APPENDIX

APPENDIX

Table 18 The results of the first performance test on the chassis dynamometer for this research project

	Diesel Mode			HCNG DDF Mode		
n	v	P	M	v	P	M
RPM	km/h	BHP	Nm	km/h	BHP	Nm
1400	47.9	22.8	116.80	61.31	29.18	149.50
1500	51.3	28.90	138.10	65.66	36.99	176.77
1600	54.7	38.20	170.80	70.02	48.90	218.62
1700	58.2	51.40	216.40	74.50	65.79	276.99
1800	61.6	65.00	258.60	78.85	83.20	331.01
1900	65	79.20	298.40	83.20	101.38	381.95
2000	68.4	92.40	330.90	87.55	118.27	423.55
2100	71.9	96.70	329.90	92.03	123.78	422.27
2200	75.3	100.50	327.30	96.38	128.64	418.94
2300	78.7	104.50	325.60	100.74	133.76	416.77
2400	82.1	107.60	321.00	105.09	137.73	410.88
2500	85.5	110.20	315.70	109.44	141.06	404.10
2600	89	112.70	310.50	113.92	144.26	397.44
2700	92.4	115.50	306.30	118.27	147.84	392.06
2800	95.8	117.90	301.50	122.62	150.91	385.92
2900	99.2	119.00	293.80	126.98	152.32	376.06
3000	102.7	119.50	285.30	131.46	152.96	365.18
3100	106.1	120.80	279.00	135.81	154.62	357.12
3200	109.5	122.00	273.00	140.16	156.16	349.44
3300	112.9	122.50	265.80	144.51	156.80	340.22
3400	116.3	122.40	257.70	148.86	156.67	329.86
3500	119.8	122.90	251.40	153.34	157.31	321.79
3600	123.2	123.00	244.80	157.70	157.44	313.34
3700	126.6	121.30	234.80	162.05	155.26	300.54
3800	130	117.60	221.60	166.40	150.53	283.65

Date : 19 September 2013

Time : 16:30

Place : LTestCar, 64/12 Srinakarin Road, Suanluang, Bangkok 10250 Thailand

Performance Test : First Test

Table 19 The results of the second performance test on the chassis dynamometer for this research project

	Diesel Mode			HCNG DDF Mode		
n	v	P	M	v	P	M
RPM	km/h	BHP	Nm	km/h	BHP	Nm
1400	49.34	23.48	120.30	63.15	30.06	144.36
1500	52.84	29.77	142.24	67.63	38.10	170.69
1600	56.34	39.35	175.92	72.12	50.36	211.11
1700	59.95	52.94	222.89	76.73	67.77	267.47
1800	63.45	66.95	266.36	81.21	85.70	319.63
1900	66.95	81.58	307.35	85.70	104.42	368.82
2000	70.45	95.17	340.83	90.18	121.82	408.99
2100	74.06	99.60	339.80	94.79	127.49	407.76
2200	77.56	103.52	337.12	99.28	132.50	404.54
2300	81.06	107.64	335.37	103.76	137.77	402.44
2400	84.56	110.83	330.63	108.24	141.86	396.76
2500	88.07	113.51	325.17	112.72	145.29	390.21
2600	91.67	116.08	319.82	117.34	148.58	383.78
2700	95.17	118.97	315.49	121.82	152.28	378.59
2800	98.67	121.44	310.55	126.30	155.44	372.65
2900	102.18	122.57	302.61	130.79	156.89	363.14
3000	105.78	123.09	293.86	135.40	157.55	352.63
3100	109.28	124.42	287.37	139.88	159.26	344.84
3200	112.79	125.66	281.19	144.36	160.84	337.43
3300	116.29	126.18	273.77	148.85	161.50	328.53
3400	119.79	126.07	265.43	153.33	161.37	318.52
3500	123.39	126.59	258.94	157.94	162.03	310.73
3600	126.90	126.69	252.14	162.43	162.16	302.57
3700	130.40	124.94	241.84	166.91	159.92	290.21
3800	133.90	121.13	228.25	171.39	155.04	273.90

Date : 19 September 2013

Time : 16:45

Place : LTestCar, 64/12 Srinakarin Road, Suanluang, Bangkok 10250 Thailand

Performance Test : Second Time

Table 20 The results of the Third performance test on the chassis dynamometer for this research project

	Diesel Mode			HCNG DDF Mode		
n	v	P	M	v	P	M
RPM	km/h	BHP	Nm	km/h	BHP	Nm
1400	49.82	23.71	121.47	65.68	31.26	145.77
1500	53.35	30.06	143.62	70.34	39.63	172.35
1600	56.89	39.73	177.63	75.00	52.38	213.16
1700	60.53	53.46	225.06	79.80	70.48	270.07
1800	64.06	67.60	268.94	84.46	89.12	322.73
1900	67.60	82.37	310.34	89.12	108.59	372.40
2000	71.14	96.10	344.14	93.79	126.69	412.96
2100	74.78	100.57	343.10	98.58	132.59	411.72
2200	78.31	104.52	340.39	103.25	137.80	408.47
2300	81.85	108.68	338.62	107.91	143.28	406.35
2400	85.38	111.90	333.84	112.57	147.53	400.61
2500	88.92	114.61	328.33	117.23	151.10	393.99
2600	92.56	117.21	322.92	122.03	154.53	387.50
2700	96.10	120.12	318.55	126.69	158.37	382.26
2800	99.63	122.62	313.56	131.35	161.66	376.27
2900	103.17	123.76	305.55	136.02	163.17	366.66
3000	106.81	124.28	296.71	140.82	163.85	356.05
3100	110.34	125.63	290.16	145.48	165.63	348.19
3200	113.88	126.88	283.92	150.14	167.28	340.70
3300	117.42	127.40	276.43	154.80	167.96	331.72
3400	120.95	127.30	268.01	159.46	167.83	321.61
3500	124.59	127.82	261.46	164.26	168.51	313.75
3600	128.13	127.92	254.59	168.92	168.65	305.51
3700	131.66	126.15	244.19	173.59	166.32	293.03
3800	135.20	122.30	230.46	178.25	161.25	276.56

Date : 19 September 2013

Time : 16:45

Place : LTestCar, 64/12 Srinakarin Road, Suanluang, Bangkok 10250 Thailand

Performance Test : Third Time

Table 21 The results of an average performance test on the chassis dynamometer for this research project

	Diesel Mode			HCNG DDF Mode		
n	v	P	M	v	P	M
RPM	km/h	BHP	Nm	km/h	BHP	Nm
1400	49.02	23.33	119.53	63.38	30.17	143.43
1500	52.50	29.57	141.32	67.88	38.24	169.59
1600	55.98	39.09	174.79	72.38	50.55	209.74
1700	59.56	52.60	221.45	77.01	68.01	265.74
1800	63.04	66.52	264.63	81.51	86.01	317.56
1900	66.52	81.05	305.36	86.01	104.80	366.44
2000	70.00	94.56	338.62	90.51	122.26	406.35
2100	73.58	98.96	337.60	95.14	127.95	405.12
2200	77.06	102.85	334.94	99.64	132.98	401.92
2300	80.54	106.94	333.20	104.13	138.27	399.84
2400	84.02	110.11	328.49	108.63	142.37	394.19
2500	87.50	112.77	323.07	113.13	145.81	387.68
2600	91.08	115.33	317.75	117.76	149.12	381.29
2700	94.56	118.20	313.45	122.26	152.83	376.14
2800	98.04	120.65	308.54	126.76	156.00	370.24
2900	101.51	121.78	300.66	131.26	157.46	360.79
3000	105.10	122.29	291.96	135.89	158.12	350.35
3100	108.58	123.62	285.51	140.39	159.84	342.61
3200	112.06	124.85	279.37	144.89	161.43	335.24
3300	115.53	125.36	272.00	149.39	162.09	326.40
3400	119.01	125.26	263.71	153.89	161.96	316.46
3500	122.60	125.77	257.27	158.52	162.62	308.72
3600	126.07	125.87	250.51	163.02	162.75	300.61
3700	129.55	124.13	240.28	167.51	160.50	288.33
3800	133.03	120.34	226.77	172.01	155.61	272.12

Date : 19 September 2013

Time : 16:45

Place : LTestCar, 64/12 Srinakarin Road, Suanluang, Bangkok 10250 Thailand

Performance Test : Overall average results on the performance test on this experiment

Table 22 An average sensor measurements in diesel mode for this research project

DIESEL OPERATION				
RPM	V (Km/H)	MAF (Volts)	TPS (Volts)	Diesel Ratio (%)
800	0	2.3	1.065	100
1000	30	2.5	1.074	100
1500	51.3	2.8	1.12	100
1600	54.7	2.9	1.131	100
1700	58.2	3	1.15	100
1800	61.6	3.1	1.19	100
1900	65	3.2	1.21	100
2000	68.4	3.3	1.23	100
2100	71.9	3.35	1.25	100
2200	75.3	3.4	1.27	100
2300	78.7	3.5	1.3	100
2400	82.1	3.6	1.32	100
2500	85.5	3.65	1.35	100
2600	89	3.69	1.39	100
2700	92.4	3.75	1.42	100
2800	95.8	3.8	1.48	100
2900	99.2	3.9	1.5	100
3000	102.7	3.931	1.56	100
3100	106.1	3.945	1.575	100
3200	109.5	3.96	1.61	100
3300	112.9	3.98	1.64	100
3400	116.3	4	1.67	100
3500	119.8	4.15	1.7	100
3600	123.2	4.3	1.75	100
3700	126.6	4.5	1.82	100
3800	130	4.7	1.98	100

Table 23 An average sensor measurements with HCNG DDF mode turned on for this research project and normal diesel substitution for this research project

HCNG Diesel Dual Fuel Operation (HCNG Fraction Data)					
n (RPM) HCNG DDF	v (KM/H) HCNG DDF	MAP - HCNG DDF (Volts)	TPS - HCNG DDF (Volts)	Diesel Ratio (%)	HCNG Substitution Ratio (%)
800	0	2.1	0.80	91.30	8.70
1000	35	2.3	0.81	92.00	8.00
1500	53	1.9	0.84	67.86	32.14
1600	58	1.95	0.85	67.24	32.76
1700	65	1.95	0.86	65.00	35.00
1800	69	1.95	0.89	62.90	37.10
1900	72	1.95	0.91	60.94	39.06
2000	75	1.99	0.92	60.30	39.70
2100	78	1.99	0.94	59.40	40.60
2200	80	2	0.95	58.82	41.18
2300	82	2.1	0.98	60.00	40.00
2400	86	2.13	0.99	59.17	40.83
2500	90	2.17	1.01	59.45	40.55
2600	92	2.21	1.04	59.89	40.11
2700	96	2.25	1.07	60.00	40.00
2800	98	2.28	1.11	60.00	40.00
2900	101	2.34	1.13	60.00	40.00
3000	105	2.35	1.17	59.78	40.22
3100	110	3.2	1.18	81.12	18.88
3200	113	3.3	1.21	83.33	16.67
3300	119	3.4	1.23	85.43	14.57
3400	125	3.5	1.25	87.50	12.50
3500	130	3.7	1.28	89.16	10.84
3600	134	4.3	1.31	100.00	0.00
3700	137	4.5	1.37	100.00	0.00
3800	142	4.7	1.49	100.00	0.00

Table 24 The results of CO emission level during the first test on this research project

Date		**19/9/2013**
Time		**10:00 AM**
Diesel Density		**0.8343 Kg/L**
Electrolyzer		**0.5 Liter / Minute**
	CO Emission Test #1 in Gram per KM (g/Km)	
RPM	**Diesel Mode**	**HCNG DDF Mode**
800	0.2	0.19
1000	0.21	0.2
1500	0.25	0.21
2000	0.31	0.25
2500	0.34	0.29
3000	0.37	0.32
3500	0.41	0.34
4000	0.45	0.39

Table 25 The results of CO emission level during the second test on this research project

Date		**19/9/2013**
Time		**10:05 AM**
Diesel Density		**0.8343 Kg/L**
Electrolyzer		**0.5 Liter / Minute**
	CO Emission Test #2 in Gram per KM (g/Km)	
RPM	**Diesel Mode**	**HCNG DDF Mode**
800	0.24	0.21
1000	0.26	0.22
1500	0.29	0.25
2000	0.33	0.28
2500	0.36	0.31
3000	0.38	0.34
3500	0.43	0.38
4000	0.46	0.41

Table 26 The results of CO emission level during the third test on this research project

Date		19/9/2013
Time		10:10 AM
Diesel Density		0.8343 Kg/L
Electrolyzer		0.5 Liter / Minute
	CO Emission Test #3 in Gram per KM (g/Km)	
RPM	Diesel Mode	HCNG DDF Mode
800	0.22	0.18
1000	0.24	0.23
1500	0.27	0.24
2000	0.31	0.25
2500	0.34	0.29
3000	0.36	0.31
3500	0.40	0.35
4000	0.43	0.39

Table 27 The results of CO emission level in average from all of the three tests on this research project

Date		19/9/2013
Time		10:15 AM
Diesel Density		0.8343 Kg/L
Electrolyzer		0.5 Liter / Minute
	CO Emission Test Average Results in Gram per KM (g/Km)	
RPM	Diesel Mode	HCNG DDF Mode
800	0.22	0.193
1000	0.236	0.216
1500	0.27	0.233
2000	0.316	0.26
2500	0.346	0.296
3000	0.37	0.323
3500	0.413	0.356
4000	0.446	0.396

Table 28 The results of HC emission level during the first test on this research project

Date	**19/9/2013**
Time	**10:00 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

HC Emission Test #1 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.1	0.08
1000	0.1	0.09
1500	0.12	0.11
2000	0.16	0.12
2500	0.19	0.15
3000	0.21	0.18
3500	0.23	0.19
4000	0.28	0.25

Table 29 The results of HC emission level during the second test on this research project

Date	**19/9/2013**
Time	**10:05 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

HC Emission Test #2 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.11	0.088
1000	0.11	0.099
1500	0.132	0.121
2000	0.176	0.132
2500	0.209	0.165
3000	0.231	0.198
3500	0.253	0.209
4000	0.308	0.275

Table 30 The results of HC emission level during the third test on this research project

Date	**19/9/2013**
Time	**10:10 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

HC Emission Test #3 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.12	0.096
1000	0.12	0.108
1500	0.144	0.132
2000	0.192	0.144
2500	0.228	0.18
3000	0.252	0.216
3500	0.276	0.228
4000	0.336	0.3

Table 31 The results of HC emission level in average from all of the three tests on this research project

Date	**19/9/2013**
Time	**10:15 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

HC Emission Test Average Results in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.11	0.088
1000	0.11	0.099
1500	0.132	0.121
2000	0.176	0.132
2500	0.209	0.165
3000	0.231	0.198
3500	0.253	0.209
4000	0.308	0.275

Table 32 The results of PM emission level during the first test on this research project

Date	**19/9/2013**
Time	**10:00 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

PM Emission Test #1 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.009	0.008
1000	0.0111	0.01
1500	0.012	0.011
2000	0.014	0.01
2500	0.016	0.01
3000	0.017	0.02
3500	0.019	0.02
4000	0.021	0.02

Table 33 The results of PM emission level during the second test on this research project

Date	**19/9/2013**
Time	**10:05 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

PM Emission Test #2 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.010	0.009
1000	0.012	0.011
1500	0.013	0.012
2000	0.015	0.015
2500	0.018	0.015
3000	0.019	0.017
3500	0.021	0.020
4000	0.023	0.020

Table 34 The results of PM emission level during the third test on this research project

Date	**19/9/2013**
Time	**10:10 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

PM Emission Test #3 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DD
800	0.011	0.010
1000	0.014	0.013
1500	0.015	0.014
2000	0.018	0.018
2500	0.020	0.018
3000	0.021	0.019
3500	0.024	0.023
4000	0.026	0.023

Table 35 The results of PM emission level in average from all of the three tests on this research project

Date	**19/9/2013**
Time	**10:15 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

PM Emission Test Average Results in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.010	0.009
1000	0.012	0.011
1500	0.013	0.012
2000	0.016	0.016
2500	0.018	0.016
3000	0.019	0.017
3500	0.021	0.020
4000	0.023	0.020

Table 36 The results of NO_x emission level during the first test on this research project

Date	**19/9/2013**
Time	**10:00 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

NO_x Emission Test #1 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.060	0.050
1000	0.090	0.100
1500	0.110	0.120
2000	0.130	0.140
2500	0.140	0.140
3000	0.160	0.160
3500	0.190	0.170
4000	0.200	0.180

Table 37 The results of NO_x emission level during the second test on this research project

Date	**19/9/2013**
Time	**10:05 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

NO_x Emission Test #2 in Gram per KM (g/Km)

n (RPM)	Diesel	Diesel + HCNG
800	0.069	0.058
1000	0.104	0.115
1500	0.127	0.138
2000	0.150	0.161
2500	0.161	0.161
3000	0.184	0.184
3500	0.219	0.196
4000	0.230	0.207

Table 38 The results of NO_x emission level during the third test on this research project

Date	**19/9/2013**
Time	**10:10 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

NO_x Emission Test #3 in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.072	0.060
1000	0.108	0.120
1500	0.132	0.144
2000	0.156	0.168
2500	0.168	0.168
3000	0.192	0.192
3500	0.228	0.204
4000	0.240	0.216

Table 39 The results of NO_x emission level in average from all of the three tests on this research project

Date	**19/9/2013**
Time	**10:15 AM**
Diesel Density	**0.8343 Kg/L**
Electrolyzer	**0.5 Liter / Minute**

NO_x Emission Test Average Results in Gram per KM (g/Km)

n (RPM)	Diesel	HCNG DDF
800	0.067	0.056
1000	0.101	0.112
1500	0.123	0.134
2000	0.145	0.156
2500	0.156	0.156
3000	0.179	0.179
3500	0.212	0.190
4000	0.223	0.201

Table 40 A summary of fuel saving measurement

Fuel Source	Diesel 1	Diesel 2	Diesel 3	HCNG 1	HCNG 2	HCNG 3
Starting Kilometer	17896	17913	17940	17987.3	18044	18106
Ending Kilometer	17913	17940	17963.5	18044	18106	18156
Net Traveling Distance (Km) at constant speed of 80Km/Hour	17	27	23.5	56.7	57	50
Diesel Consumption (Liter)	2.305	1.73	2.10	2.31	1.8	1.50
Total cost at the filling point (Baht)	70	52.6	70	70	60	50
CNG Consumption (Kg.) (1kg/10.50B)	n/a	n/a	n/a	0.84	1.068	1.089
Total cost at the filling point (Baht)	n/a	n/a	n/a	8.9145	11.21	11.43
H_2 Flow Rate (Liter / Minute) no cost!	0.5	0.5	0.5	0.5	0.5	0.5
Overall Expenses (Diesel + HCNG)	n/a	n/a	n/a	78.9145	71.21	61.43
OEM Factory Data on Fuel Consumption (KM/L)	7.3	7.3	7.3	7.3	7.3	7.3
Total Fuel Consumption (KM/L) per Trail (Diesel Only) (80KM/H)	7.375	15.6	11.19	24.54	31.6	33.33
Net cost per Kilometer (1 KM/Baht)	4.117	1.94	2.978	2.31	1.24	1.228

(Note: @60Km Constant Speed – HCNG will result in 40+ Km / Liter of Diesel)

REMARK:

1. Approximately Fuel Saving is equal to about 58.36% as comparing to the Diesel Operation Mode
2. Cost of Diesel Depends on Each Filling Stations Not always the same and also depending on each day the price can go up and down
3. The test is purposely done with constant speed without traffic at the average constant speed of approximately 80KM/Hour

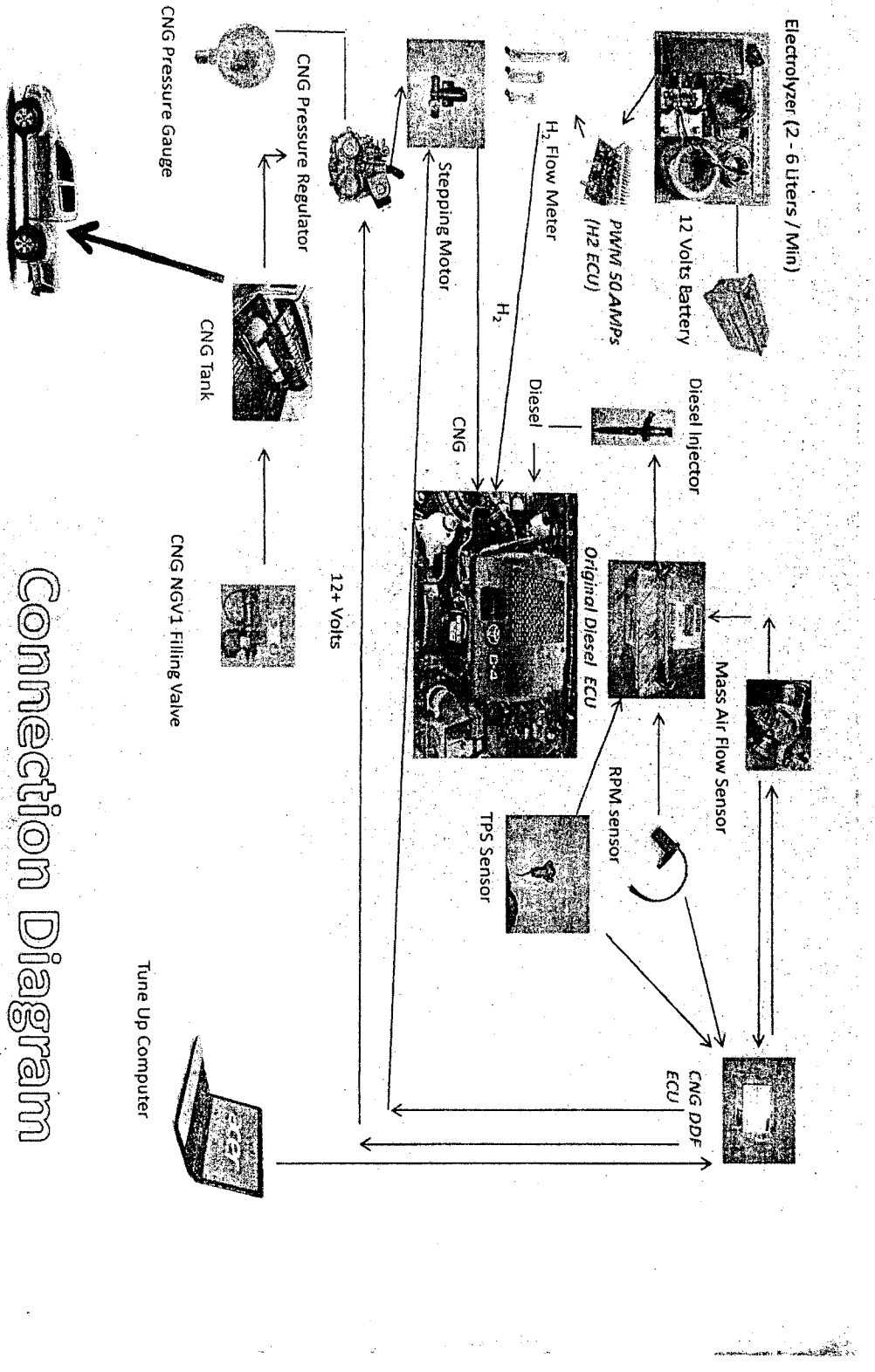


Figure 25 An overview of the connection diagram

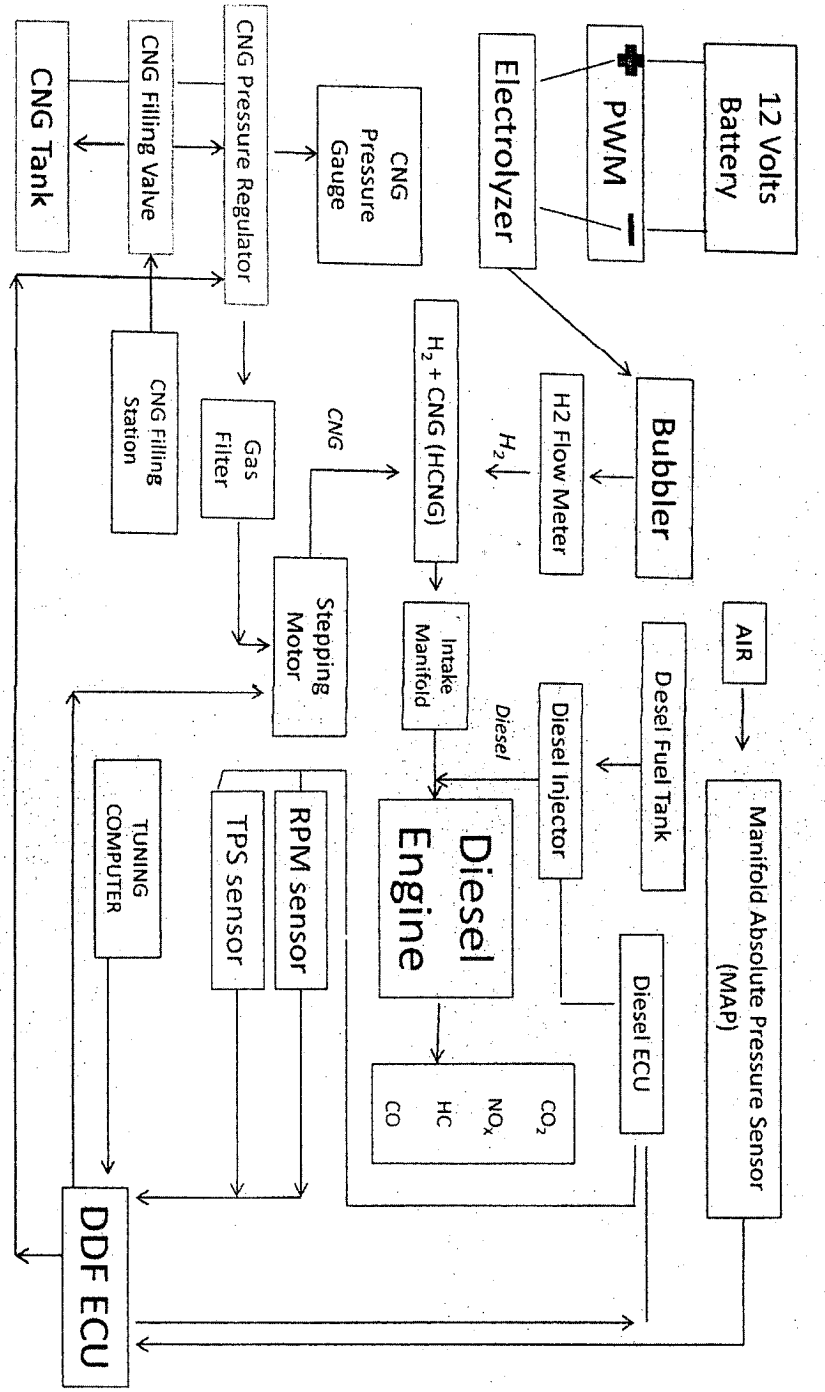
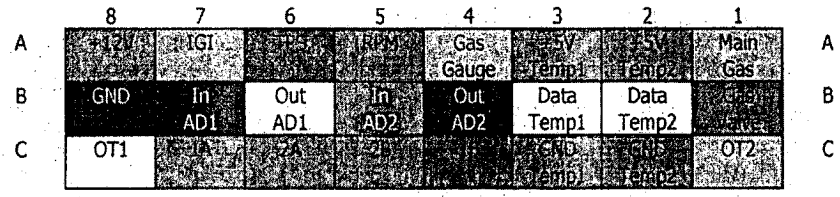


Figure 26 An overview of the complete designed HCNG DDF system

ผังตำแหน่งสายไฟ การวายสาย แบบเก่า



ตำแหน่ง	สี	ชนิดสาย	ความหมาย	ความยาว/M	หมายเหตุ
A8	แดง	AWG18	+12V	1.0	
A7	ส้ม	AWG24	IGI	1.0	
A6	น้ำเงิน	AWG24	TPS	2.0	
A5	น้ำเงิน	AWG24	RPM	2.0	
A4	เหลือง	AWG24	Gas Gauge		
A3	แดง	Standard	+5V Temp 1	2.0	Temp 1 มีสัญญาณไฟ +5V นำไปใช้ได้
B3	ขาว	Standard	Data Temp 1		
C3	Shield	Shield	GND Temp 1		
A2	แดง	Standard	+5V Temp 2	1.5	Temp 2
B2	ขาว	Standard	Data Temp 2		
C2	Shield	Shield	GND Temp 2		
A1	น้ำเงิน	AWG18	Main Gas	2.0	
B8		AWG18	GND	1.0	
B7		สายคู่	IN AD 1	2.0	ลดน้ำมัน IN 1
B6		AWG24	OUT AD 1		ลดน้ำมัน OUT 1
B5	แดง	สายคู่	IN AD 2	2.0	ลดน้ำมัน IN 2
B4		AWG24	OUT AD 2		ลดน้ำมัน OUT 2
B1	น้ำเงิน	AWG18	Gas Vaive	2.0	
C7	แดง	AWG24	1A	1	Step Motor
C6	ส้ม	AWG24	2A	1	
C5	น้ำเงิน	AWG24	2B	1	
C4	น้ำเงิน	AWG24	1B	1	
C8	ขาว	AWG18	OT1	0.5	
C1	เหลือง	AWG18	OT2	0.5	

Figure 27 Wiring diagram for the controlled unit

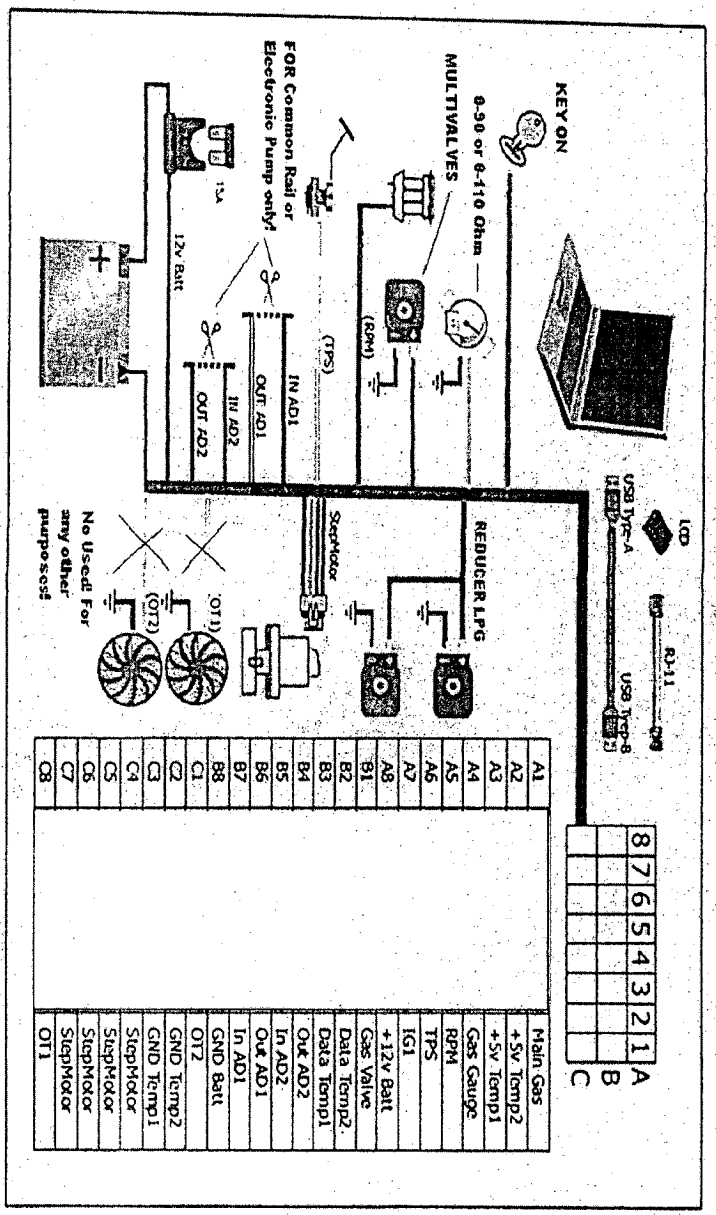


Figure 28 Diesel dual fuel (DDF) ECU connection diagram

Table 41 Brake thermal efficiency of original diesel operation and HCNG DDF operation

RPM	BSTE (Diesel Mode) %	BSTE (HCNG DDF mode) %
1500	20	23.32
1600	21.25	23.39
1700	22.36	25.21
1800	24.23	26.95
1900	25.46	28.24
2000	25.98	29.32
2100	26.78	29.98
2200	27.25	31.12
2300	29.41	32.82
2400	30.15	33.84
2500	31.25	35.05
2600	33.25	37
2700	33.45	38.25
2800	35.25	39.12
2900	35.89	40.12
3000	36.45	41.23
3100	34.26	38.75
3200	34.55	38.59
3300	33.25	37.56
3400	33.2	38.01
3500	31	36.89
3600	30	37.56
3700	29.2	33.98
3800	28.45	33.86