

ComAp



**Bi-Fuel  
conversion  
Caterpillar C-32**

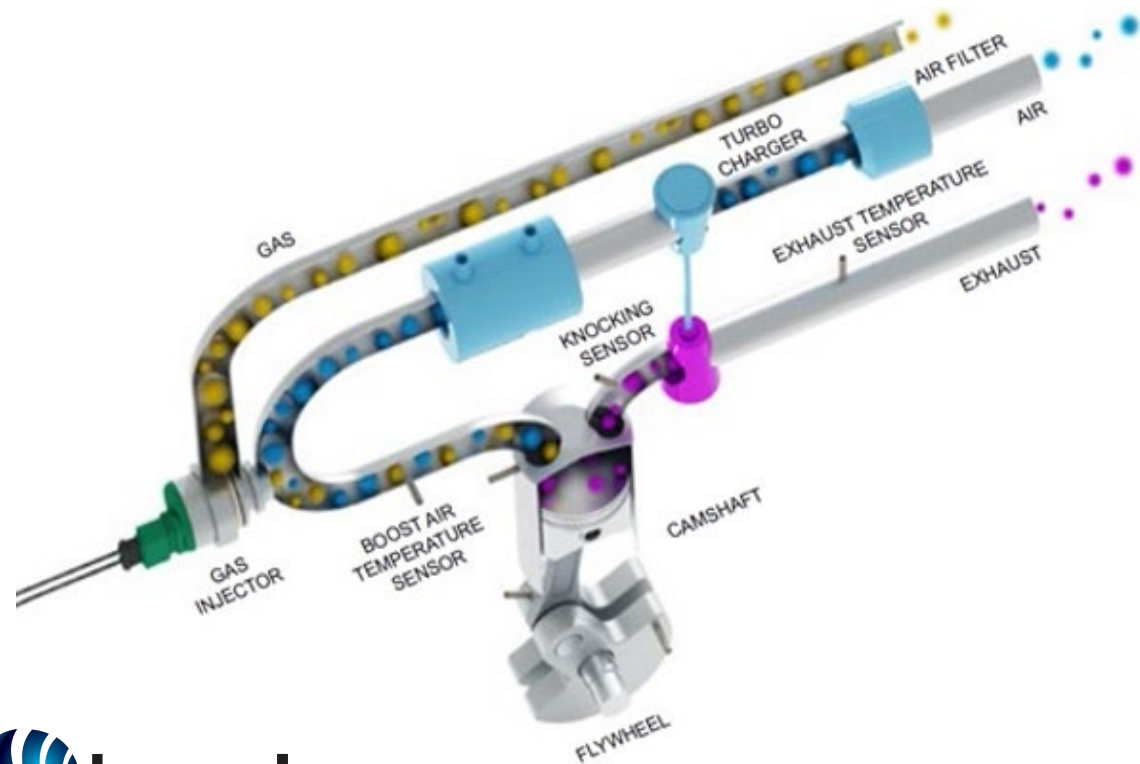
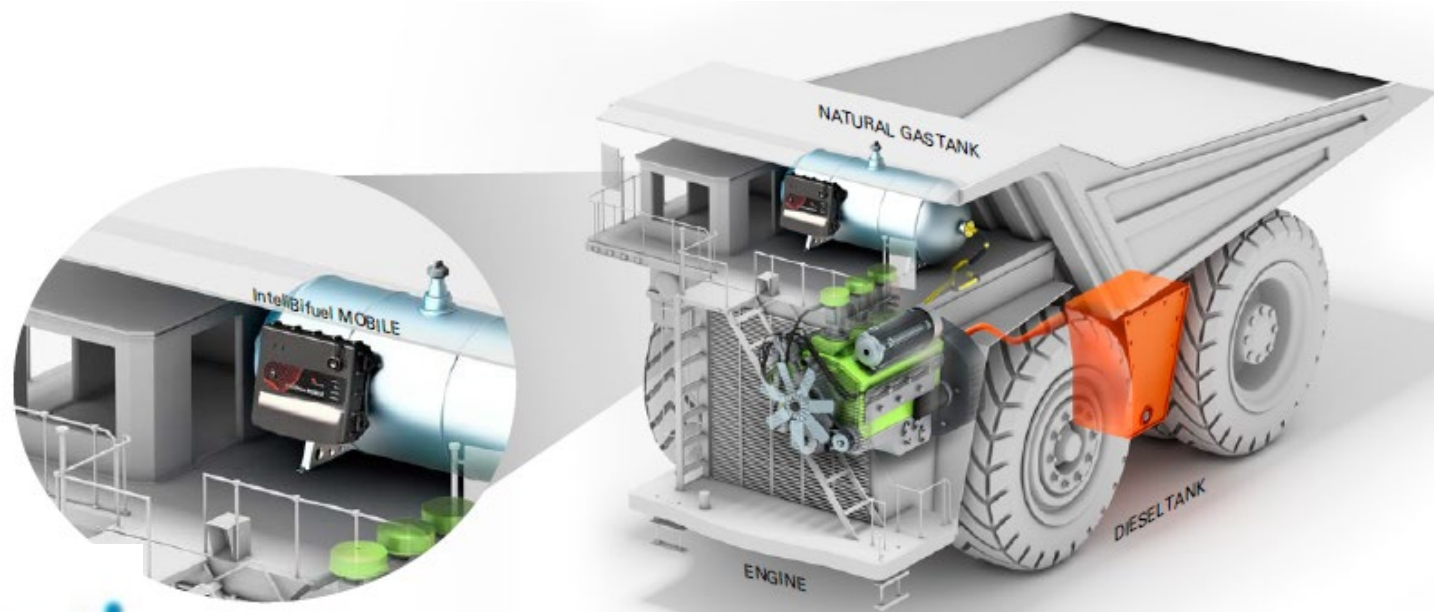


**LIMEDA  
INTERNATIONAL**

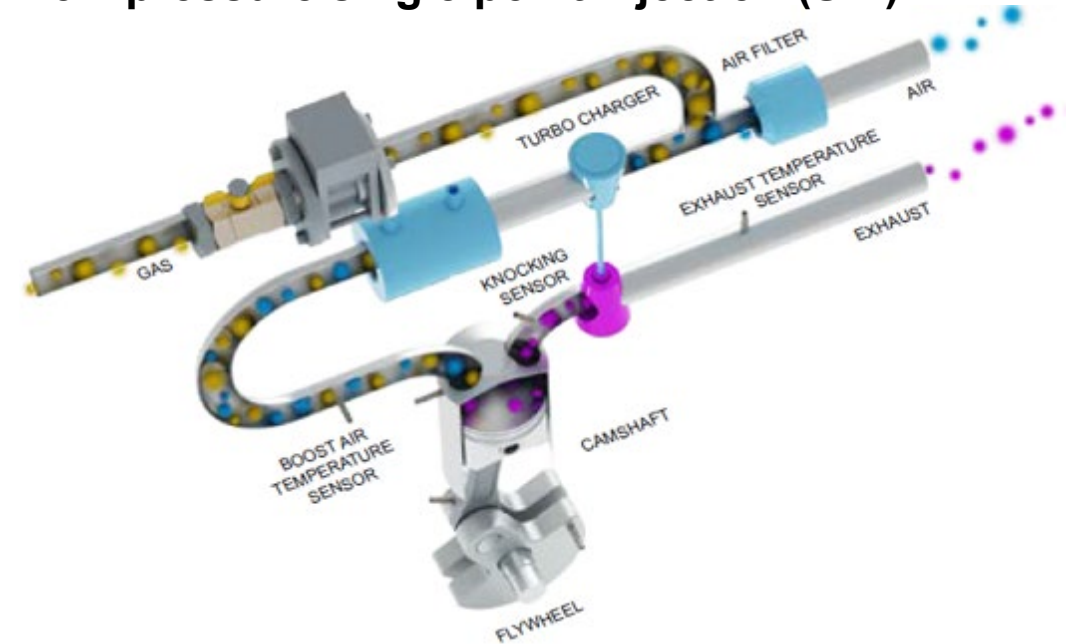
# Technological principle:

## High pressure single point injection (SPI) - Truck

- 4 – 9 bar
- Injection after the intercooler
- Sequential gas injection
- Ideal for CNG/I NG solutions

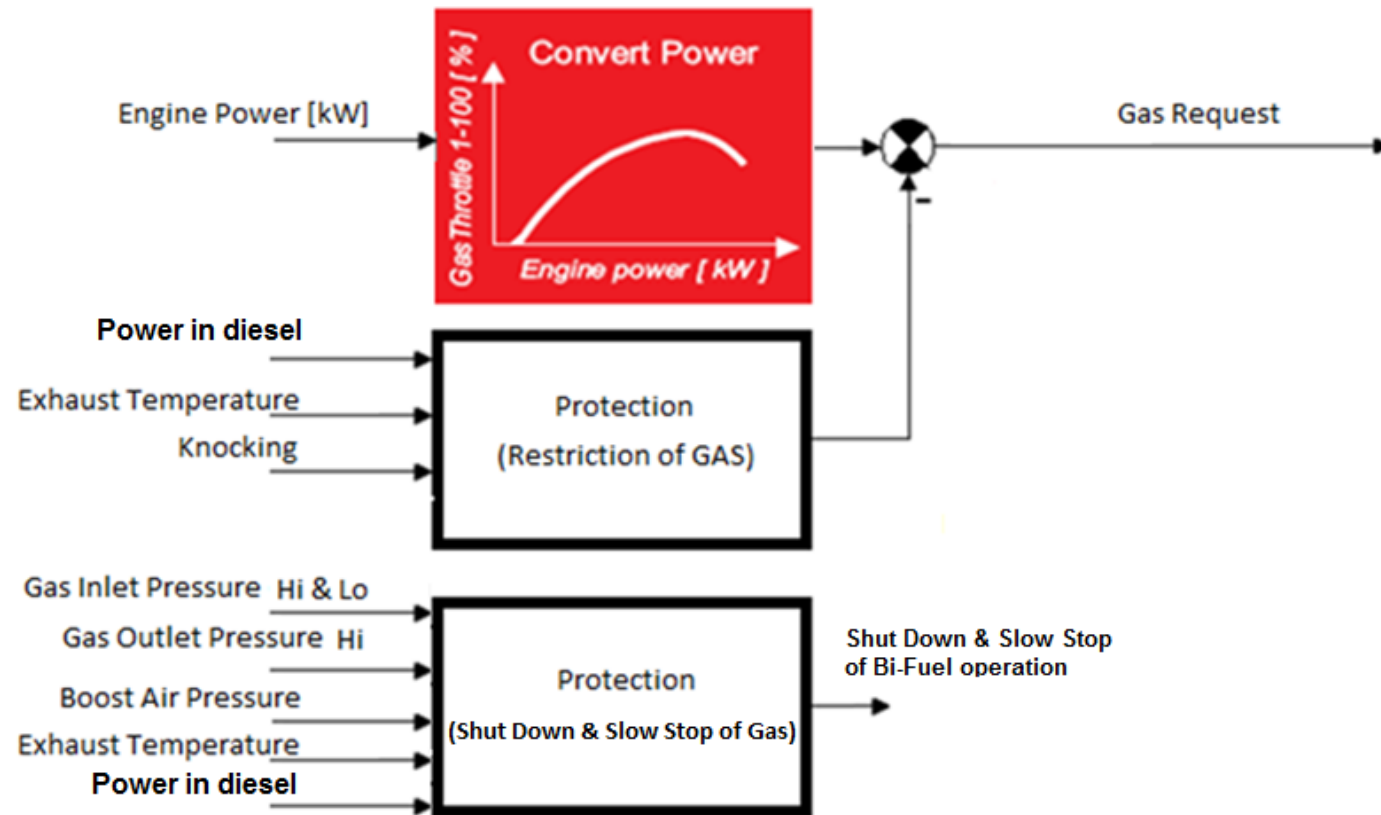


## Dyno test configuration Low pressure single point injection (SPI)



# Bi-Fuel Mode

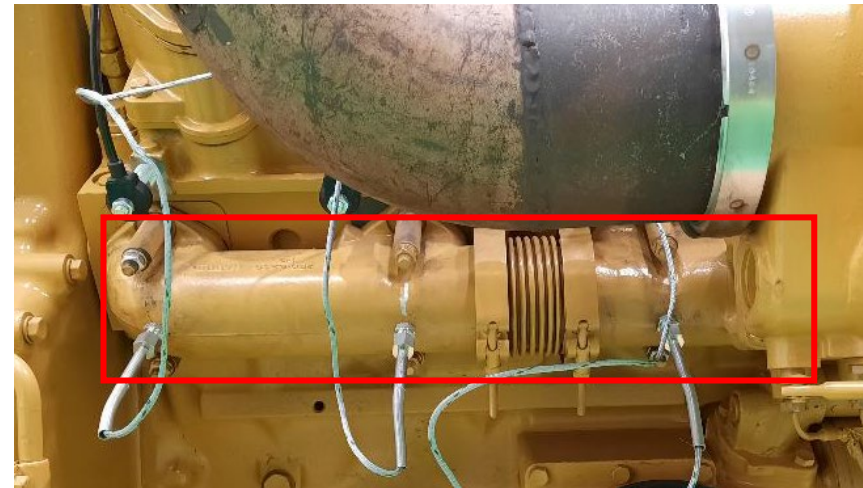
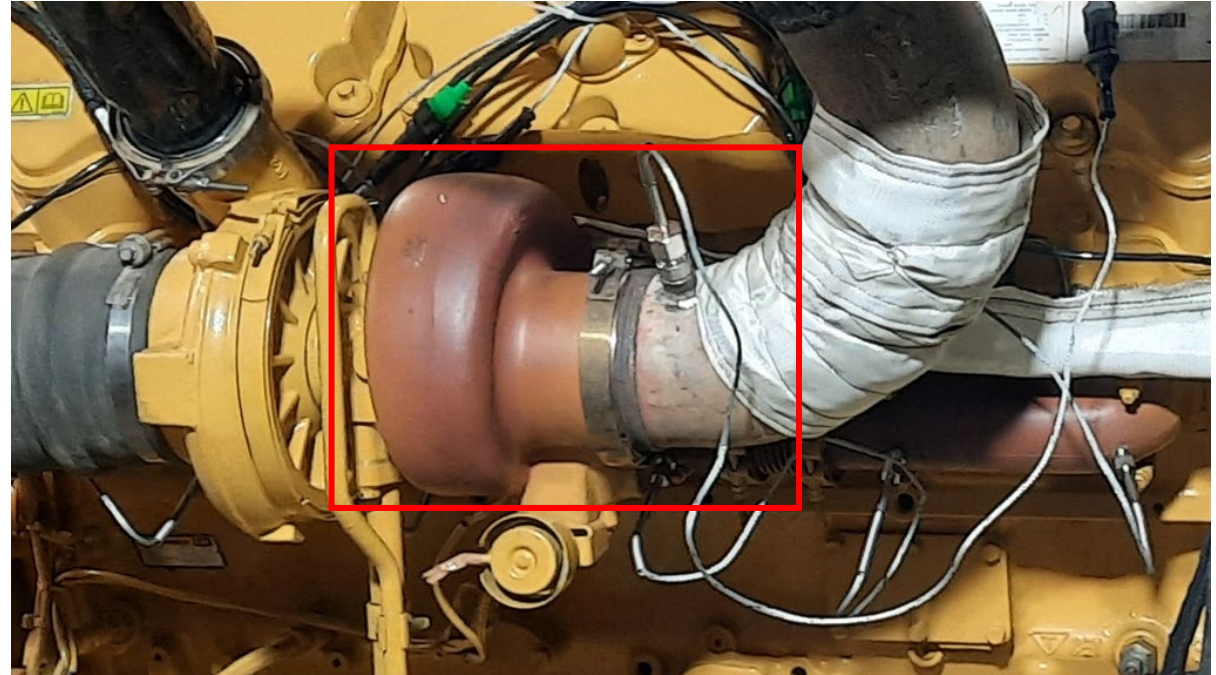
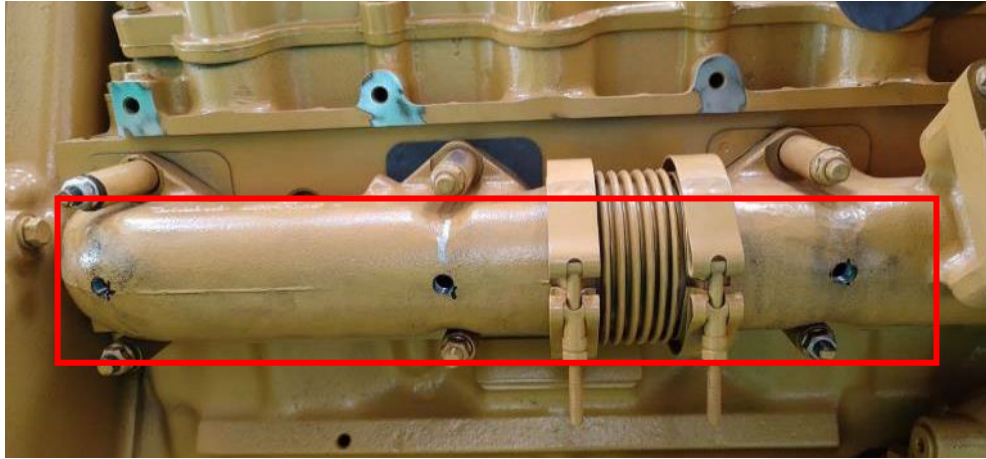
## Principle of control and protections



## Engine modification and installation.

### Exhaust temperature sensors:

- Modified exhaust manifold and turbocharger outlet elbow.
- Installed exhaust temperature sensors (12 Nos.) for monitoring individual cylinder temperatures.
- Thermocouples (2 Nos.) for monitoring exhaust temperature downstream turbocharger.



### Denox sensors:

- 12 Nos. of knock detection sensors (Denox sensors) installed on both cylinder heads.
- Covered with thermal protection shield to avoid damage due to high temperature.



Denox sensors with thermal protection

### Cam position sensor :

- Modified camshaft gear.
- Modified camshaft cover.



### **Boost air pressure and temperature sensor :**

- Boost air pressure and temperature (One each) on left side of the engine.
- Dump truck will be equipped with two sensors each for boost air pressure and temperature sensors.



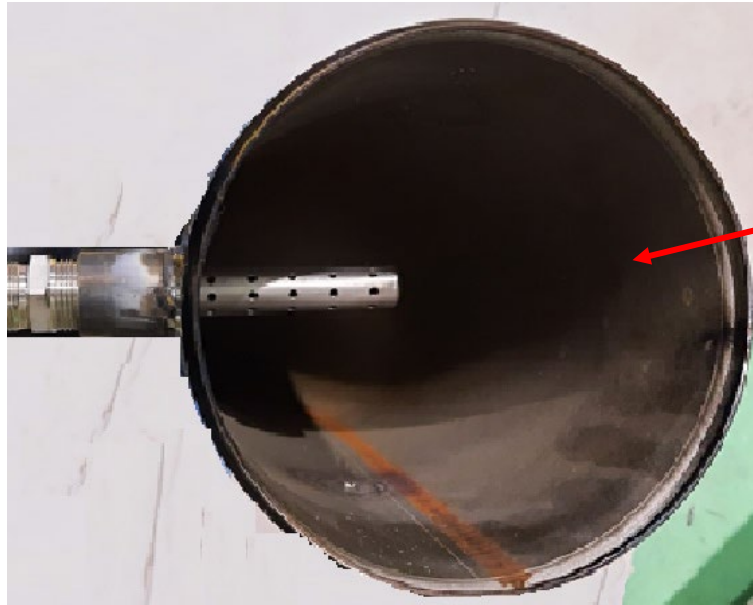
Modified Air intake duct for installation of pressure and temperature sensors

## Injector and Nozzle:

- Two SPI units installed on both bank of engine.
- Air intake manifolds are modified and installed nozzles for gas mixing.



SPI Unit



Modified air intake manifold

## Gas train :

Consisting following components

1. Ball Valve
2. Filter
2. Gas Pressure Regulator
3. Dual Shut-off valves
4. Pressure and temperature Switches



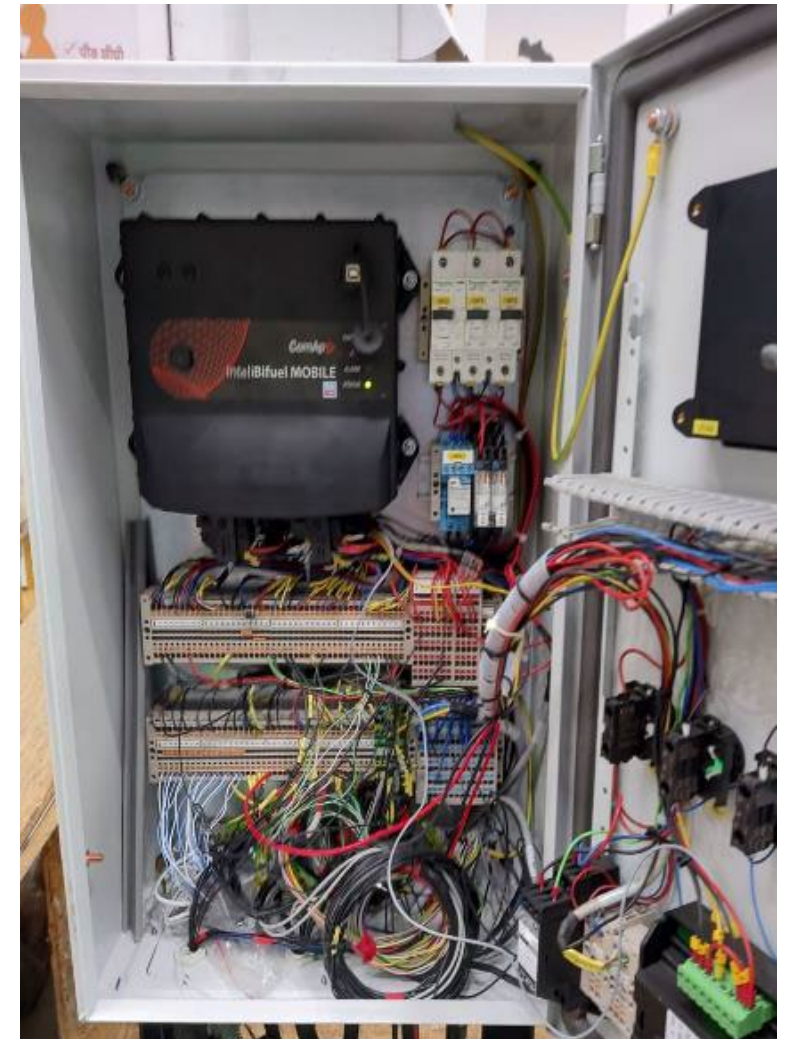
Gas Train

## HSC Panel & Harness :

- ComAp HSC control panel mainly consisting of
  1. IBF-mobile unit
  2. Denox controller
  3. PWM module
  4. Inteli vision 5 -display module
  5. Emergency stop switch
- Harness installation to connect Bi-Fuel sensors to Bi-Fuel controller



HSC PANEL



## Engine mapping in Bi-Fuel operation

### Purpose :

1. To understand the overall behaviour of the engine operating under Bi-Fuel operation.
2. To identify the permissible gas substitution with safe engine operation.
3. To identify the possible amount of reduction in diesel consumption.
4. To monitor knocking/detonation with gas substitution.

### Procedure :

1. Real time engine parameter monitoring at various G/D ratio and recording through win scope.
2. Recording and analysing sound patterns of individual cylinders at various G/D ratio.
3. Data evaluation.



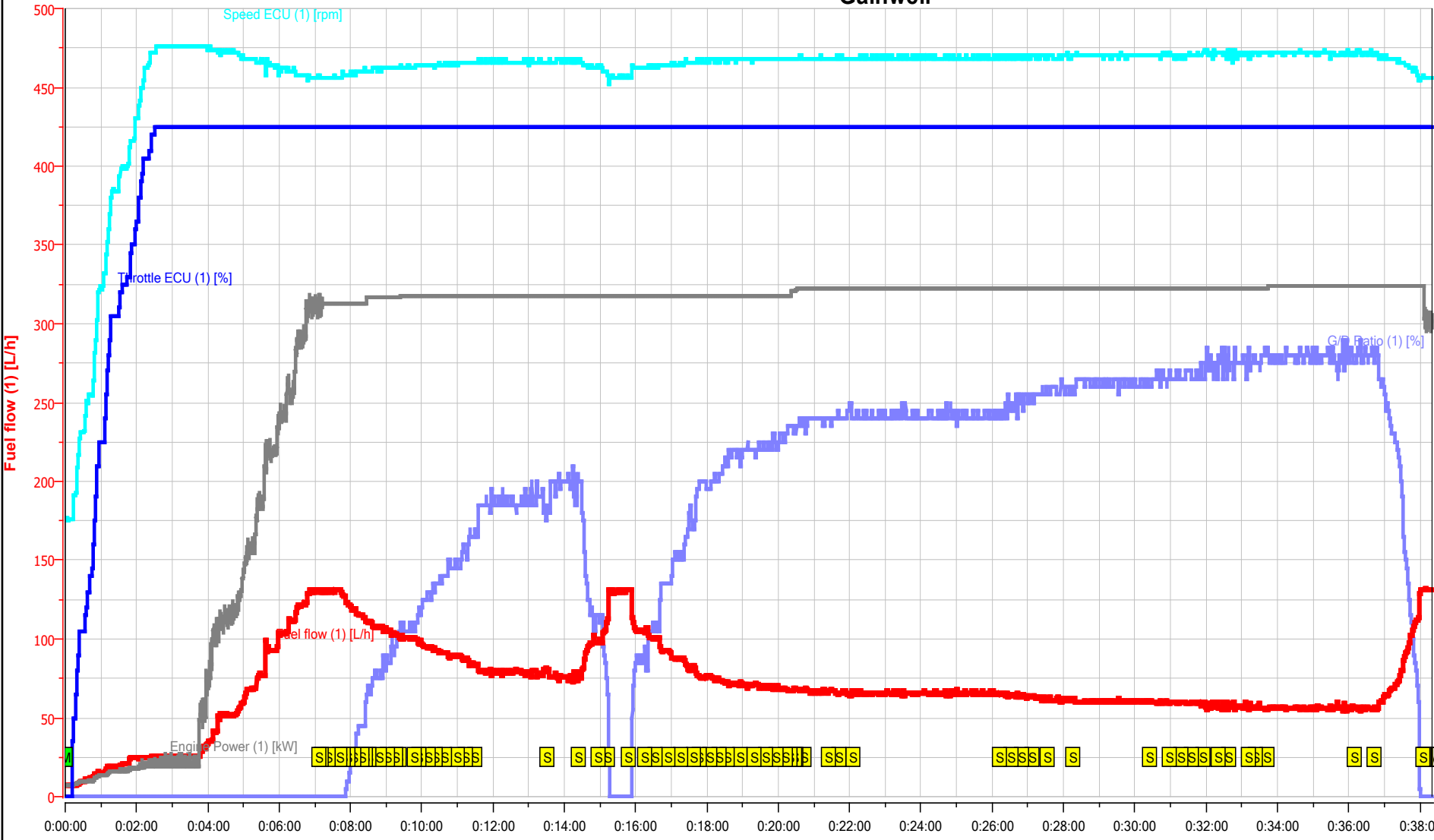
## Engine performance – Bi-Fuel operation

APP [%]	Power [kW]	G/D Ratio [%]	Diesel consumption (diesel mode) (Lit/Hr)	Diesel consumption (Bi-Fuel mode) (Lit/Hr)	Diesel Saving (Lit/Hr)
60	300	30	77	54	23
60	460	39	110	67	43
65	300	30	77	52	15
65	518	44	124	72	52
70	650	30	160	117	43
75	300	25	80	60	20
75	400	50	104	52	52
75	500	53	127	60	67
75	600	40	149	94	55
75	650	30	160	117	43
75	700	24	170	136	34
85	300	30	75	53	22
85	400	45	106	59	47
85	500	56	132	59	73
85	600	40	157	93	64
85	650	30	166	117	49
85	700	28	172	124	40
90	600	38	157	97	60
100	500	50	133	67	66
100	600	38	158	98	60

- This table presents samples of measured and already evaluated data.
- Gas/Diesel ratio was set in terms of avoiding knocking and maintain steady and safe BF operation at water brake test cell.

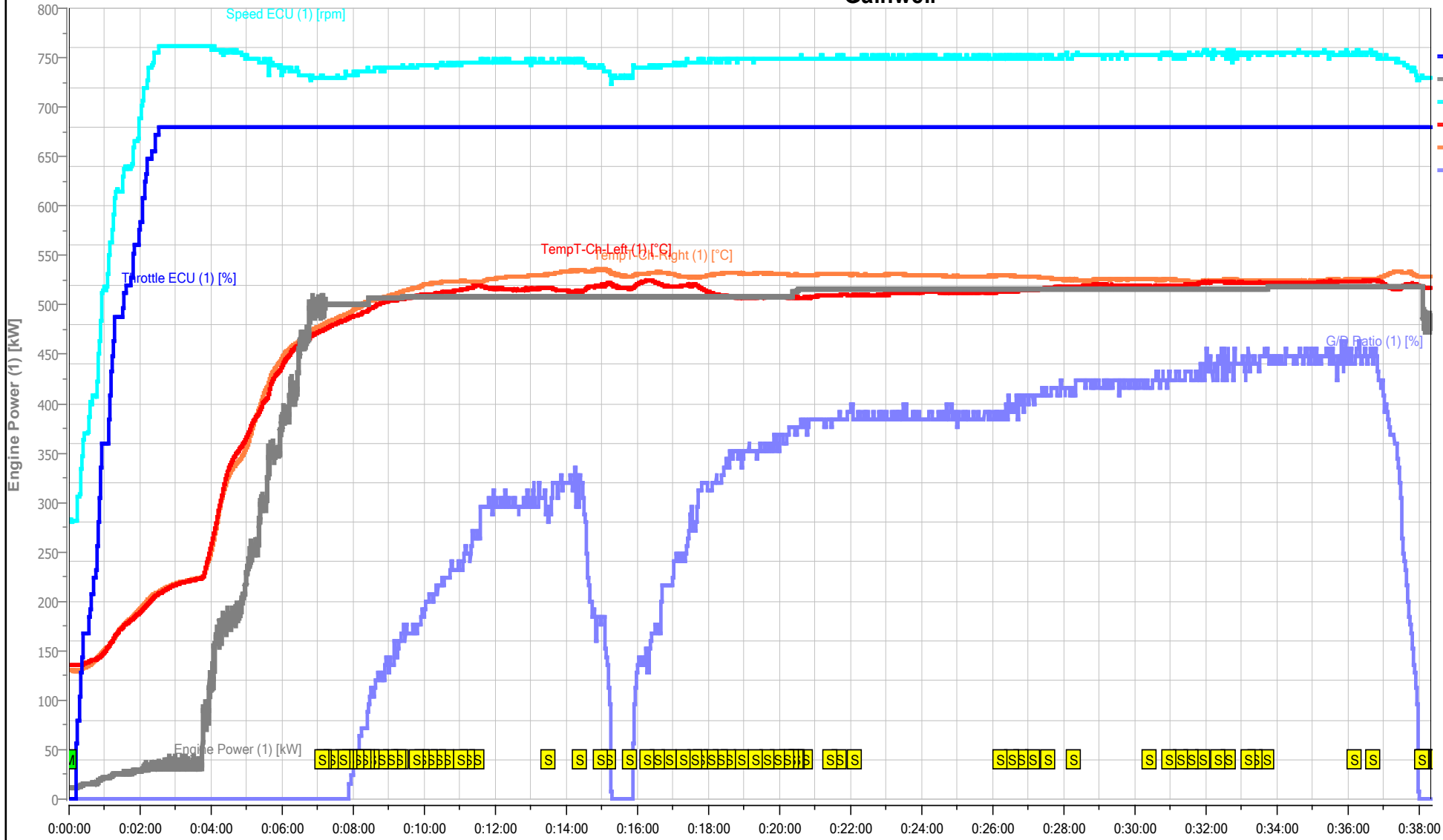
Sample of evaluated data –Bi-fuel operation

# Gainwell



Name	Time	Value	Max	Min	Avg
Throttle ECU (1) [%]	0:38:20	85	85	0	83
Engine Power (1) [kW]	0:38:20	489	518	11	446
Speed ECU (1) [rpm]	0:38:20	1824	1904	700	1835
Fuel flow (1) [L/h]	0:38:20	131	132	7	71
G/D Ratio (1) [%]	0:38:20	0	58	0	33

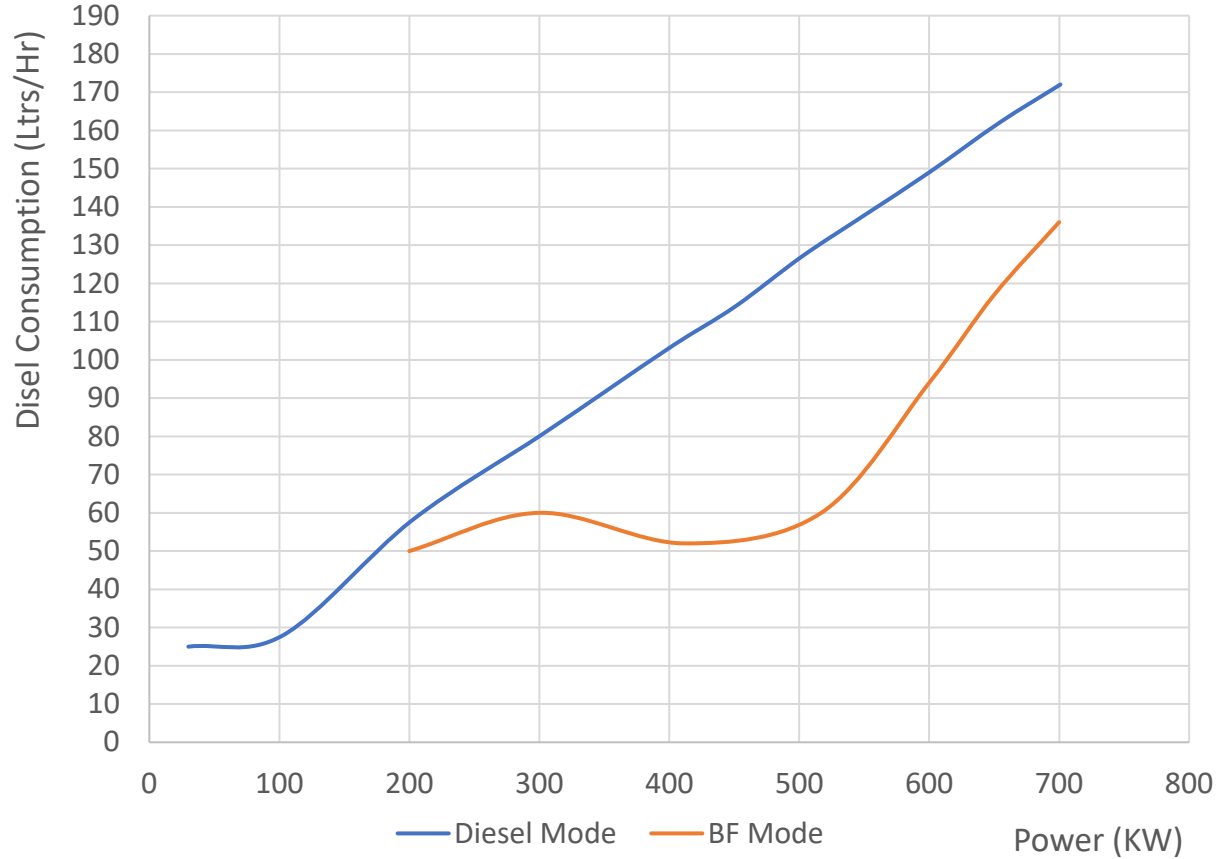
# Gainwell



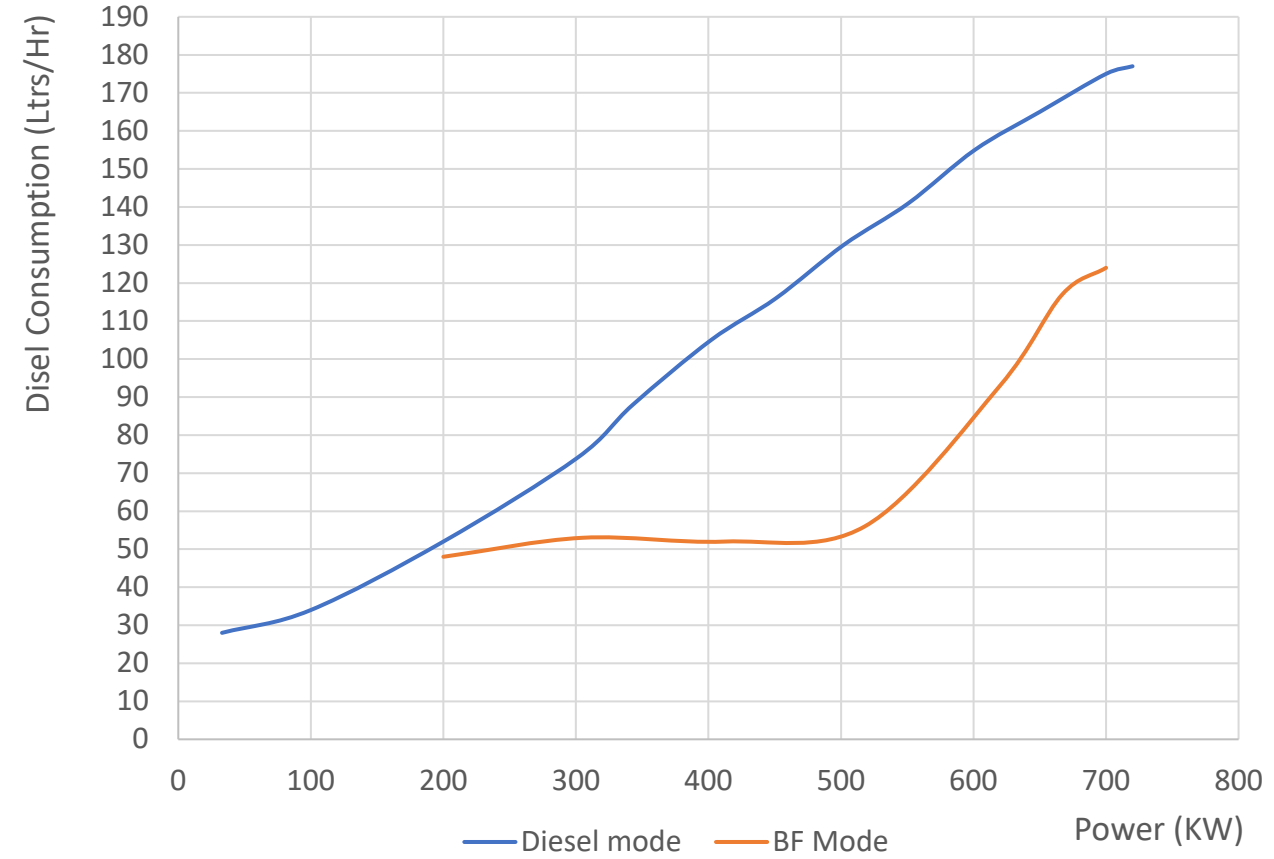
Name	Time	Value	Max	Min	Avg
Throttle ECU (1) [%]	0:38:20	85	85	0	83
Engine Power (1) [kW]	0:38:20	489	518	11	446
Speed ECU (1) [rpm]	0:38:20	1824	1904	700	1835
TempT-Ch-Left (1) [°C]	0:38:20	420	426	110	382
TempT-Ch-Right (1) [°C]	0:38:20	429	436	105	390
G/D Ratio (1) [%]	0:38:20	0	58	0	33

# Engine performance – Bi-Fuel operation

## DieselConsumption @ 75 % APP

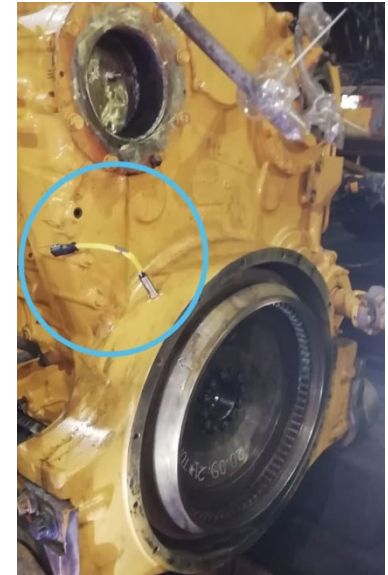


## DieselConsumption @ 85 % APP



Comparison diesel consumption with/without gas substitution .

# Glimpses of installation on the Truck



THANK YOU FOR YOUR TIME!

**CATERPILLAR C32 777**

2021-04-08

Total operational hours: 9610 hrs based on ECM report

Diesel: INR	80	litre
LNG: INR	35	m <sup>3</sup>

Average saving per hour: **545** INR

Expeting the calorific value of 1 m<sup>3</sup> LNG equals to 1 kg Diesel

Estimated G/D ratio for selected engine operations (+/- 5%)

G/D %			RPM			
			≤1099	1100-1499	1500-1899	1900-2400
L O A D	0-49%	0-334 kW	0	0	0	
	50-59%	334-402 kW	50	55	60	
	60-69%	402-470 kW	50	55	60	
	70-79%	470-539 kW		50	60	60
	80-89%	539-607 kW		35	40	40
	90-100%	607-682 kW		25	30	30

Diesel consumption
l/h
20
115
130
145
160
180

Summary of operational time based on ECM report

TIME Hours			RPM			
			≤1099	1100-1499	1500-1899	1900-2400
L O A D	0-49%	0-334 kW	4461	1141	1870	
	50-59%	334-402 kW	22	73	115	
	60-69%	402-470 kW	9	80	100	
	70-79%	470-539 kW		52	100	
	80-89%	539-607 kW		40	100	
	90-100%	607-682 kW		520	900	
Σ hours			<b>9583</b>			

x

Time distribution per time unit

TIME in %			RPM			
			≤1099	1100-1499	1500-1899	1900-2400
L O A D	0-49%	0-334 kW	46,55	11,91	19,51	
	50-59%	334-402 kW	0,23	0,76	1,20	
	60-69%	402-470 kW	0,09	0,83	1,04	
	70-79%	470-539 kW		0,54	1,04	0,00
	80-89%	539-607 kW		0,42	1,04	0,00
	90-100%	607-682 kW		5,43	9,39	0,00

DIESEL Consumption l/h			RPM			
			≤1099	1100-1499	1500-1899	1900-2400
L O A D	0-49%	0-334 kW	8,92	2,28	3,74	
	50-59%	334-402 kW	0,25	0,84	1,32	
	60-69%	402-470 kW	0,12	1,04	1,30	
	70-79%	470-539 kW		0,75	1,45	0,00
	80-89%	539-607 kW		0,64	1,60	0,00
	90-100%	607-682 kW		9,36	16,20	0,00
Σ l/h			<b>49,82</b>			

DIESEL Reduction l/h			RPM			
			≤1099	1100-1499	1500-1899	1900-2400
L O A D	0-49%	0-334 kW	0,00	0,00	0,00	
	50-59%	334-402 kW	0,13	0,46	0,79	
	60-69%	402-470 kW	0,06	0,57	0,78	
	70-79%	470-539 kW		0,38	0,87	0,00
	80-89%	539-607 kW		0,22	0,64	0,00
	90-100%	607-682 kW		2,34	4,86	0,00
Σ l/h			<b>12,10</b>			

Total G/D % **24,29**

## 3D mapping & Configuration

### Purpose :

1. The configuration is prepared in ComAp controller v engine operation in Bi-Fuel mode.
2. This also includes setting limits of denox sensors, ex operation.

3D Closed Loop of GD relative fill air example

