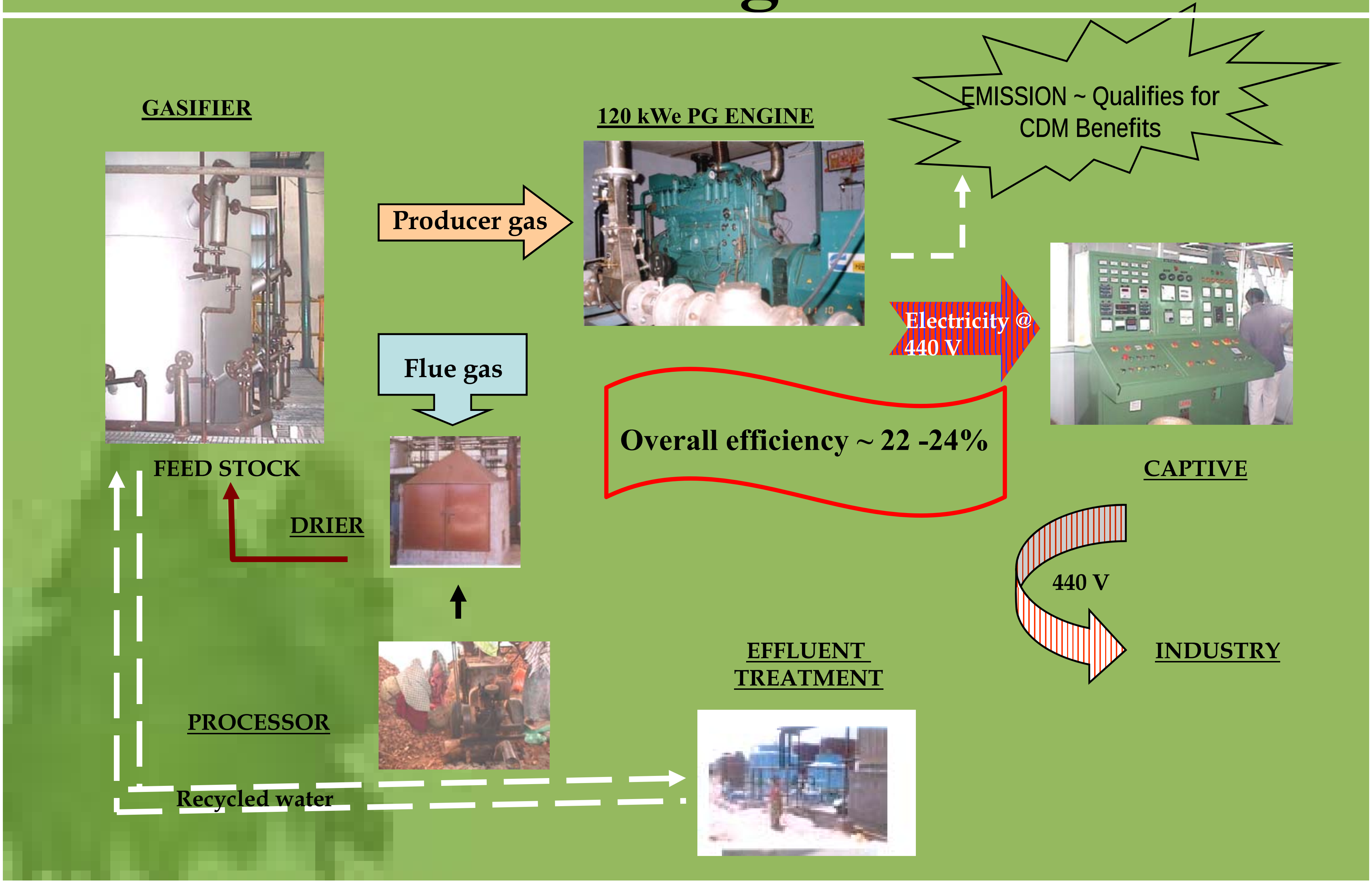
The Company

- Group Company of United Bleachers Limited, Mettupalayam, TN, one of the largest textile processing facilities in Tamil Nadu.
- UBL Imports over 270 kWe of power from TNEB grid @ Rs. 4.50 (US c 10)/kWh

The Power Plant

- 120 kWe power plant supported by 150 kg/hr Gasifier). Commissioned in August 2003.
- 100 % gas based system with Cummins gas engine GTA 855 G
- Feedstock is coconut shell & Julifora Prosopis
- 300 kg/hr waste heat drier installed to dry biomass with free energy from engine exhaust

Plant Configuration

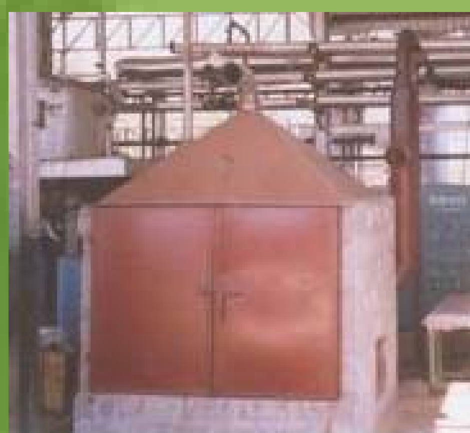


Snap Shots

The Power Plant

Gasifier Unit

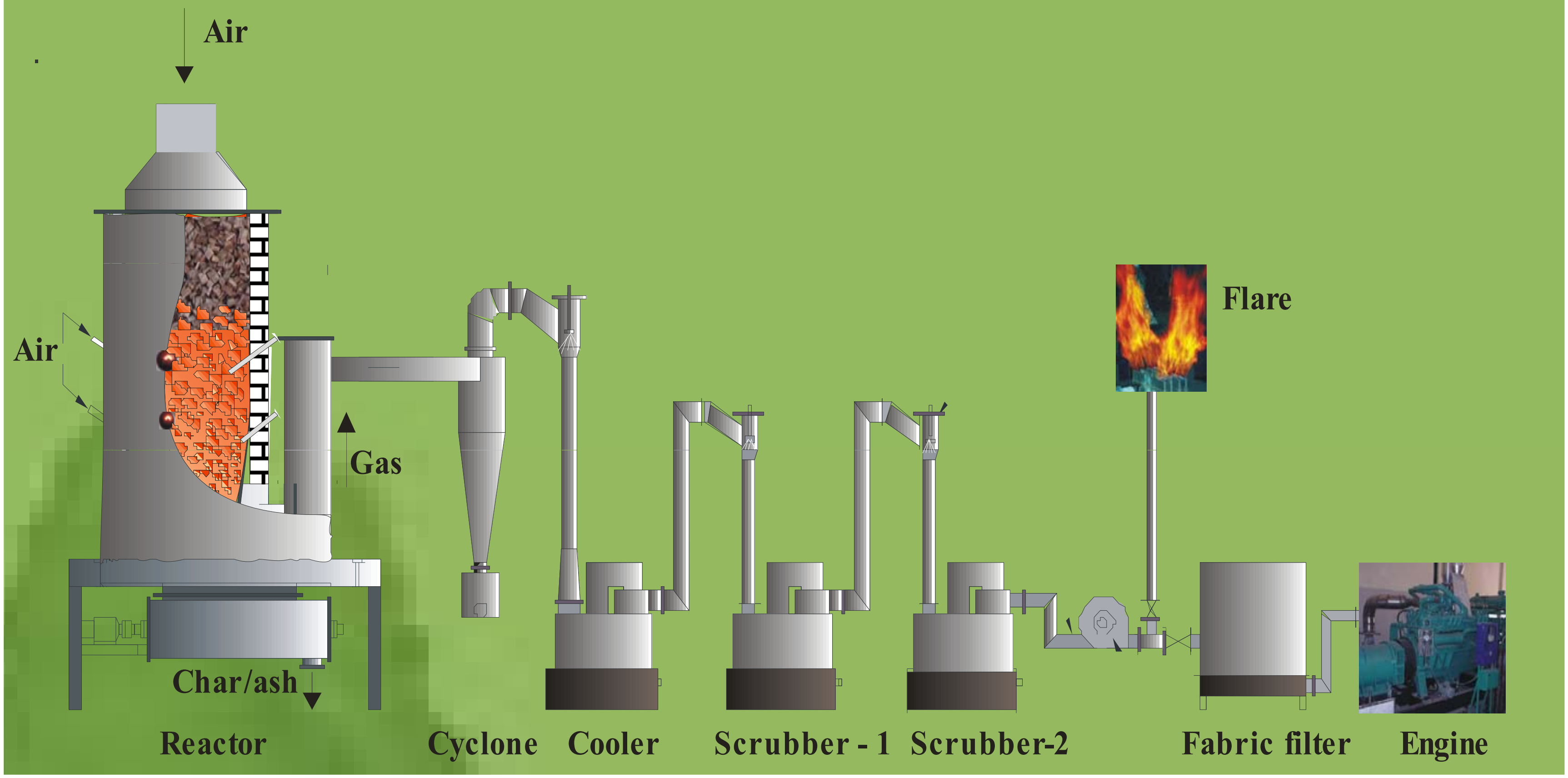
PG Engine



Biomass Drier

Effluent Treatment

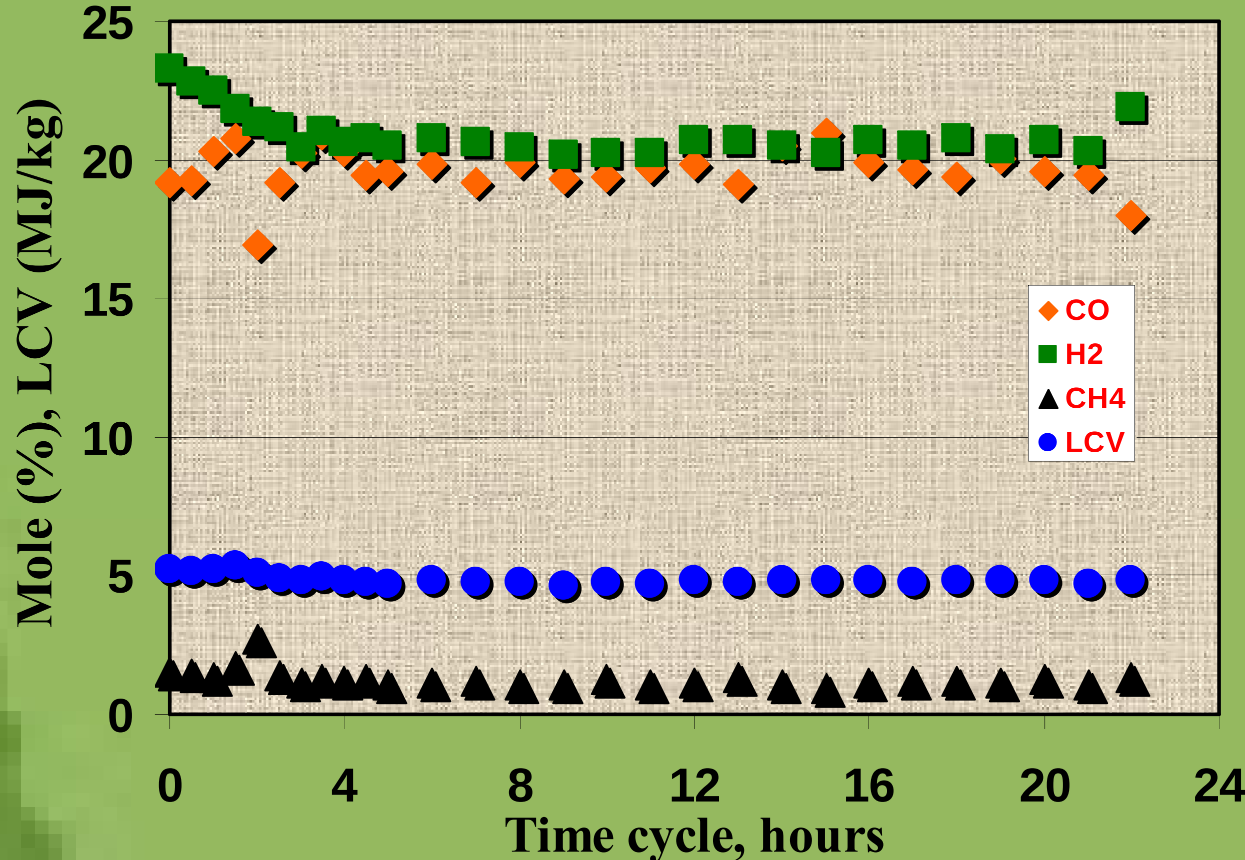
The Arrangement



Performance

- Max output of 134 kWe at an optimum ignition timing of 22° CA; nominal output is120 kWe
- 30 - 40% fluctuation in load
- Duty cycle 24 hours x 6 days
- Specific biomass consumption 1.1 $\pm$ 0.1 kg/kWh
- Biomass-to-Electricity : 22 - 24%
- Operated for more than 7500 hours

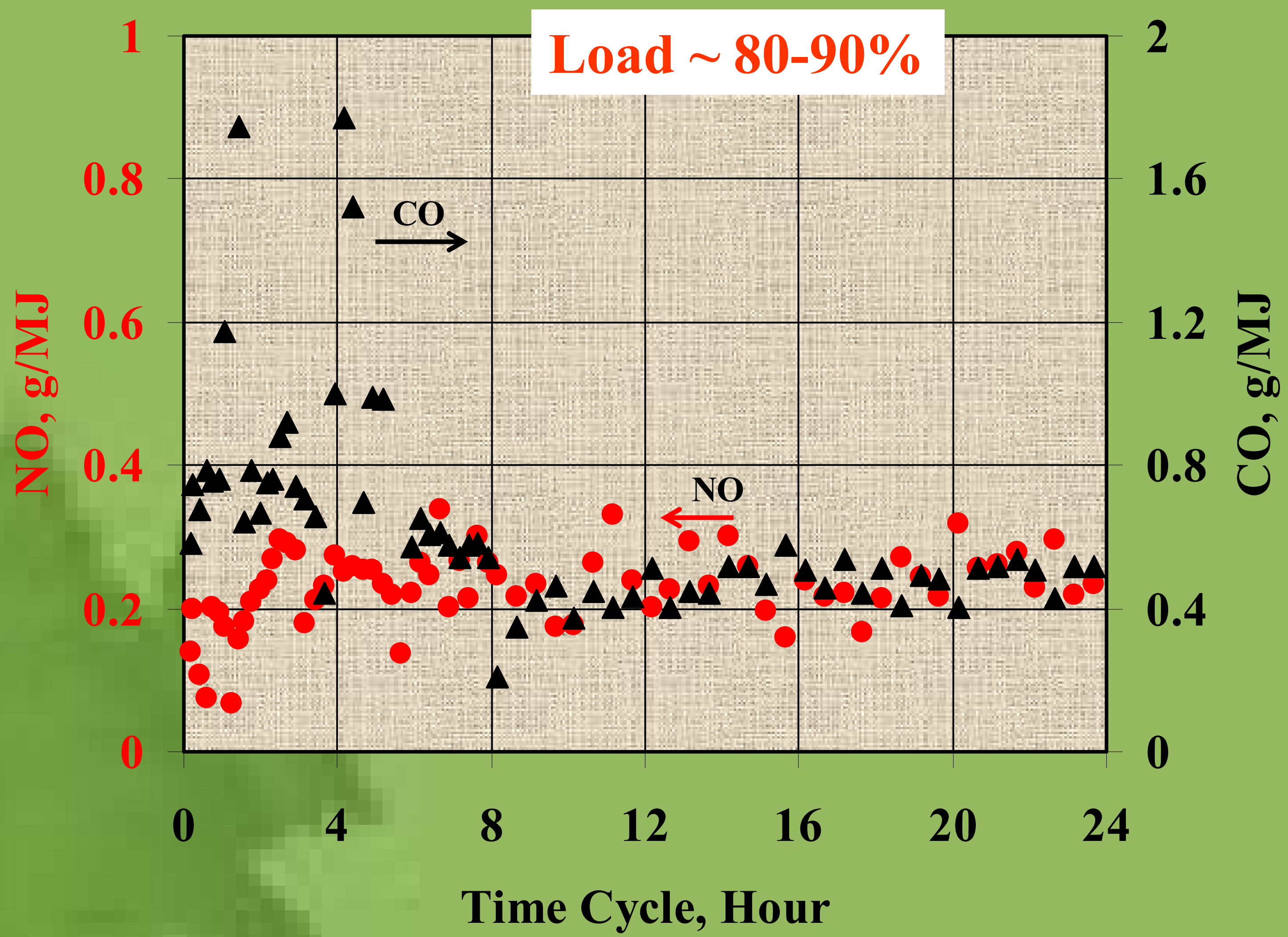
Producer Gas Composition



H_2 & CO : 19 $\pm$ 1%; CH_4 : 1.5%; LCV 4.7 + 0.1 MJ/kg

Cold Gas Efficiency : 80 - 82%

Emission

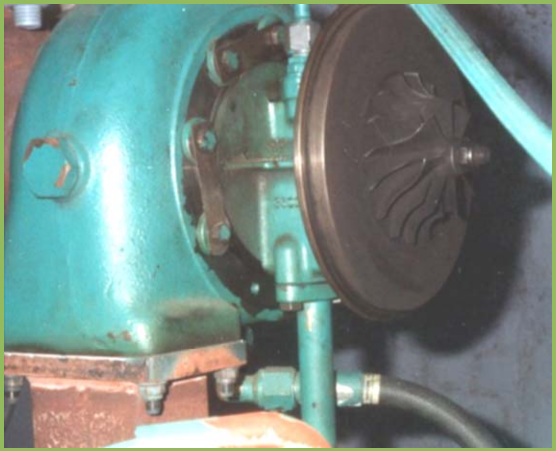


Load ~ 80-90%
CO
NO
NO, g/MJ
CO, g/MJ
Time Cycle, Hour
0
0.2
0.4
0.6
0.8
1
0
0.4
0.8
1.2
1.6
2
0
4
8
12
16
20
24

Emissions Norms

Parameter/Country	USA	EU	Japan	India
CO	3.06	1.4 - 1.8	1.67	1.25 (3.9)
NOx	2.56	2.56	2.6 - 3.06	2.22 (5.0)
HC	0.36	0.36	0.4 - 0.56	0.3 (0.98)
PM	0.15	0.15 - 0.24	-	0.1 –0.2 (<3.5 Bosch)
KOEL Engine results between 6 to 20° CA for all CRs at Φ = 1.0 – 1.2				
Parameter/CR	**17.0**	**14.5**	**13.5**	**11.5**
CO	1.1 – 11.0	11.0 – 15.0	4.0 –16.0	9.0 –14.0
NOx	0.03 – 0.28	0.02 – 0.22	0.03 –0.20	0.05
PM	< 0.014			
Greaves Engine results between 12 to 24° CA for CR=12.0 at Φ = 0.94 - 0.97				
CO	0.58 – 1.2			
NOx	0.32 – 0.7			
PM	< 0.0005			
Cummins Engine results between 22 to 24° CA for CR=10.0 at Φ = 1.01 -1.03				
CO	0.4 – 1.8			
NOx	0.2 – 0.7			
PM	<< 0.0005			

Joint field inspection by IISc & Cummins after 3000 hours



Compressor Impeller

Compressor Casing

- Least amount of deposits on the engine components ~ particulate matter < 200 ppb
- Spark plug found clean
- No wear of cylinder liner

Lube Oil Analysis

Parameter	Fresh Oil	Used Oil (496 hrs)	Limit*
Kinematic viscosity @ 40° C, cSt	114	95	Low - 85 High - 155
TBN, mg KOH/g	5.7	2.2	2.0

*as per Cummins

- Oil quality inspected after every 200 hours and well within the qualifying limits
- No water content in the oil
- Wear metals < 100 ppm
- Oil change recommended at 500 hours

Techno-Economics

Investment Details

Capital Investment: 100,000 US$

Federal Govt. Subsidy : 27,000 US$

Electricity Generation Cost	**US Cent/kWh**
Feed stock	3.4 (2.7 per kg)
Maintenance	0.35
Labour	1.0
Sub-Total (A)	4.75
Depreciation (B) at 6% per annum	0.45
Sub-Total (A+B)	**5.20**
Revenue from Charcoal (C)	0.50
Net Generation Cost (A+B-C)	**4.70**
Grid Electricity	10.0
Sale of Electricity	7.70
Income for 0.6 Million units/year	**18,000 US$**
Return on Investment (with out subsidy)	18%
Return on Investment (with subsidy)	25%

Achievements

Scenario (end of 2005)

- Knowledge base on PG engine operation has been established
- Technology demonstrated with better reliability and uninterrupted operation
- Issues w.r.t. gas engine/s satisfactorily addressed
  - Technical issue w.r.t turbocharger on larger engine
  - Cummins considering extending warranties on engines with PG
  - Cummins willing to label gas engines as PG engines and market them
- Currently turbocharger basic studies are on to optimize the performance further
- More than 12 units totaling to 3.0 MWe equivalent plants working; Cumulative experience > 27,000 hours
- Cost of electricity generation ~ 5 US Cents against 10 US Cents (grid)

Thinking you