Original Research Article

Dual Fueling a Diesel Engine with Producer Gas Produced From Woodchips

ABSTRACT

The aim of this work was to study the diesel fuel savings in dual fueling a small diesel powered genset with a small Imbert style downdraft gasifier fueled with hardwood wood chips. Eight different runs were conducted, five with the engine fueled with diesel alone to characterize fuel consumption on diesel, three dual fueling the engine with diesel and producer gas. Generator power to a portable electric heater was measured and diesel fuel savings calculated for the power generated. It was found that dual fueling the generator saved about ¾ of the diesel fuel needed.

Keywords: *Dual fueling, downdraft Imbert style gasifier, gasification, wood chips, fuel savings*

1. INTRODUCTION

Modern civilization depends on using the abundant material resources provided by nature. Today fuel energy stored in solid, liquid and gaseous form is the most needed resource in today's world economy. During US colonial times, wood was the dominant fuel resource, surpassed by coal in 1885. Coal was then surpassed by petroleum in 1949 and natural gas in 1957. The use of petroleum and natural gas then quadrupled in a single generation [1]. The change from biomass fuel to fossil fuels at the end of the 19^{th} century was necessary to fulfill the ever-growing energy demand of the increasing population and fast-growing industry. This all resulted in a global temperature rise, known as global warming, over the past 140 years [2]. Associated with global warming, a rise in the CO_2 level in the atmosphere can be noticed [3].

In 2016, the US consumed a total of 13,504.00 thousand barrels of crude oil per day [4]. Therefore, the US independence on foreign sources of energy is of great national interest.

According to the Unites States Census Bureau research, the U.S. population increased from 151.3 million in 1950 to over 308.7 million in 2010 and is expected to reach 439.0 million in 2050 [5]. Energy consumption has increased by 280.5% to a total of 97.444 quadrillion British thermal units (Btu) per day [6] and is expected to increase by 5% by 2040, whereas an increase of 11% is expected in an high economic growth case. [7]. Data from EIA [8] show that in 2016, 78.5% of the energy consumed was supplied by fossil fuels, with petroleum accounting for nearly 35.9%, natural gas for 28.4% and coal for 14.2%. 8.4% of the consumed energy was supplied by nuclear energy and about 10.2% from the renewable energy sector. Biomass feedstock accounts for 47% of the total US renewable energy consumption, making biomass the single largest renewable energy source in the U.S. [9]. For example, photosynthesis converts solar energy into biomass of up to 220 billion metric tons a year. This biomass can be converted into approximately 10 times today's world energy consumption [10]. The U.S. joint study of the Department of Energy (DOE) and the Department of Agriculture (USDA) identifies that an estimated 1366 million dry tons of biomass feedstock from forest and agricultural resources are annually available for the production of biofuels and energy [11].

The increasing cost of energy and material resources are directing industrial, commercial, farm-based, and municipal enterprises in the U.S. and many other nations to develop more sustainable modes of operation [12], because fossil fuels, the primary sources of energy on earth, are finite [13]. Many studies suggest that the cost of fossil fuel exploration and extraction will continue to rise, perhaps to unprecedented levels [13, 14, 15, 16].

In both the United States and the developing world there is an increasing need for low-tech, low-cost solutions to our energy, resource, and waste management challenges. Today, the U.S. forest industry produces approximately 67 million dry tons of Forest Residual Biomass (FRB) from harvesting and converting wood into consumer products, which equals approximately 3.4 million barrels of oil equivalent (BOE). Currently FRB is partially used to produce mulch or is left unused in the forest by the harvesting operations and cannot be utilized for biofuel and/or value-added product production due to long transportation distances [17].

Finding ways to utilize appropriate technologies for alternative energy systems will be among the solutions that will remediate the impacts of fossil fuel utilization [18].

In order to utilize the biomass available for energy production, it is necessary to develop more scientific and applied knowledge of the process, using not only high-grade Forest Biomass (FB) but also low-grade FB and Forest Waste Biomass (FWB), e.g. infected trees, stumps, and other forestry and agricultural residues and/or waste biomass.

The production of bio energy and fuels from any biomass is very dependent on keeping constant process parameters throughout the production chain as well as throughout the year. Inconsistent biomass supply results in losses and overall low performance in the process. Seasonal growth and variations occurring during this period make it even harder to predict the energy output of the used biomass. To overcome the seasonal effect, a diverse portfolio of a biomass mixture, based on regional availability, needs to be developed to insure a consistent delivery of biomass with set quality parameters to the biorefinery. This will result in a consistent process which helps in maximizing the biorefinery output and overall performance.

The present cost range of \$12 to \$24 per Barrel of Oil Equivalent (BOE) for FB can be expected [19]. In addition, the pretreatment and the conversion processes needed for the biochemical route typically raise production cost for biofuels to \$60–\$120 per BOE, making only high fuel prices, above \$50-\$75 per bbl. for the production of bioenergy from biomass economically feasible [20].

Gasification can effectively use FRB and other FB byproducts currently little utilized to reduce dependence on fossil fuel without requiring more forest to be cut for fuel.

The downdraft gasifier has been proven to be the most successful design for small scale power generation due to its low tar, an inhibiting by-product of the process, production. Downdraft gasification has not yet been successful for large scale power production at the megawatt scale. The downdraft gasifier consists of 5 major zones: 1) drying, 2) conversion, 3) Charring, 4) oxidation, and 5) reduction zone. The Imbert style gasifier design is one in which the gasifier contains a throated combustion zone such that the diameter for the pyrolysis zone decreases into and through the combustion zone and increases again through the reduction zone [21]. Figure 1 shows a diagram of an Imbert style gasifier we have built at the Cleanwater Educational research Facility (CERF) located at the Village of Minoa, New York Waste Water Treatment Plant (WWTP).

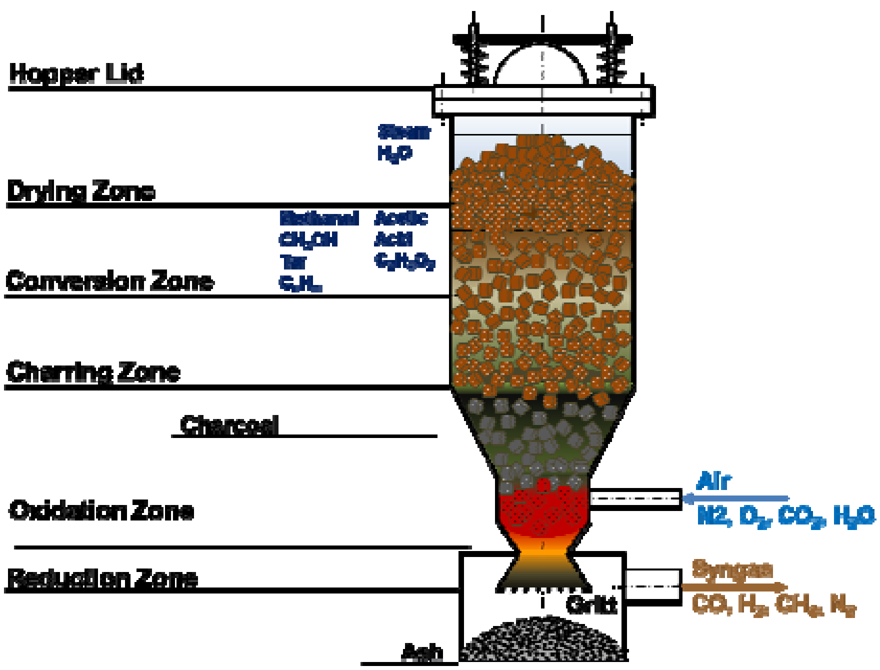

Figure 1: Imbert Style Gasifier [22]

A previous reported a pilot-scale downdraft, Imbert-type gasifier shown in Figure 2 below was designed and constructed to be used at CERF, located at the in municipal wastewater treatment plant of Minoa, NY [23]. Figure 3 below shows a design sketch for the CERF gasifier [23]. This research is a continuation of the pilot scale gasifier located in Minoa. A pilot study of dual fueling a diesel powered genset with the CERF gasifier fueled with woodchips was performed. The objectives of this research are to determine the feasibility and savings of diesel fuel in dual fueling the genset with producer gas produced from woodchips.

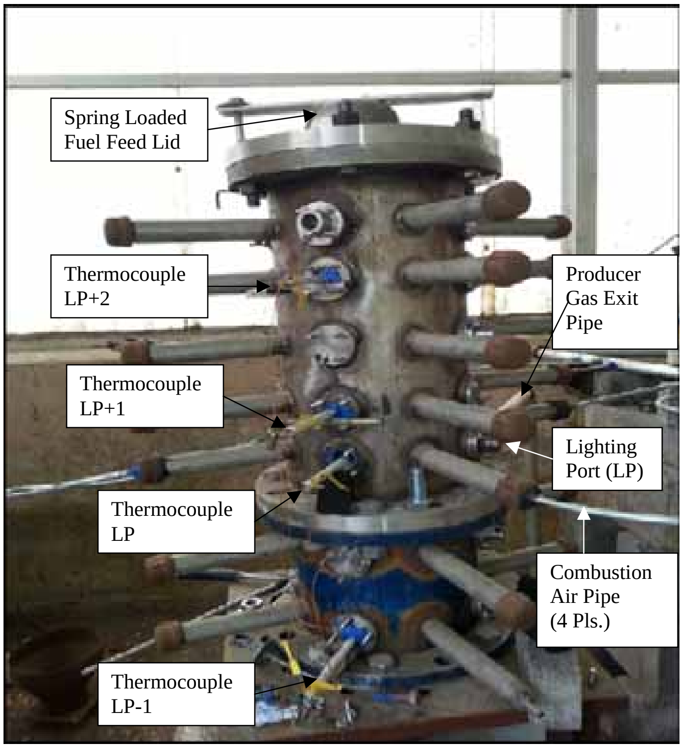

Figure 2: CERF Gasifier [23]

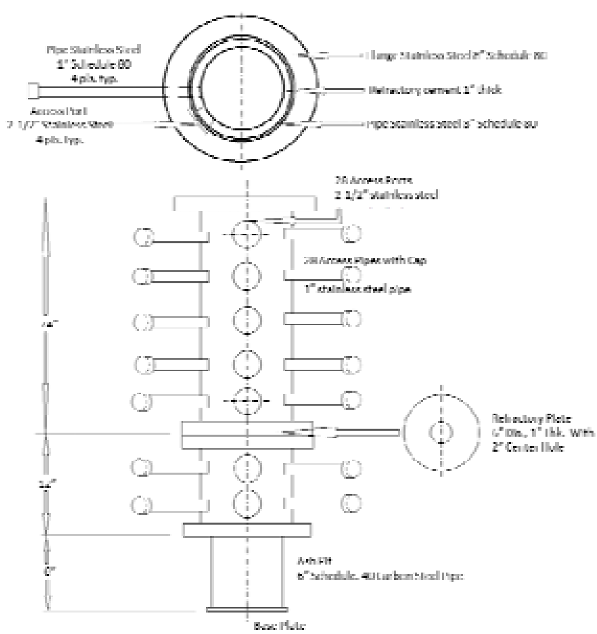

Figure 3: CERF Gasifier Design Sketch [23]

Gasifiers are relatively simple devices. The mechanics of their operation, such as feeding and gas cleanup, also are simple. The successful operation of gasifiers, however, is not so simple. No neat rules exist because the thermodynamics of gasifier operation are not well understood. Yet, nontrivial thermodynamic principles dictate the temperature, air supply, and other operating variables of the reactors that we build [24].

Biomass largely consists of hydrocarbons, hydrocarbons combined with the proper amount of oxidizer break down largely into the fuel gases hydrogen, carbon monoxide and methane starting at temperatures above 600°C (1112°F) [24]. Reaction times at this temperature are comparatively slow and the breakdown of hydrocarbons at lower temperatures tends to produce larger amounts of tar. For these reasons gasifiers are generally operated such that the temperatures in the combustion and reduction zone are 700°C (1292°F) to 1000°C (1832°F) [24]. Operation at temperatures above 1000°C requires that the gasifier be built from more expensive heat resistant materials.

2. MATERIALS AND METHODS

The genset (engine and generator) was build using a Basant 6hp (4.5kW), 650 rpm, 1 cyl., 1.4l Lister diesel engine. The generator was made by connecting 480V 20mfd oil filled run capacitors in a Y connection across the windings of a Baldor squirrel cage induction motor MM3709 230/460 V, 7.5hp (5.6 kW), 3 phase, 3500 rpm motor with a D1325 frame. Figure 4 shows the genset. Figure 5 shows the gasifier and genset system. Producer gas from the gasifier was cooled in the radiator, filtered in the hay filter and mixed with a small amount of outside air in the engine carburetor. The engine governor controlled the amount of diesel introduced to the engine so that the engine speed remains constant. The engine needed a minimal amount of diesel to ignite the producer gas-air combustion charge. The governor introduced more diesel to make up for insufficient or weak producer gas. A 1500-Watt 120 Volt portable electric heater was used as a load to the generator.

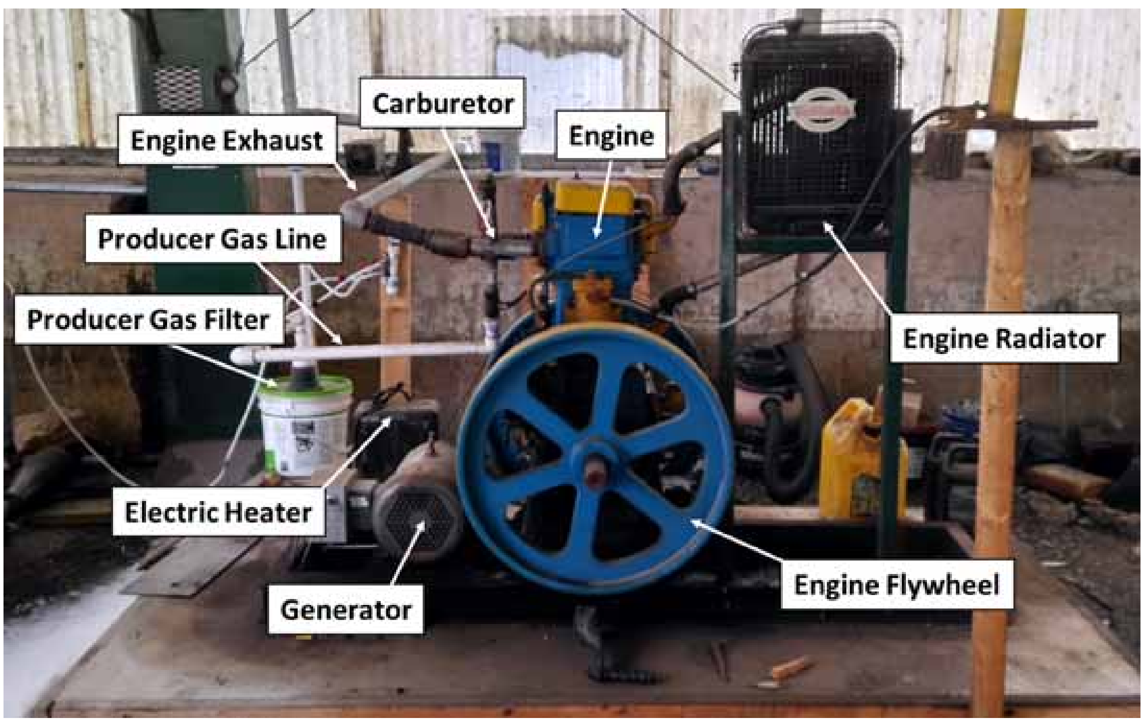

Figure: 4. CERF Genset [25]

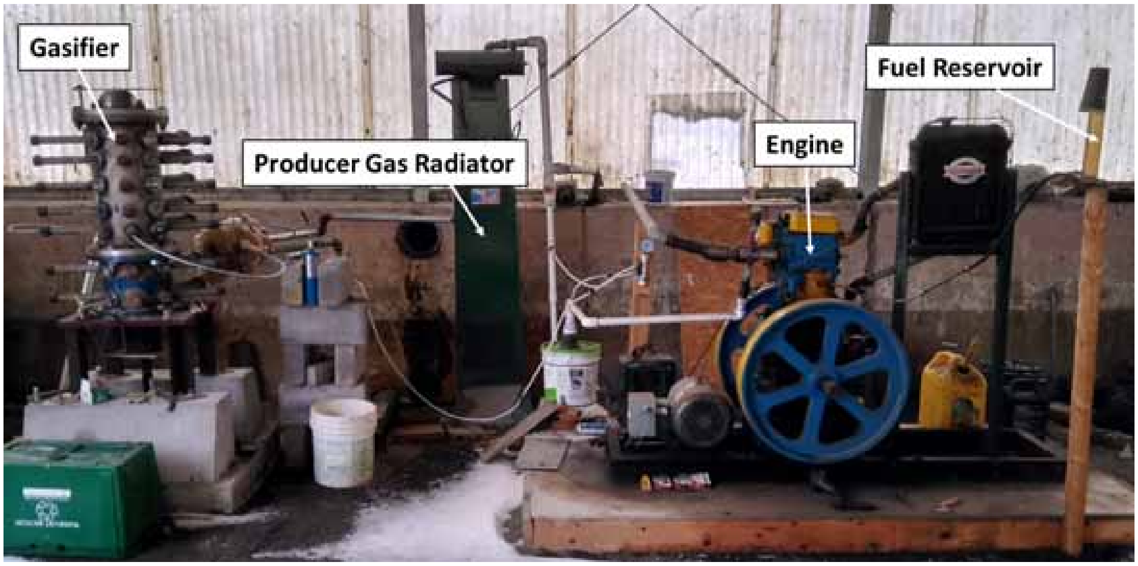

Fig. 5. CERF Gasifier Genset System [26]

Hardwood woodchips approximately ¾" (19mm) square and 1/8" (3mm) thick at approximately 12.5% Moisture Content (MC), at a oven dry basis, fueled the gasifier for a 30 minutes run. During each run approximately 2.5lbs (1,134g). Of chips were used. Successful operation of the gasifier requires an adequate char-bed for each run that is formed from the leftover fuel from the previous run. Based on our experience operating the gasifier, the char-bed should extend to the level of the combustion air nozzles or lighting port to minimize the formation of tar. Ideally the char-bed is not overly disturbed beyond a moderate tamping to shake down the ashes from the char-bed to the ash pit. Starting vacuum to the gasifier was provided by a 1 HP (0.75kW) Shop Vacuum Cleaner (shop vac) and the gasifier lit by momentarily touching a propane torch flame to the fuel through the lighting port. The diesel engine was then started and shortly thereafter the generator load was applied. Once the gasifier temperature at the lighting port reached 1800°F the vacuum from the shop vac was turned off and the engine vacuum was applied to the gasifier by opening carburetor and producer gas line valves to the gasifier and closing the carburetor outside air valve until it was 95% closed. Engine fuel level in the graduated cylinder diesel fuel reservoir was noted as well as volts and amps supplied by the generator to the generator load, the portable electric heater. The gasifier top was opened approximately 15 minutes into the run and the fuel tamped down with a steel rod. At the same time at the beginning and at the end of the run voltage and amperage supplied to the heater were noted as well as the gasifier temperature at the lighting port level. At the end of the run the diesel fuel level in the fuel reservoir was noted.

Energy content of the diesel fuel used by the engine during the run, D_{en}, was calculated by:

$$D_{en} = \text{milliliters of fuel consumed x 139,000 Btu/ 3785 ml per gallon} \quad [1]$$

where 139,000 Btu is the energy content of 1 gallon of diesel fuel [8].

Energy provided to the generator load (heater), G_{en}, was calculated by:

$$G_{en} = \text{Avg. volts measured x Avg. amps measured / 3.412 Btu per watt hour x 2 runs per hour} \quad [2]$$

Genset efficiency, G_{eff}, for each run was calculated from:

$$G_{eff} = 100 * D_{en} / G_{en} \quad [3]$$

Baseline runs for determining genset efficiency with the engine operating on diesel fuel alone were first conducted. The average genset efficiency running on diesel alone, G_{effd}, was used to calculate the quantity of diesel, d_{alone}, the genset would require to generate G_{en} for dual fuel runs if the genset were operated on diesel fuel alone by:

$$d_{alone}\ (ml) = G_{en} / G_{effd} \times 139{,}000 \text{ Btu per gallon} / 3785 \text{ ml per gallon} \qquad [4]$$

Diesel fuel savings (%), D_{fs}, for a dual fuel run were calculated from:

$$D_{fs} = 100 \times (d_{alone} - \text{actual quantity of diesel used (ml)}) / d_{alone} \qquad [5]$$

3. RESULTS AND DISCUSSION

Results from 5 diesel alone runs and 3 dual fuel (diesel and gasified woodchips) runs are shown in Table 1 below. Runs 1 – 5 were with the engine fueled by diesel alone. Runs 6 – 8 were with the engine dual fueled.

Table 1. Genset Run Results

Run	Diesel Usage [ml]	Avg. Volts [V]	Avg. Amps [A]	G_{en} [Btu]	D_{en} [Btu]	G_{eff} [%]	G_{effd} [%]	d_{alone} [ml]	D_{fs} [%]
1	340	115	10.00	1961.90	12486.13	15.71	16.84	NA	NA
2	320	115	10.60	2079.61	11751.65	17.70		NA	NA
3	305	115	9.80	1922.66	11200.79	17.17		NA	NA
4	365	125	10.60	2260.45	13404.23	16.86		NA	NA
5	310	114	9.80	1905.94	11384.41	16.74		NA	NA
6	131	151	12.50	3220.08	4810.83	66.93		520.81	74.85
7	120	152	10.30	2670.91	4406.87	60.61		431.99	72.22
8	125	149	13.00	3304.52	4590.49	71.99		534.47	76.61

As can be seen above, values for G_{eff} for Runs 1-5 appear low for the thermal efficiency of a diesel engine which generally is reported to be about 30% for small diesel engines. Raman and Ram [27] state that during their testing the diesel thermal efficiency dropped from 28% to about 17%. The same is reported for our runs on average were the genset was running on diesel alone efficiency G_{effd} in Table 1 above, when the engine was operated at partial load as it was the case in these runs rather than at full throttle or 100% loading. It is apparent from the d_{alone} and D_{fs} columns in Table 1 that dual fueling with woodchips can save a considerable amount of diesel fuel in operating the genset. The 72% - 76% diesel savings reported above are within the 60% - 90% range of savings reported by Malik et al. and Martinez et al. [28, 29, 30]. Unfortunately reporting the overall thermal efficiency of the dual fueled runs was impractical because of the necessity of having a relatively undisturbed char bed from the previous run before starting a given run. Calculating the amount of woodchips consumed in a run would have required emptying, weighing and replacing the char bed before each run which would have disturbed the char bed structure and led to difficulty in producing adequate, tar free producer gas during the run.

The governor on the Basant diesel engine is a spring-loaded device working with spinning centrifugal weights that reduces or increases the amount of diesel injected into the combustion chamber if the engine speed increases or decreases from the set point. In dual fueling a minimal amount of diesel is needed to ignite the producer gas drawn into the combustion chamber. As producer gas is drawn into the engine running on diesel the engine speed will increase and the governor will decrease the amount of diesel injected proportionally but not necessarily to the point where less producer gas is ignited so the governor is not completely effective in preventing over-revving of the engine when dual fueled. A higher generator rpm produces a higher voltage. This is seen in the higher average voltages reported in the dual fueled runs in Table 1. For operating a portable resistance heater, the higher voltages were not a problem but for other applications the higher voltages may not be allowable. For these cases the governor may need to be adjusted occasionally or changed.

4. CONCLUSION

This study shows that approximately ¾ of the diesel fuel required to operate a genset may be saved by dual fueling the diesel engine with producer gas produced by gasifying woodchips. To prevent over-voltages when dual fueling the diesel engine governor may need to be adjusted or changed.

6. REFERENCES

1. U.S. Energy Information Administration (EIA), History of energy in the United States: 1776-2012. Available: https://www.eia.gov/todayinenergy/detail.php?id=11951 (Accessed 7 January 2018).
2. Klyashtorin LB, Lyubushin AA, On the coherence between dynamics of the world fuel consumption and global temperature anomaly, Energy and Environment, 2003;14(6):773-782.
3. Walker LK, On global warming and the role of fossil fuels, Australian Institute of Mining and Metallurgy. Available: http://www.ausimm.com.au/content/docs/l_k_walker.pdf (Accessed 4 January 2018)
4. U.S. Energy Information Administration (EIA), Official Energy Statistics from the US Government, Total Consumption of Petroleum Products. Available: https://www.eia.gov/energyexplained/index.cfm?page=oil_home#tab3 Accessed 7 January 2018).
5. U.S. Census Bureau, A Look at the 1940 Census. Available: https://www.census.gov/newsroom/cspan/1940census/CSPAN_1940slides.pdf (Accessed 7 January 2018).
6. U.S. Energy Information Administration (EIA), Official Energy Statistics from the US Government, Table 1.1 Primary Energy Overview. Available: http://www.eia.doe.gov/aer/txt/ptb1601.htmlhttps://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2016_energy.pdf (Accessed 7 January 2018).
7. U.S. Energy Information Administration (EIA), Official Energy Statistics from the US Government, Annual Energy Outlook 2017. Available: https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf (Accessed 7 January 2018).
8. U.S. Energy Information Administration (EIA), Official Energy Statistics from the US Government, "U.S. Primary Energy Consumption by Source and Sector/ Available: https://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2016_energy.pdf (Accessed 7 January 2018).
9. U.S. Energy Information Administration (EIA), Official Energy Statistics from the US Government, U.S. energy consumption rose slightly in 2016 despite a significant decline in coal use, April 5, 2017". Available: https://www.eia.gov/todayinenergy/detail.php?id=30652 (Accessed 7 January 2018).
10. Babu, BV, Biomass pyrolysis: a state-of-the-art review, Biofuels Bioproducts & Biorefining, 2008;2(5):393-414.
11. Department of Energy (DOE), U.S. Department of Agriculture (USDA), Biomass as Feedstock for a Energy and bioproducts Industry: The Technical Feasibility of a Billion-ton annual Supply. 2005. Available: http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf (Accessed 7 January 2018).
12. Bates R, Dölle K, Producer gas Use in Internal Combustion Engine – A Practical Approach, International Journal for Innovative Research In Multidisciplinary Field (IJIRMF), 2017;3(7):157-165
13. Ivanhoe L.F., (1995), "Future world oil supplies: There is a finite limit", *World Oil*. *216* (10). ISSN: 0043-8790. Available: http://dieoff.org/page85.htm http (Accessed 4 January 2018)
14. Hall C, Tharakan P, Hallock J, Cleveland C, Jefferson M, Hydrocarbons and the evolution of human culture, *Nature*, 2003;426:318–322
15. Maggio G, Cacciola G, A variant of the Hubbert curve for world oil production forecasts, *Energy Policy. 2009;37*:4761-4770
16. Rehrl T, Friedrich R, Modeling long term oil price and extraction with a Hubbert approach, The LOPEX model. *Energy Policy 2006;34*:2413-2428
17. U.S. Department of Energy (DOE), U.S. billion-ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry, August 2011. Available:https://energy.gov/sites/prod/files/2015/01/f19/billion_ton_update_0.pdf (accessed 4 January 2018)
18. Schade C, Pimentel D, Population crash: Prospects for famine in the twenty-first century, Environmental Development and Sustainability, 2012;12:245-262

19. Sefik M, Tunc MS, van Heiningen, ARP, Hemicellulose Extraction of Mixed Southern Hardwood with Water at 150 °C: effect and time, *Ind. Eng. Chem. Res.*, 2008;*47:*7031–7037.
20. Lange JP,Lignocellulose conversion: an introduction to chemistry, process and economics, Bioproduct and Biorefining,2017;1:39–48
21. Ni M, Leung DYC, Leung MKH, Sumathy K, An overview of hydrogen production from biomass Fuel, Process Technology, 2006;87:461–472.
22. Image by Klaus Dölle, Imbert Style Gasifier, pdf-file
23. Bates R, Dölle K, Start-Up of a Pilot Scale Downdraft Imbert Style Gasifier using Willow and Sugar Maple Wood Chips, International Journal for Innovative Research In Multidisciplinary Field (IJIRMF), 2017;3(6):379-386
24. Reed TB, Das A, Handbook of Biomass Downdraft Gasifier Engine Systems,Biomass Energy Foundation,1988
25. Image by Klaus Dölle, CERF Gen Set, pdf-file
26. Image by Klaus Dölle, Gen Set System, pdf-file
27. Raman P, Ram N, Performance analysis of an internal combustion engine operated on producer gas, in comparison with the performance of the natural gas and diesel engines, *Energy,2013;* 63:317-16.
28. Malik A, Singh L, Singh I, Utilization of Biomass as Engine Fuel, Journal of Scientific & Industrial Research, 2009; 68:887-3.
29. Martínez JD, Mahkamov, K, Andrade RV, Silva Lora EE, Producer gas production in downdraft biomass gasifiers and its application using internal combustion engines, Renewable Energy, 2012;38(1):1-9.
30. Bates R, Dölle K, Producer gas Use in Internal Combustion Engine – A Practical Approach, International Journal for Innovative Research In Multidisciplinary Field (IJIRMF). 2017;3(7):157-165