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Energy Supply Chain of Co-Firing system to generate electricity

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By

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August 29, 2019

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ABSTRACT

The problem of air pollution on the streets of the national capital of India, New Delhi is a major concern. Majority of the pollutants are generally originated from either the vehicles on the roads or the burning of crops from the neighbouring states of the National Capital Region (NCR). To improve the condition of the air quality by the vehicles, implementation of the Electric Vehicles (EVs) in an energy supply chain is a suitable plan. The objective of this paper is to plan a supply chain of generation of electricity by the process of co-firing that prompts benefits both in blend of innovation utilized and financial process duration. The most easily available renewable source of waste is biomass and utilizing it to produce electricity can be a great alternative to the traditional sources of energy. So, the process of co-firing can be done to generate electricity. Combustion on renewable resources leads to less discharge of carbon and more ecological atmosphere. Co-firing biomass has gained international attention and interest in recent past as it is environmentally friendly and economical as both the fuels used can be combusted in same atmosphere. A model of an energy process is analysed and is concluded that the usage of Electric trucks (Tesla Semi) instead of conventional trucks would reduce the carbon footprint and the whole energy supply chain is studied and the cost analysis of the process is explained. The cost of the plant with the baseline method of transportation with the conventional trucks is greater than that of cost of plant with electric trucks (Tesla Semi).

DEDICATION

This paper is dedicated to my father- **Subash Chandra Panda**, my mother- **Geeta Panda**, my sister- **Debashraddha Panda** and my best friend- **Jyoti Chauhan**

ACKNOWLEDGEMENTS

Firstly, I would like to thank the God, almighty for all the strength and support he has given me in life to face different challenges. I always thank him for the peace and happiness he has made available for me. I am blessed to have an amazing family and wonderful friends.

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LIST OF ABBREVIATIONS

ADKIC: Amritsar Delhi Kolkata Industrial Corridor

AEO: Annual Energy Outlook

ALT: Atmospheric Lifetime

ATA: Atmospheric Absolute

CAGR: Compound Annual Growth Rate

CO: Carbon Emission

CO2: Carbon Dioxide

DAF: Dissolved air flotation

ECN: Energy Research Centre of the Netherlands

EDFC: Eastern Dedicated Freight Corridor

EV: Electric Vehicle

GHG: Greenhouse Gases

GWP: Global Warming Potential

HCV: Heavy Commercial vehicle

HSD: High Speed Diesel

IEA: International Energy Agency

INL: Idaho National Laboratory

INR: Indian Rupee

IPCC: Intergovernmental Panel on Climate Change

IREDA: Indian Renewable Energy Development Agency Limited

K: Judgmental Factor (25%)

LCA: Life Cycle Assessment

MW: Megawatt

MT: Metric Tonne

NASA: National Aeronautics and Space Administration

NCR: National Capital Region

NREL: National Renewable Energy Laboratory

ORNL: Oak Ridge National Laboratory

PC: Pulverised coal

Q: Quintal (100 Kilograms)

RBI: Reserve Bank of India

RRTS: Regional Rapid Transport System

RPR: Residue to Product Ratio

SDG: Sustainable Development Goal

SO2: Sulphur Dioxide

TCO: Total Cost of Operation

TG: Turbo Generator

TJ: Terajoule

TPH: Tonnes per Hour

TWh: Terawatt hours

USD: United States Dollar

WHO: World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Air Pollution in New Delhi

After the 2008 Olympics in Beijing, China, the issue of air pollution was discussed at international levels. Escaping the limelight was another major country in Asia, India. New Delhi, the capital of India conducted The Commonwealth Games in October 2008, and this was the time when the issue of air quality was questioned again in 2018.

Still after ten years in 2018, the issue of air pollution has not yet controlled. The ppm levels have risen more. According to the Central pollution control board, dust pollution containing PM 2.5, PM 10, PM 1 rose to 261 micrograms per metre cube again in 2018 as compared to 2008 [1].

The statistics are shocking. Air pollution is at least indirectly related to tens of thousands of deaths every year and this number is rising. Two out of five residents in New Delhi suffer from various respiratory disease, like Asthma, lung disease, bronchitis and heart problems. The exponential growth of India’s economy is one of the main reasons for this problem of air pollution. While focusing on the growth of national economy, the environment has been affected harshly. From 1995 to 2006, the number of registered vehicles in New Delhi rose from 1.5 million to 4.5 million and this number is further increasing by the introduction of economical four wheelers [2].The government has tried to tackle this problem by ordering the usage of compressed natural gas in all public vehicles, but this is yet to solve the problems of personnel vehicles owned by individuals.

According to the world health statics 2016, 7 million people died in 2012 globally due to indoor and outdoor air pollution. In India itself, 1.5 million people died from the effects of the air pollution [3].

Delhi is infamous for stifling air that is presently turning the notable white marble walls of the Taj Mahal green.

The city confronted a noteworthy air quality emergency toward the end of 2018 as the contamination prompted flight cancellations, caused traffic collisions, shut schools, and started protests. One minister depicted Delhi as a "gas chamber," and the city pronounced a general wellbeing crisis.

Many other Indian urban communities are managing serious air pollution as well, yet a considerable quantity of the particulates that cover the metro districts start in country regions, and rural regions are similarly as gravely influenced by poor air, if not more so. In 2015, around

75% of deaths connected to air contamination in India, some 1.1 million individuals, happened in rural zones.

Sixty six percent of India's population still lives outside of urban areas, and 80 % of these families depend on biomass like wood and fertilizer for cooking and warming. Agricultural practices like burning harvest stubble additionally are far-reaching.

This smoke floats over real urban communities, where it blends with traffic exhaust, industrial facility discharges (emissions), and construction dust. It can likewise expand into inland by highlights like slopes and mountains, leaving a couple of regions in the nation where Indians can inhale simply [4]. Figure 1 shows the map of air pollution in different regions of India.

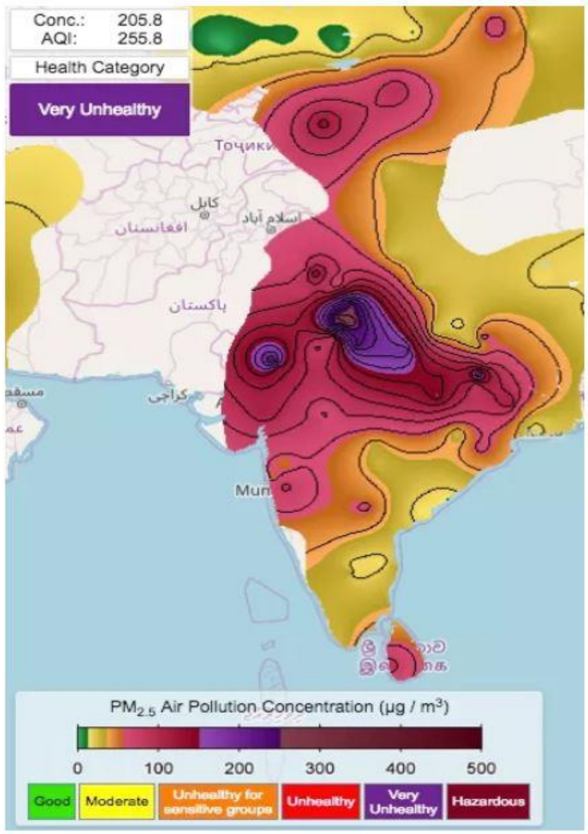


Figure 1 A map of particulate air pollution in India on October 31, 2018. Adapted from Berkeley Earth[4]

Being the capital city of the biggest democracy in the world, the level of air pollutants in the city is extremely high and even more than the hazardous level defined by World Health Organization (WHO). This problem could be solved in various ways, though it would take a good amount of time. As mentioned in the Sustainable Development Goal 3 of WHO, by 2030, the levels of pollutions can be reduced to a great extent if the implementation of environmental and sustainable rules are done as soon as possible.

Air pollution comes under Sustainable Development goal 3 (SDG 3) i.e., Good Health and well-being and SDG 11, i.e., Sustainable cities and communities (11.6). Objective of SDG 3 is that by 2030, improve the air quality of the capital city by taking sustainable measures and working together to obtain a healthy environment and to reduce the toxic levels of air below the stated levels by WHO [5].

1.2 Reason for Air Pollution

To investigate the problems and finding for the air pollution in New Delhi, a causal loop diagram was analysed. A causal loop diagram is a method of system thinking which analyses the complexity and variability within the whole system. The causal loops consist of the variables, the loops and the signs.

Figure 2 shown below analyses the reason for air pollution in New Delhi. Starting from the traffic congestion, which leads to the addition of air pollution and hence a (+) sign is shown in the arrow which is focused to air pollution.

Traffic congestion in New Delhi has a very significant role in the rise of particulate matter which causes air pollution. Traffic congestion happens due to increase in the number of vehicles which subsequently affects the quality of air in the capital city.

According to an analysis by the Centre of Science and environment, congested roads are increasing the pollution. It is estimated that the traffic in New Delhi is increasing by 7% every year due to the addition of approximately 537 cars and 1158 two-wheelers every day on the streets of the capital city. With no difference in peak and non-peak hours traffic, the high capacity of vehicles on 13 through roads has an average maximum speed of 26 Km/hr (27 km/hr for non- peak hours) which has a regulated speed of 40-55 km/hr [6]

Another reason for air pollution is the deforestation, which causes soil erosion and because of the cutting of trees, air pollution increases. Deforestation influences global air pollution as trees release vapours into the air which affects the atmospheric temperatures and causes an imbalance and increases the atmospheric temperature. Deforestation affects the air we breathe; this is due to the reason that trees take in carbon dioxide and other pollutants which causes air pollution [7].

The firecrackers recently have caused an increased level of ppm in the air and affected the air quality. In October 2017, after the Indian festival of light, Diwali, the residents of New Delhi complained about watering eyes and aggravated coughs as the level of PM 2.5 were on an upscale [8].

Industrial emissions have a negative impact on the quality of air in New Delhi. Combustion/burning of industrial wastes or emissions from power and waste processing plants contributes more to this problem [9].

During the peak crop burning season, the air pollution is about 20% more than the threshold for the safe air as defined by WHO. Although Delhi shows the level of air pollution very high throughout the year, the PM 2.5 rises in the month of October and November because of the crops being burned in the nearby states of New Delhi (Punjab, Haryana and Uttar Pradesh). Outrageous fires amid the post-monsoon season can pump on average around 150 micrograms for every cubic meter of the fine particulate issue into the city, multiplying the measure of contamination and expanding total levels 12 times higher than WHO suggestions [10].

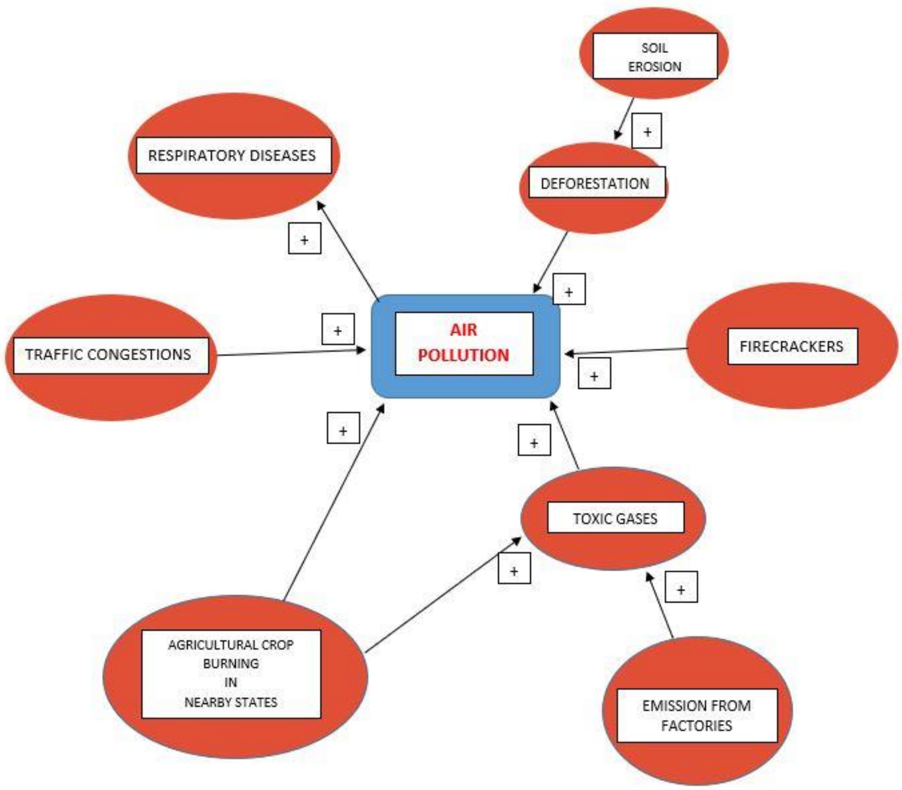


Figure 2 Causal Loop Diagram

1.3 Burning of Crops

Figure 3 shows the burning of different crop residues in various regions of India for the year 2014. Red shade exhibits the highest amount of the biomass burned for the respective crop in the respective map. Red is followed by orange shade. The darker shade of green displays least amount of biomass burned.

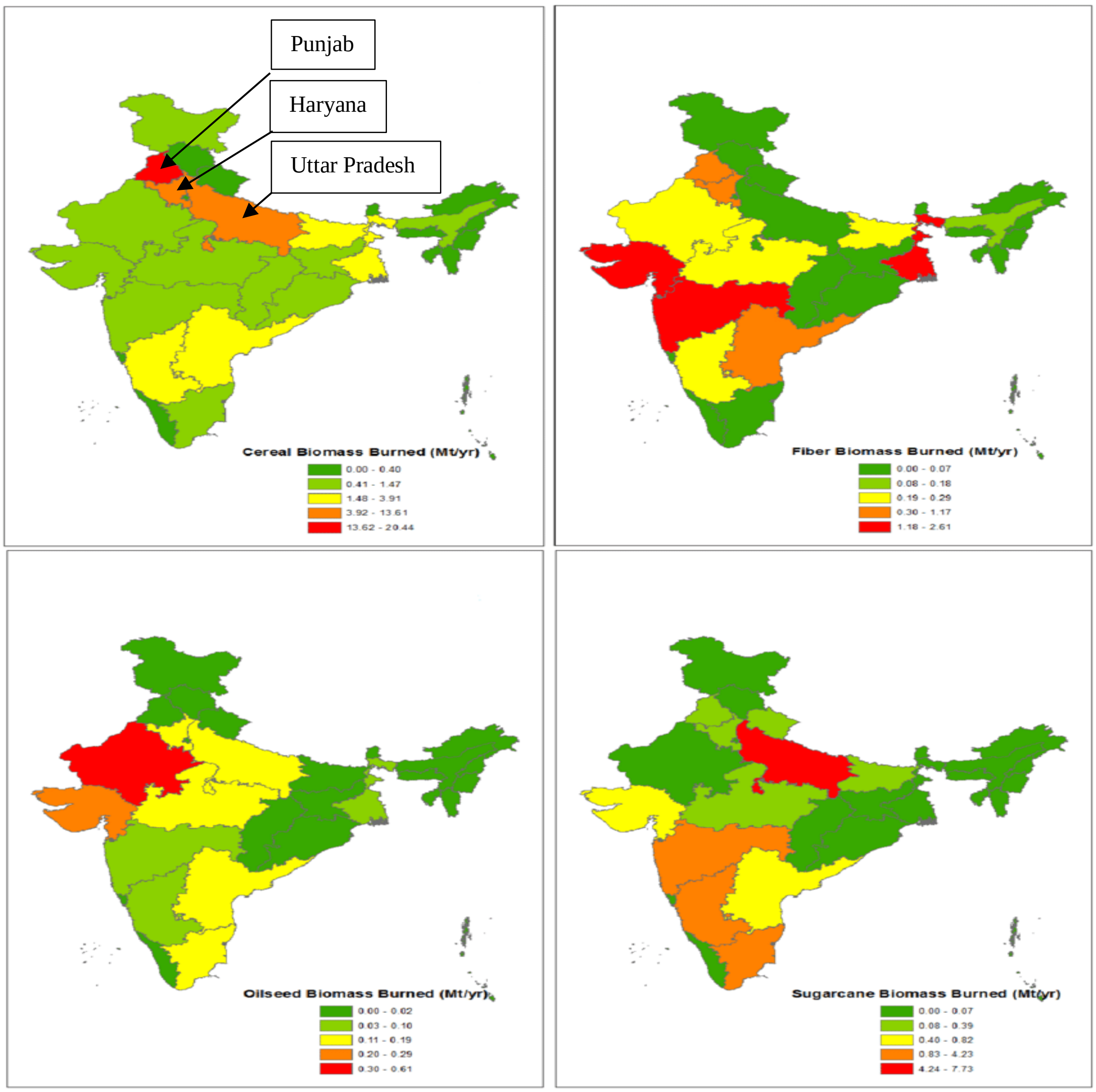
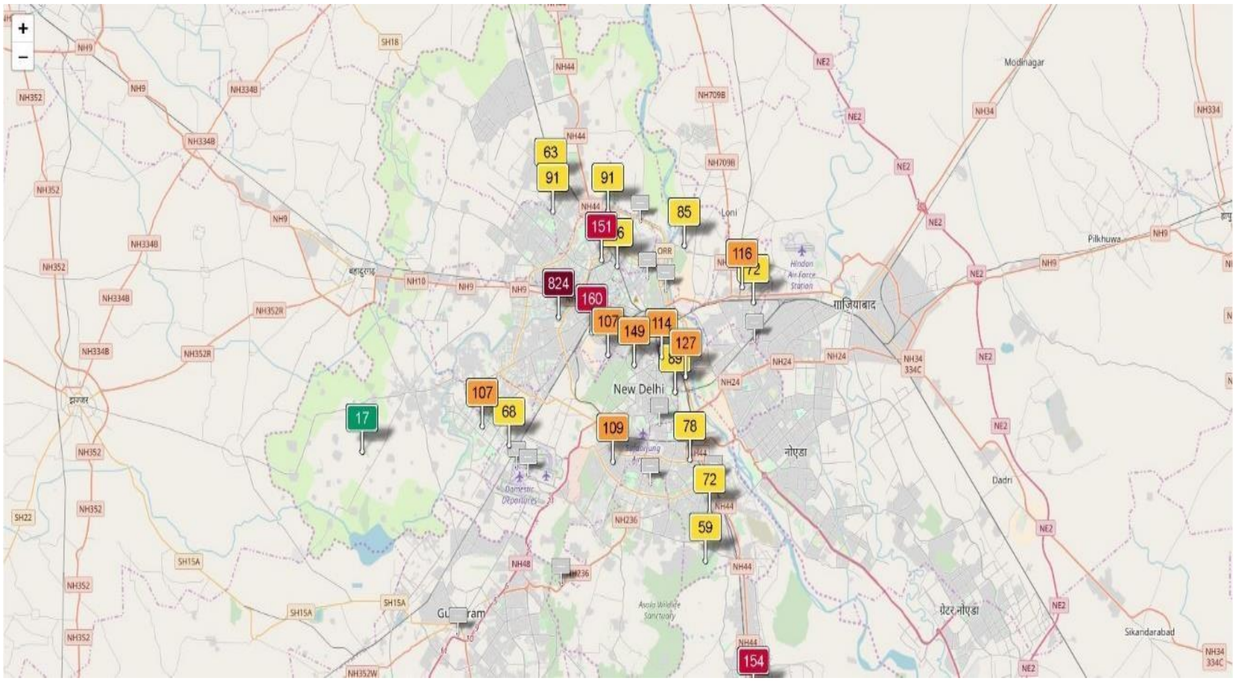


Figure 3 Emission of Air Pollutants from Crop Residue Burning in India in 2014: Adapted from N Jain [11]

The major reason for the air pollution in the New Delhi is because of the burning of crops in the nearby states surrounding New Delhi and vehicular pollution. Figure 4 displays the air quality index visual map of New Delhi in 2018.

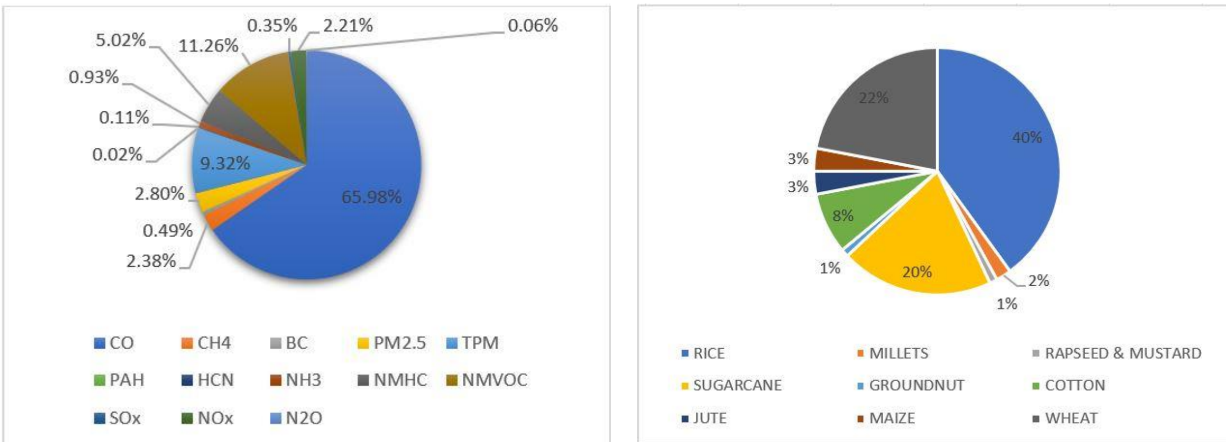


Air Quality Index

AQI	Air Pollution Level	Health Implications
0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk
51 -100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101-150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151-200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
201-300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.
300+	Hazardous	Health alert: everyone may experience more serious health effects

Figure 4 Air Pollution in Delhi in 2018: Air Quality Index Visual Map

Figure 5 (a) shows the emissions of different pollutants and green house gases (GHG) that were emitted due to the burning of crop residues for 2014. Figure 5 (b) shows the individual contribution of crops in the emission of pollutants.



(a) (b)

Figure 5 (a) Emission of different pollutants and GHGs due to field burning of crop residues. (b) Contribution of different crops

From Figure 3, highest amount of cereal crop residue was burned in Punjab, followed by Haryana and Uttar Pradesh. Uttar Pradesh contributed to maximum burning of the sugarcane biomass due to the cultivation of sugarcane in most of the parts (especially western part) of the state. Oil seed residues were burned in Rajasthan and Gujarat whereas the fibre was burned the most in the states of Maharashtra, Gujarat followed by Haryana and Punjab.

In 2014, considering the emission from different crop burning, the highest amount of pollutant emitted was from rice husks and then followed by wheat, maize, etc. In the list of pollutants emitted, the highest was the carbon emission (CO), which contributed to about 65.98% of the total emission which was more than the addition of other pollutants (Figure 5 (a)).

1.3.1 Alternatives

1.3.1.1 Dump

Dumping agro residue to create landfill is a wastage of the resource. It also reduces the potential of usage of the renewability properties of this organic fuel.

1.3.1.2 Use as biomass

The best usage of agro residue is to use it as biomass. It is a trade-off situation to both the farmer and the companies/vendors buying this organic agro residue to use it as biomass. Biomass will help to reduce carbon emission. The use of biomass to produce electricity has increased by an average of 13TWh per year from 2000 to 2008 shown in figure 6 below [12].

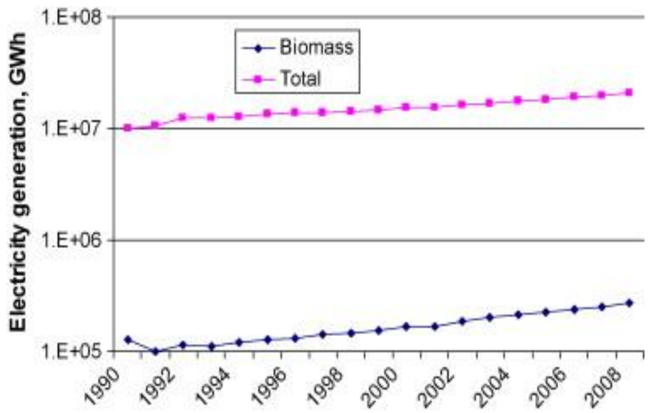


Figure 6 Biomass and total world electricity generation time trend adapted from Evans A, et.al [12]

1.3.1.3 Burning of biomass

The amount of crops that are being burned as wastage has two major problems, one is harmful to the environment and the other by eliminating the essential valuable materials that can be used from these biomasses. According to studies in Indian Institute of Technology (Kanpur), air pollution in New Delhi has a major concern over the last few years from the burning of crops especially in the months of October and November which affects the quality of air drastically [13].

Burning agricultural waste has been identified as a major health hazard. It does not only cause high levels of pollutants and particulate matters in the air it also is a major source of air pollution which contributes about 12%-60% of the particulate matter concentration. It also causes the loss of important nutrients present such as nitrogen, phosphorus, etc. from the top layers of the soil making it infertile. Punjab produces about 19-20 million tonnes of paddy straw and approximately 20 million tonnes of wheat straw. About 85-90% of the paddy straw is burned in the field causing a humungous amount of pollution [14]. Crop residue burning is an offence under the Air act of 1981, the code of criminal procedure and other various laws. National green tribunal has imposed fines ranging from Rs. 2500 (US$ 38.50) to Rs. 15000 (US$ 230.80) on farmers to prevent them from burning the agro residue [15].

Figure 7 and Figure 8 shown below depicts the intensity of fires in the agricultural lands in Haryana and Punjab respectively which is been captured by NASA in 2016 [14]. The stronger intensity of the red dotes on the geographical maps depicts the larger magnitude of fire in the agricultural field.

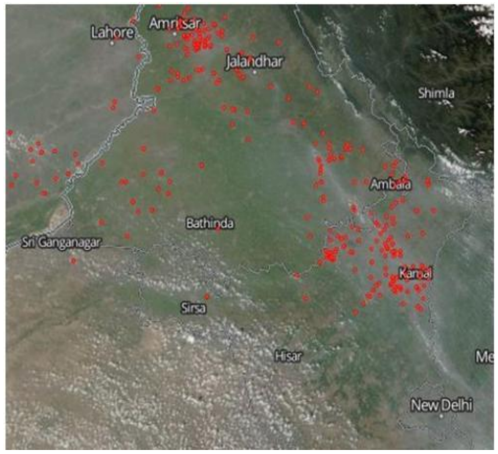


Figure 7 NASA image depicting fires in agricultural lands in Haryana taken from Mukherjee in 2016 [14]

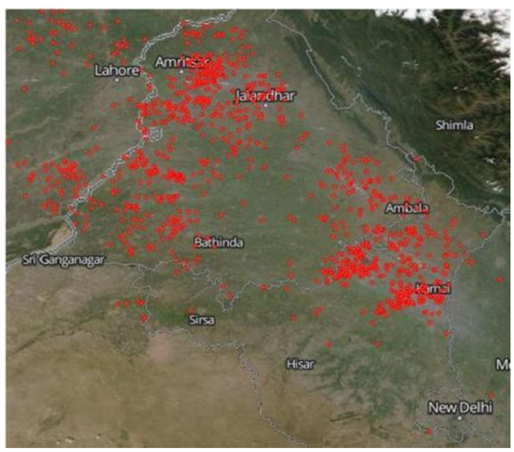


Figure 8 NASA image depicting fires in agricultural lands in Punjab taken from Mukherjee in 2016 [14]

1.4 Biomass

1.4.1 Total Biomass Energy

Biomass has always been an important energy source in an agronomical country like India. The scope of producing energy from the biomass is immense. It is a carbon neutral fuel which is renewable and easily available. About 32% of the total primary energy usage in the country is energy obtained from the biomass and approximately 70% of the country's population depends upon it [16].

India has more than 5,940 MW biomass-based power plants involving 4,946 MW grid associated and 994 MW off-grid control plants (Table 1). Out of the grid interactive power limit, significant number originates from bagasse cogeneration and around 115 MW is from waste to energy control plants. Though off-grid limit involves 652 MW of non-bagasse cogeneration, around 18 MW biomass gasifier system is utilized for addressing power needs in rural zones, and 164 MW equal biomass gasifier system is sent for power applications in industries [16].

Table 1 Total Biomass based power

Program/scheme wise physical progress	
Sector	**Achievements (capacity in MW) (as on 31.03.2016)**
I. Grid Interactive Power (Capacities in MW)	
Biomass Power (Combustion, Gasification and Bagasse Cogeneration)	4,831.33
Waste to Power	115.08
Sub-total Grid Interactive	4,946.41
II. Off-Grid / Captive Power (Capacities in MW)	
Biomass (non-bagasse) Cogeneration	651.91
Biomass Gasifiers	
· Rural	18.15
· Industrial	164.24
Waste to Energy	160.16
Sub-total Off-Grid	994.46
Total Biomass Based Power	**5,940.87**

From figure 9, indigenous coal production is not satisfactory and hence 25% of the coal in India is imported from overseas and this percentage is increasing. India imports energy from different countries for a long period of time. According to International Energy Agency (IEA), India's total energy import increased more than three times from 11% to 35% in around 20 years from 1990 to 2009 [17].

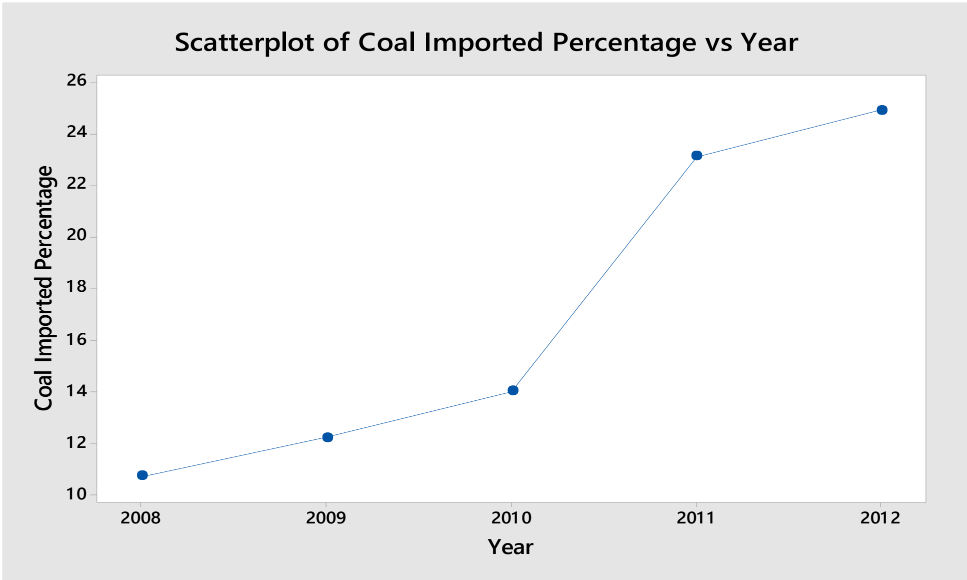


Figure 9 Overview of coal imported by India from 2008-09 to 2012-13 adapted from Ministry of Coal, Government of India [17]

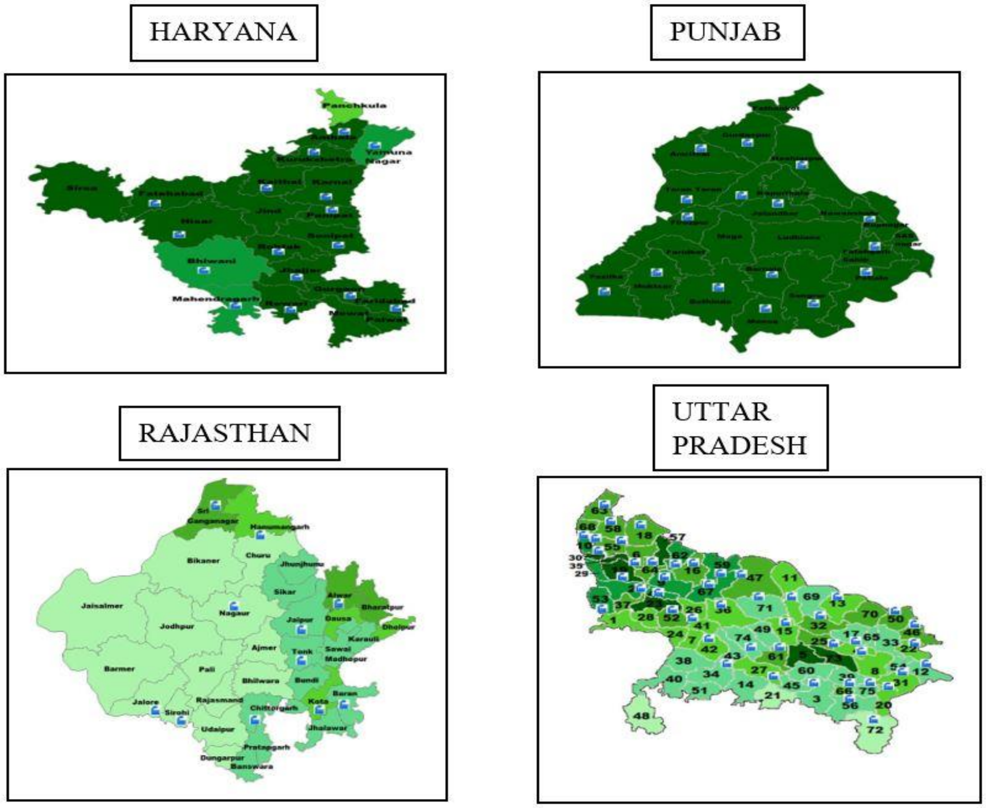
India has a very large supply of agricultural waste which can be used for bioenergy. There can be variable use of bioenergy which will complement the usage of non-renewable fuels especially coal.

1.4.2 Background of Crop Residue and Crop Burning

Farming/agriculture comprises a major part in India's economy. While agro residues is utilized in aggressive options like cows feed, animal bedding, fuel, natural compost and so on, about 234 million tons/year (for example 30%) of gross build-up created in India is out there as excess. Consistently, farming alone creates 140 billion loads of biomass, loads that is approximately 50 billion tons of oil. The energy created from farming biomass waste will displace fuel, downsize discharges of ozone-harming substances and supply a sustainable power source to individuals in developing nations, that still need access to power [18].

Agro residue generation in the nearby states can be used for the biogas plant near New Delhi which are the crops, the woods and the burnt agro residues. These wastes can be filtered and differentiated for the usage of biomass in a biogas plant.

Figure 10 shown below depicts the agro residue generation in the neighboring states of the capital city of New Delhi in 2019. Most of the regions of Punjab, Haryana and the western Uttar Pradesh are rich in agro residue which produces more than 5 tonnes/hectare of biomass.



Legend	Agro-residue generation density (tonnes/hectare)
	More than 5.0
	4.1 to 5.0
	3.1 to 4.0
	2.1 to 3.0
	1.1 to 2.0
	0 to 1.0

Figure 10 Agro residue generation industries in neighboring states of the capital city of New Delhi in 2019 [19]

Table 2 shown below represents the annual production of different crops and the fraction of the crop burnt in 2008-09. The residue to grain proportion varies from1.5– 1.7 for cereal crops, 2.15– 3.0 for fiber crops, 2.0–3.0 for oilseed crops and 0.4 for sugarcane. Added sum dry harvest residue created by nine noteworthy yields was 620.40 Mt. There was an extensive variety in yield deposits age over distinctive conditions of India relying upon the yields developed in the states, their cropping intensity, and profitability [11].

Table 2 Crop wise production, residue generated, and coefficients used for inventory in 2008-09[11]

Crop	**Annual Production**	**Dry Residue generated**	**Residue to crop ratio**	**Dry matter fraction**	**Fraction burnt**
Rice paddy	153.35	192.82	1.50	0.86	0.08–0.8#
Wheat	80.68	120.70	1.70	0.88	0.1–0.23*
Maize	19.73	26.75	1.50	0.88	0.10
Jute	18.32	31.51	2.15	0.80	0.10
Cotton	37.86	90.86	3.00	0.80	0.10
Groundnut	7.17	11.44	2.00	0.80	0.10
Sugarcane	285.03	107.50	0.40	0.88	0.25
Rapeseed &Mustard	7.20	17.28	3.00	0.80	0.10
Millets	18.62	21.57	1.50	0.88	0.10
Total	**627.96**	**620.43**			

Gadde et al. (2009).

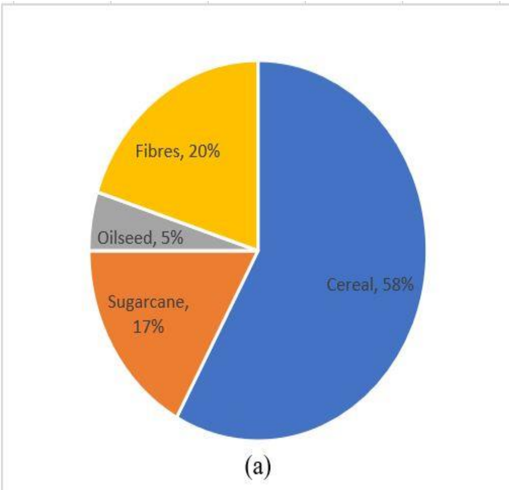
* 0.23 is for Haryana, Punjab, H.P., U.P.

Table 3 shows the crop residue generated in various states of India for the year 2008-09. Haryana, Punjab and Uttar Pradesh are highlighted to show the amount of cereal, fibre, oilseed crops and sugarcane that is produced. Among the distinctive yield classes, 361.85 Mt of the residue was produced by grain crops pursued by fiber crops (122.4 Mt) and sugarcane (107.5 Mt). Generation of grain crop residues was most noteworthy in the states of Uttar Pradesh (72 Mt) trailed by Punjab (45.6 Mt), West Bengal (37.3 Mt), Andhra Pradesh (33 Mt) and Haryana (24.7 Mt). Uttar Pradesh contributed greatest to the generation of residues of sugarcane (44.2 Mt) while deposits from fiber crop were predominant in Gujarat (28.6 Mt) trailed by West Bengal (24.4 Mt) and Maharashtra (19.5 Mt). Rajasthan and Gujarat produced about 9.26 and 5.1 Mt respectively separately from oilseed crops [11].

Table 3 Crop wise residue generated in various states of India for 2008-09[11]

Crop wise residue generated (MT/yr)				
States	**Cereal crops**	**Fiber crops**	**Oilseed crops**	**Sugarcane**
Andhra Pradesh	33.07	16.07	2.50	5.80
Arunanchal Pradesh	0.56	0.00	0.06	0.01
Assam	8.15	2.01	0.29	0.41
Bihar	19.87	3.27	0.20	1.87
Chhattisgarh	8.87	0.01	0.11	0.01
Goa	0.24	0.00	0.01	0.02
Gujarat	8.18	28.62	5.06	5.85
Haryana	24.73	7.58	2.15	1.93
Himachal Pradesh	1.95	0.00	0.01	0.02
Jammu & Kashmir	2.76	0.00	0.11	0.00
Jharkhand	7.34	0.00	0.09	0.13
Karnataka	11.73	3.55	0.81	8.80
Kerala	1.14	0.01	0.00	0.10
Madhya Pradesh	16.05	3.51	2.13	1.12
Maharashtra	8.75	19.51	0.57	22.87
Manipur	0.78	0.00	0.00	0.01
Meghalaya	0.44	0.13	0.01	0.00
Mizoram	0.10	0.00	0.00	0.01
Nagaland	0.89	0.01	0.06	0.07
Orissa	13.38	0.56	0.16	0.24
Punjab	45.58	9.32	0.08	1.76
Rajasthan	22.19	2.96	9.26	0.15
Sikkim	0.14	0.00	0.01	0.00
Tamil Nadu	11.69	0.78	1.56	12.37
Tripura	1.22	0.02	0.00	0.02
Uttar Pradesh	72.02	0.04	2.49	41.13
Uttarakhand	2.40	0.00	0.03	2.11
West Bengal	37.26	24.43	0.95	0.62
A & N Islands	0.04	0.00	0.00	0.00
D & N Haveli	0.05	0.00	0.00	0.00
Delhi	0.17	0.00	0.00	0.00
Daman & Diu	0.01	0.00	0.00	0.00
Pondicherry	0.10	0.00	0.00	0.06
All India	**361.85**	**122.37**	**28.72**	**107.50**

Cereal crops created 58% of residue while rice alone contributed 53% and wheat positioned second with 33% of cereal crop deposits in 2008-09 (Fig. 11 (a) and Fig. 11 (b)). Fiber crops contributed 20% of deposits produced with cotton positioning first (90.86 Mt) with 74% of harvest buildups. Sugarcane buildups created 17% of the absolute harvest residues. Oilseed crops produced 28.72 Mt of buildup every year (Fig. 11 (a)).



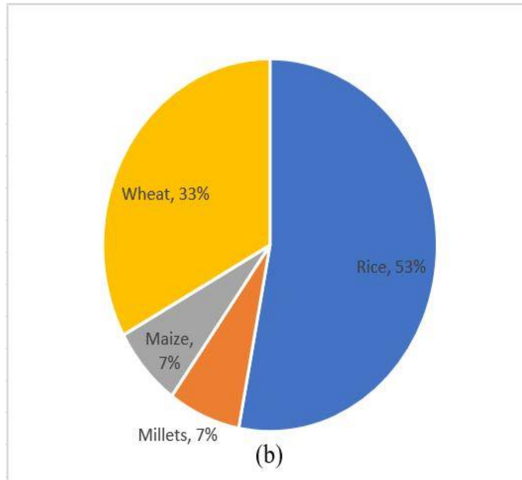


Figure 11 (a) Contribution of different crops categories in residue generation. (b) Contribution of different cereal crops in residue

1.5 Research Question

Is building a model of the energy supply chain for transport vehicles (delivery trucks) an improvement in:

Cost

Energy

Carbon footprint/emissions

The problem for which this report would propose the solution is air pollution in the capital of India, New Delhi. Being the capital city of the biggest democracy in the world, the level of air pollutants in the city is extremely high and even more than the hazardous level defined by WHO. This problem could be solved in various ways, though it would take a good amount of time. But maybe by 2030, the levels of pollution can be reduced to a great extent if the implementation of environmental and sustainable rules are done as soon as possible.

Air pollution comes under sustainable development goal 3 (SDG 3) i.e., good health and well-being and SDG 11, i.e., sustainable cities and communities (11.6). Target is that by 2030, improve the air quality of the capital city by taking sustainable measures and working together to obtain a healthy environment and to reduce the toxic levels of air below the stated levels by WHO [20].

1.6 Importance

The importance of this research paper is because of the following:

- Construct an energy model to increase electricity for EV truck adoption.
- The plant's output will generate reliable, cheap electricity that would encourage the implementation of EV.
- Electric vehicles will use electricity from the plant's production for the raw biomass supply chain from the origin to the plant.
- Electricity production is achieved from two renewable sources of biomass co-firing, one of which is biomass itself and the other is biocoal.

This research work is done to evaluate the impacts of coal co-firing with biomass to reduce air pollution (CO2 emission) in New Delhi by utilizing the raw agro residue which is burnt by the farmers in nearby states. A process/model of co-firing biomass and biocoal is proposed and working into a supply chain for this system to reduce the carbon footprint and studying the overall cost analysis and improvement in energy.

Investigating the problems and finding for the air pollution in New Delhi is imperative as it will analyze the complexity of the system, which is contained within a few sub systems. The paper also proposes an improved energy supply chain by analyzing a new process under the energy supply chain of the delivery trucks around New Delhi in India which includes the cost benefits, the environment factors and energy effectiveness.

CHAPTER 2

LITERATURE REVIEW

2.1 Biomass Co-firing with Coal

Biomass co-firing can be simply defined as simultaneously mixing and combusting biomass with other fuels like coal to produce electricity. Solid biomass co-firing is the use of solid biomass like wood pellets and chips in the coal fired power plant. In unavailability of biomass, the other fuel increases its volume so that the process runs smoothly [21].

Co-firing biomass with coal is a renewable and an emerging solution to tackle the amount of carbon emissions. In a country like India, which has such a large biomass generation, this can be an optimum solution for the reduction of carbon footprints. Indian Renewable Energy Development Agency Limited (IREDA) claims that 460 million tonnes of agricultural waste can replace about 260 million tonnes of coal that is produced every year. This quantity is more than the coal imported from overseas (192.54 tonnes) estimated for 2012-13Hence, the use of the biomass produced in India can notably reduce the import of coal. . Co-firing biomass can improve the combustibility of high ash Indian coal. Biomass can be used as per availability. In the worst-case scenario, if there is an unexpected unavailability of biomass, the power plant can still work on coal. [17]

Figure 12 below shows the forecast of biomass renewable energy consumption by the Annual Energy Outlook (AEO). AEO 2013 predicts that the growth (in percentage) of biomass utilization will be higher in co-firing than current biomass plants. The annual growth for the biomass co-firing is about 10% whereas the dedicated plant has the annual growth of approximately 3%.

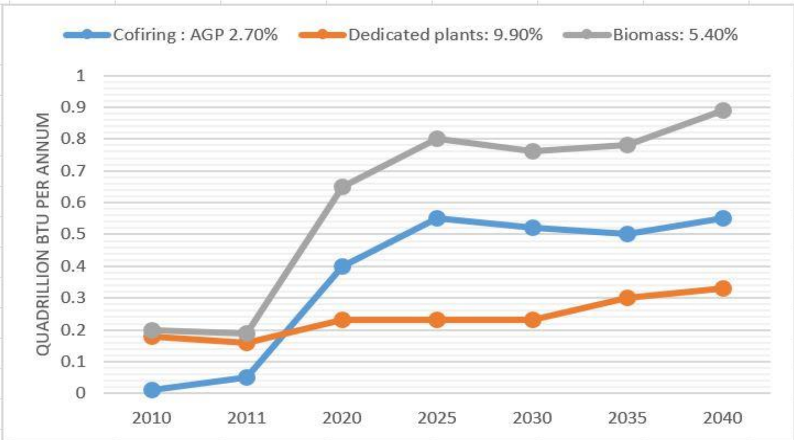


Figure 12 Forecasts of biomass renewable energy consumption.
AGP – Annual Growth Percentage 2011-2040
Adapted from data from Annual Energy Outlook 2013, U.S. Energy Information Administration, April 2013 [17]

Co-firing biomass has several interesting opportunities, especially for utility companies and their customers to protect their environment by reducing carbon emissions and lowering the amounts of greenhouse gases. It creates new opportunities and chances for companies from various fields like, manufacturing, food processing, construction, agricultural and forestry to motivate the use of bio waste to produce clean energy sources and to manage large agro residues. In addition to this, the cost of building a new co-firing plant is relatively economical as the instruments and systems used for dedicated biomass power plants can be used for the co-firing process [22].

2.2 Co-firing

Co-firing method is combustion of two or more fuels to produce electricity by adding biomass and high efficiency coal boilers [23]. Figure 13 shows a basic industrial process diagram of the co-firing process.

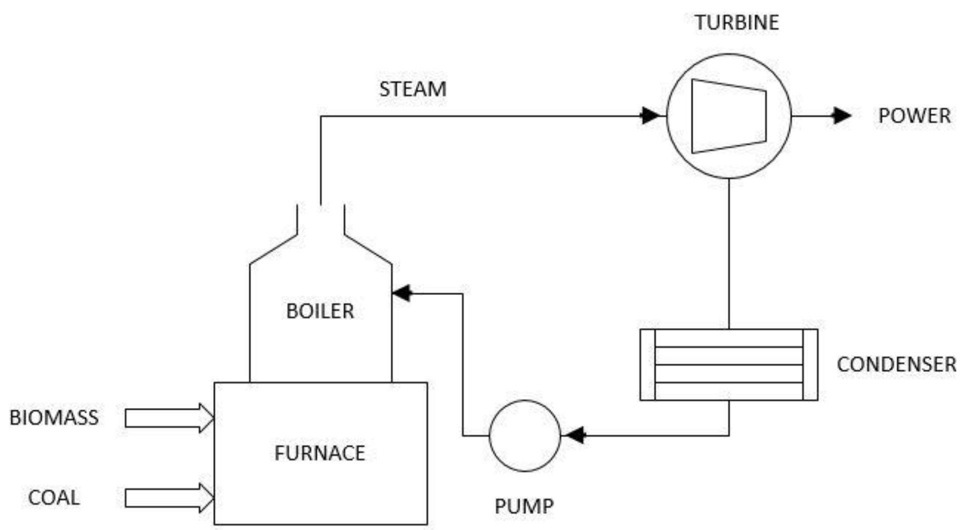


Figure 13 Co-firing process diagram

Co-firing technique technically has 3 processes: direct co-firing, indirect co-firing and parallel co-firing.

Direct co-firing is a process where the biogas and coal are directly heated up in the boiler and the process continues. In indirect co-firing the biomass is first gasified and then fuel gas is co-fired into the boiler. And in parallel co-firing, biomass is burnt in a separate boiler for steam generation [24]. Energy production in a powerplant with partial substitution of coal with biomass is a co-firing system [24]. Biomass co-firing proposes renewable energy generation with minimum cost and reduced carbon emissions. Biomass contains lesser quantity of sulphur than coal and due to which lesser amount of SO_2 is generated.

2.2.1 Direct Co-firing

Direct co-firing is the least expensive alternative which operates in an uncomplicated operation. The biomass is directly fed to the boiler after passing through similar factories - crushers, bunkers and pulverisers - as coal. The biomass can be blended with coal in the fuel yard or can be nourished to the combustion chamber independently. Multi-fuel fluidised bed boilers accomplish efficiencies over 90% while vent gas emission is lower than for common grate ignition because of lower burning temperatures due to the burning of shredded/crushed pieces of coal [24].

Direct co-firing is a basic methodology and the most well-known and most affordable strategy for co-firing biomass with coal in a boiler, for a majority of pulverised coal (PC) boiler [21].
In direct co-firing, biomass is directly fed to the boiler/furnace after being milled with the coal together or separately. This mixture is combusted in the burner. The co-firing rate is usually 3-5% but may rise to about 20% when cyclone burners are used, but still for the optimum results PC boilers is used [21].

a) Mixing biomass with coal

The first procedure of direct co-firing biomass is mixing the biomass with coal. From figure 14, the biomass and coal together are sent to mill and passed to the burners and then into the boilers. From the boiler, steam is generated which is used for production of electricity.

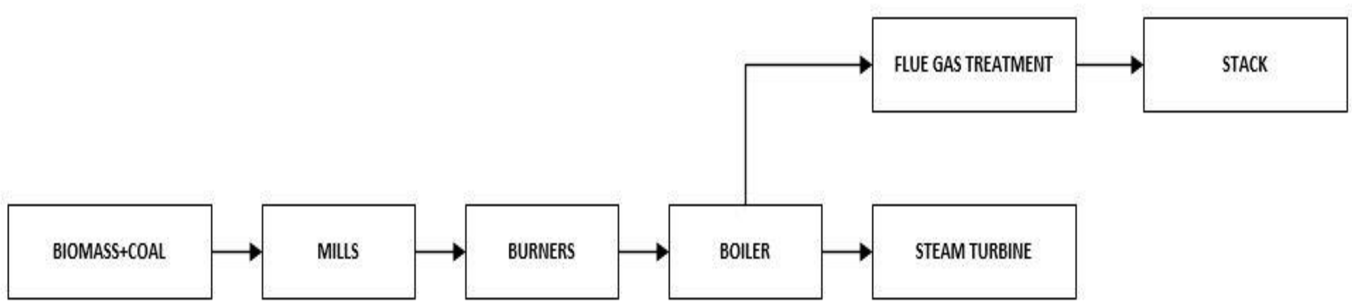


Figure 14 Direct co-firing: Mixing biomass with coal

b) Separate biomass feeding system

The second procedure is separate biomass feeding system, in which biomass and coal are separately sent to the burner after passing through the mills as shown in the figure 15.

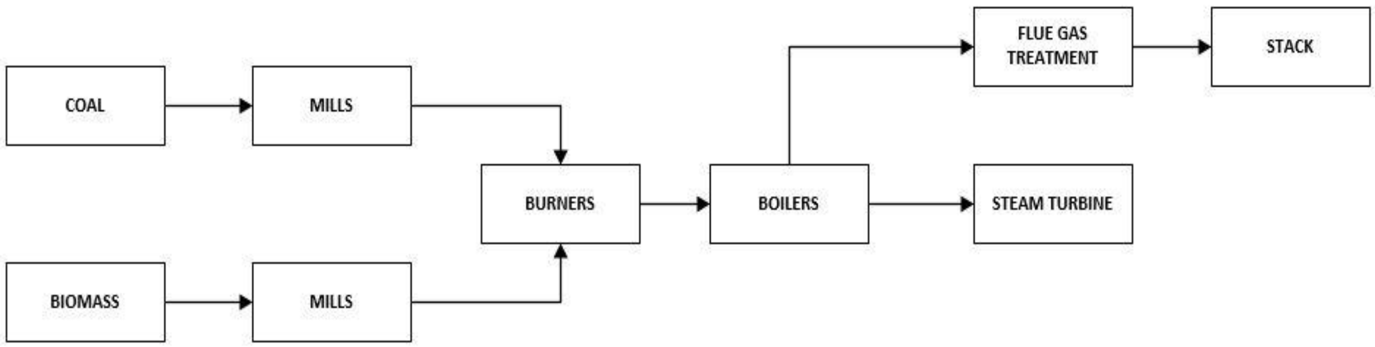


Figure 15 Separate biomass feeding system

2.2.2 Indirect Co-firing

In indirect co-firing, biomass is co-fired in an oil or gas-fired system. It exists in two structures, gasification-based co-firing and pyrolyzation-based co-firing. As shown in figure 16, in gasification-based co-firing, the biomass feedstock is nourished into a gasifier in the beginning of the procedure to create syngas, which is rich in CO, CO2 H2, H2O, N2, CH4, and some light hydrocarbons. This syngas is then fired together with natural gas in a committed gas burner. The net heating estimation of the syngas delivered from the gasification procedure has an inverse relationship with the dampness or the moisture substance of the feedstock, which ranges from 8% in corn stover to 38% in white pine. The other method of indirect co-firing depends on pyrolysis, where the biomass fuel experiences a undesirable refining procedure to deliver a fluid fuel like bio-oil just as strong char, and after that the bio-oil is co-fired with a base fuel, for example, flammable gas in a power station. Gasification offers a remarkable favourable position in that it is fuel adaptable as far as the base fuel utilized since it can oblige coal, oil, and flammable gas [21].

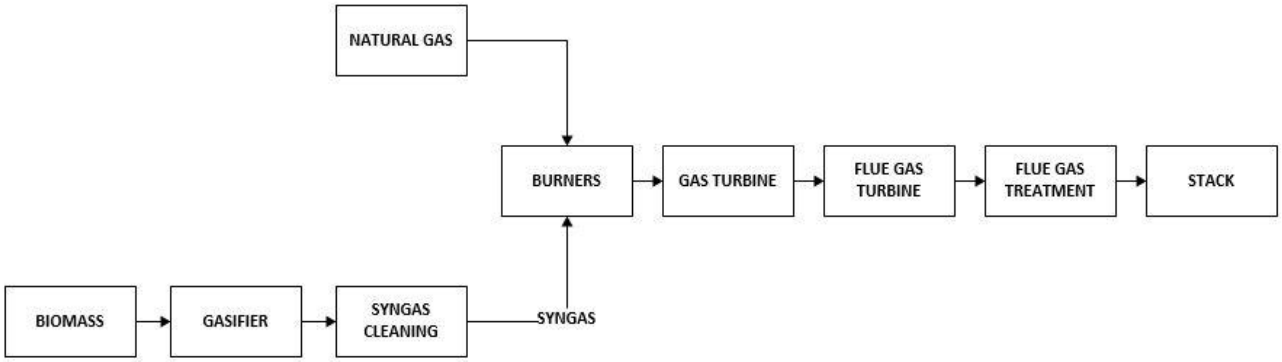


Figure 16 In-direct co-firing

2.2.3 Parallel Co-firing

In parallel biomass co-firing, biomass pre-handling, feeding, and ignition exercises are completed in discrete, dedicated biomass burners. As shown in Figure 17, parallel co-firing includes the establishment of a totally isolated outer biomass-fired boiler to create steam used to produce power in the power plant. Coal and biomass are separately treated before being sent into the boiler system. Rather than utilizing high pressure steam from the primary boiler, the low-pressure steam produced in the biomass heater is utilized to fulfil the process needs of the coal-fired power plant. Parallel co-firing offers higher rates of biomass energy to be utilized in the boiler. This method additionally offers lower operational hazards and more prominent dependability because of the accessibility of independent and dedicated biomass burners running parallel to the current heater unit. There is a decreased tendency for deposition formation issues like fouling and slagging, since the system configuration keeps biomass vent gas from reaching the boiler heating surfaces and the burning procedure is better streamlined. In any case, this methodology is more expensive than direct co-firing because of the dedicated boiler system. Its application is typical in mechanical pulp and paper industries where it utilizes results from paper creation like bark and waste wood [21].

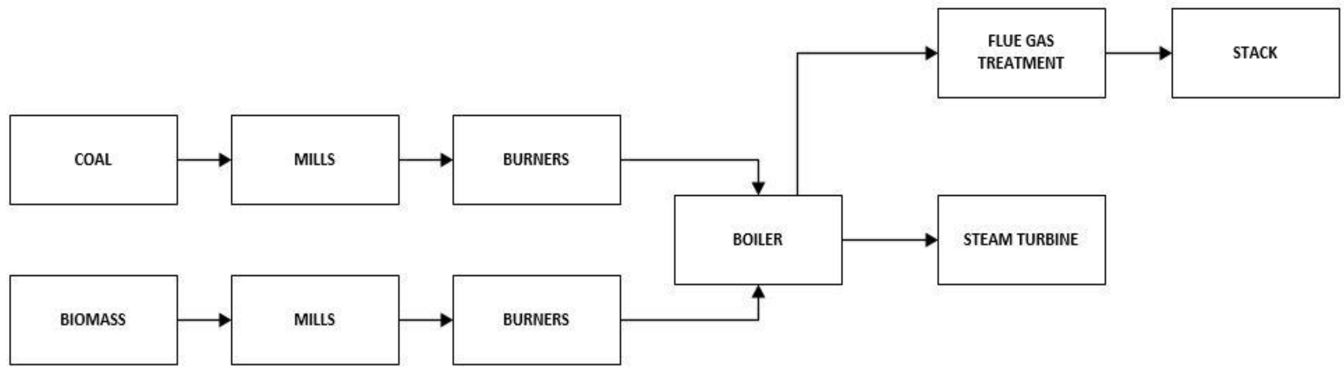


Figure 17 Parallel Co-firing

2.3 Torrefaction Process

Biomass was the basic source of energy worldwide until two or three generations back when the energy density, storability and transportation of non-sustainable energy sources (fossil fuels) engaged amongst the quickest social changes in the history of mankind- the Industrial transformation. In just two or three hundred years, coal, oil and gaseous fuels have prompted the progress of outstandingly capable, high volume, delivering transportation structures that have transformed into the foundation of the world economy. By over-reliance on fossil fuels, resources have incited common and energy security concerns.

There is much enthusiasm for torrefaction as a strategy for changing biomass into an element like coal. Torrefaction is not another innovation — it has been utilized mechanically for a long time to roast coffee beans, however its application to biomass for bioenergy creation is new.

Torrefaction makes both woody and herbaceous biomass brittle (simple to crush/grind), improves the fuel properties (increases the carbon and decreases the oxygen and hydrogen) and makes it increasingly appropriate for burning/combustion and gasification applications. It delivers a low-dampness, hydrophobic substance with extremely low organic movement, making it truly stable in various conditions.

Torrefaction happens as biomass is gradually warmed to a temperature range of 200-300°C in a situation without oxygen. This is sufficiently hot to totally dry the material and produce chemical changes without causing ignition. At warm treatment temperatures of 50-150°C, biomass loses free water, or the water that flows all through the plant tissues, which diminishes the material's total thickness. At temperatures of 150-200°C, hydrogen and carbon bonds start to break, which asserts that water is held firmly in the plants micropores, and makes the biomass lose its fibrous nature, making it significantly simpler to crush. In prolonged time, at temperatures of 200-300°C, or the torrefaction run, not just has the material deprives most of its dampness while holding the greater part of its energy value (90% of starting energy content), it experiences chemical changes that enormously improve its coal-like characteristics. Carbonization and devolatilization happen, bringing about the outflow of off gases that can be reused to help control the torrefaction process. This makes transportation of biomass over long distances and burning of biomass more secure for people and the environment, since volatiles are not radiated into the climate. Destruction of the plant's cell structure makes it weak, further improving its grindability and making the material progressively uniform and predictable. The mix of these changes decreases the material's capacity to rehydrate, so it sheds instead of absorbing outer moisture and is less inclined to decay. Torrified biomass has comparable burning attributes to coal, and the darkened material seems progressively like it, as well [25].

Bio coal is produced by a process called Torrefaction. It is a thermal process in which biomass is converted into a better strength and higher fuel like characteristics which is a byproduct of biomass [26]. Figure 18 shows the generation of biocoal from biomass through a torrefaction process.

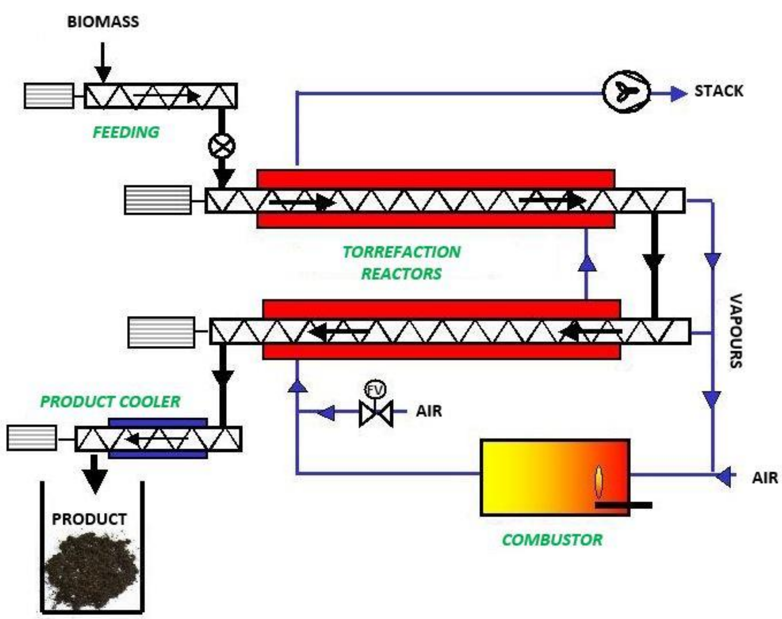


Figure 18 Torrefaction Process

Bio coal has better strength and higher fixed carbon and calorific value which make it burn longer [7]. As it is produced from biomass, it is environment friendly and can be renewed.

2.3.1 Torrefaction Attributes

There are seven major torrefaction attributes listed below [25]:

Improved Stability: Hydrophobicity studies led by Idaho National Laboratory (INL) and Oak Ridge national Laboratory (ORNL) found that Torrefaction drastically decreases the requirement for costly secured stockpiling and long-distance transportation.

Improved Flowability: Grinding studies at INL have discovered that torrified biomass has improved molecule size and shape sphericity after granulating, which makes it less demanding to deal with current high-volume transportation framework and progressively reasonable for thermochemical applications, for example, gasification, co-firing and pyrolysis.

Improved Energy Esteem: Torrefaction studies directed by INL showed that biomass holds most of its energy content while depriving dampness and low energy content volatiles, which expands heating quality and improves combustion efficiency.

Reduced Logistics Cost: The Energy Research Centre of the Netherlands (ECN) reported that torrefaction and densification expand mass density almost four-fold and can decrease logistics cost by 30%.

Reduced Processing cost: INL grinding studies on deep dried and torrified biomass found critical decrease in grinding energy required raw biomass.

Reduced Variability: The ECN has discovered that torrified biomass has increasingly predictable dampness content and beats more controlled than untreated biomass, bringing about better mixing of differing plant fractions.

Reduced Storage Off-Gases: INL and University of British Columbia studies showed torrified biomass emits lower CO,CO_2, and CH_4 off-gases compared to non-torrified biomass.

2.4 Energy Balance

In figure 19, the emissions of greenhouse gases from different application of coal is shown. According to the National Renewable Energy Laboratory (NREL) in Colorado, USA, the energy balance of co-firing 15% biomass with coal which reduces greenhouse gases by 18% co firing biomass and bio coal will further reduce the emission of greenhouse gases [23]. The use of charging stations and not traditional sources of electricity will be provided by the exclusive charging stations for electric vehicles. Combustion is more controlled, and uniform as compared to coal and boiler's response to steam is quicker due to larger quantity of volatile material. Bio coal has higher thermal value and lower ash content as compared to coal [27].

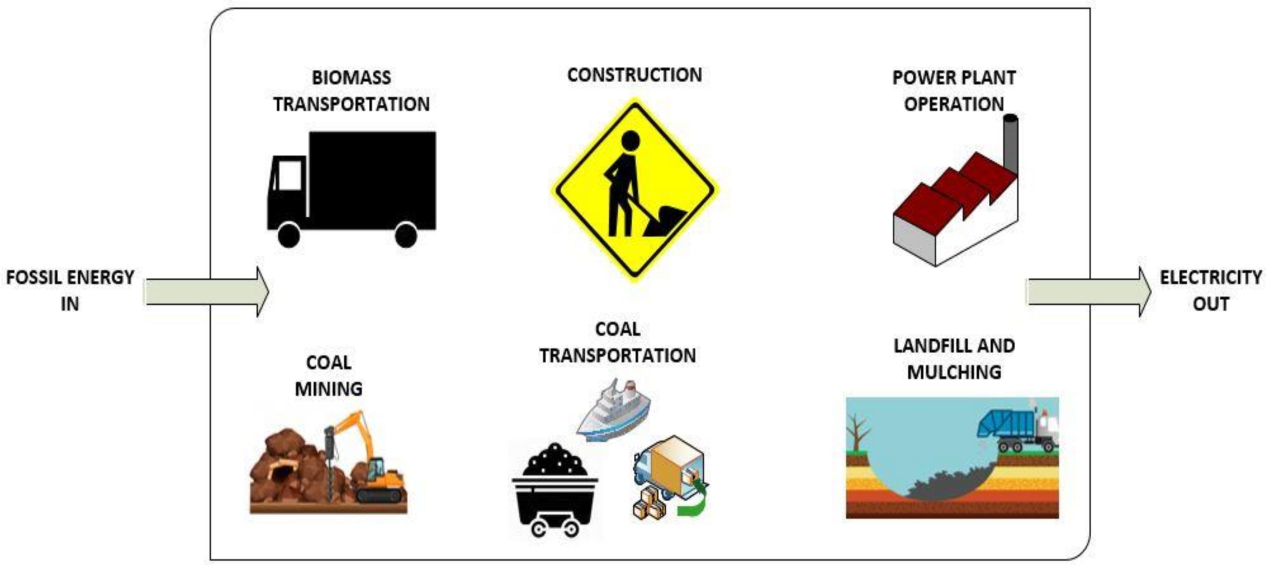


Figure 19 Energy balance of co-firing biomass and coal[23]

In figure 20, the negative impact of moisture on biomass is that it requires higher temperature for drying which requires higher energy and hence reduces the energy which is converted [21]. It also increases the inflated ratio of vapours in the feedstock which reduces the quantity of combustible gases (CO, H2).

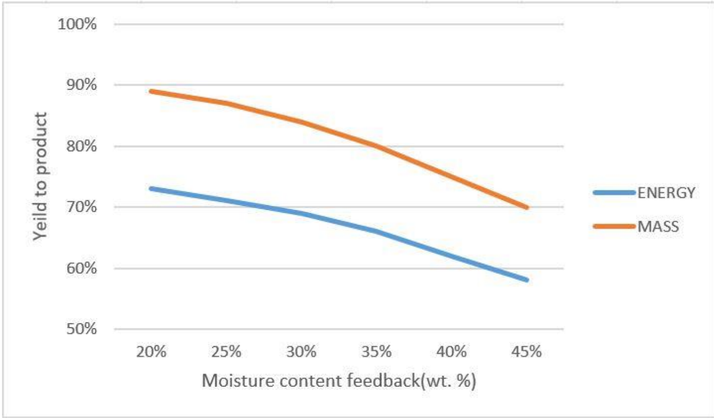


Figure 20 Relation between moisture content and yield to product

Figure 21 shown below describes the life cycle of the biomass plant. From an actual life cycle perspective, CO2 discharged when combusting biomass will be consumed during plant development, bringing about an inexact carbon neutral burning procedure with extra CO2 emission from the supply chain network process [28].

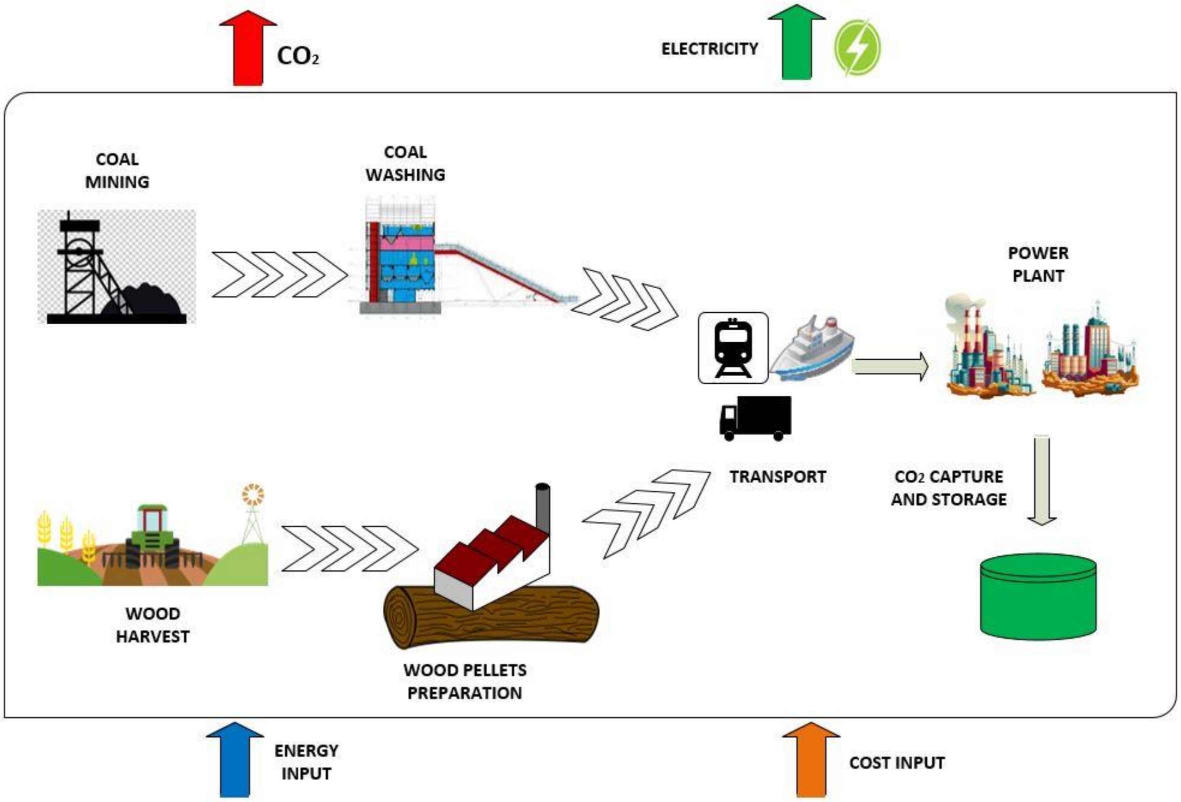


Figure 21 The life cycle of biomass to biofuels and bioproducts [28]

Biomass is a renewable source of energy which is generally produced from agricultural wastes, wood and organic materials, seaweed, etc. Compared to other sources of fuel, biomass is also considered as "carbon neutral" [21]. Carbon neutral technically means that biomass does not add any carbon to the atmosphere. Carbon neutrality is the ability to produce energy without adding carbon to the environment (table 4). It means that the carbon produced during the generation of energy is consumed by the newly grown plants. Plants are absorbing carbon dioxide as they develop. The carbon builds tissues and feeds the plant during the release of oxygen. The carbon recombines with oxygen when plant material is burned. The carbon dioxide resulting is released back into the atmosphere. In terms of carbon neutrality, trees absorb CO2 from the atmosphere when they grow, and this CO2 is released back to the atmosphere when burned. As compared to the burning of coal, which is subterranean when exposed to the atmosphere during combustion carbon to the atmosphere which was earlier underneath the ground. This causes the change in the carbon content in the atmosphere. Therefore, biomass contributes far less to the greenhouse effect than is the case with traditional fossil fuels. The oil and coal-based fuels are deposited under the ground for millions of years. Such conventional fuel burning produces carbon emissions that interact with the normal carbon cycle and damage the climate [29]

World Business Council for Sustainable Development (WBCSD, 2015) summarized a classification of definition of carbon neutrality which is shown in the table 4 below:

Table 4 Definitions of Carbon Neutrality

Type	Definition	Example
Inherent carbon neutrality	Biomass carbon was only recently removed from the atmosphere; returning it to the atmosphere merely closes the cycle	All biomass is *inherently carbon neutral*
Carbon-cycle neutrality	If uptake of carbon (CO_2) by plants over a Biomass harvested from regions where forest carbon stocks given area and time is equal to emissions of are stable is *carbon-cycle neutral* biogenic carbon attributable to that area, biomass removed from that area is carbon-cycle neutral	Biomass harvested from regions where forest carbon stocks are stable is carbon-cycle neutral
Life-cycle neutrality	If emissions of all greenhouse gases from the life cycle of a product system are equal to transfers of CO_2 from the	Wood products that store atmospheric carbon in long-term and permanent storage equal to or greater than life-cycle emissions associated with products are at least *life-cycle neutral*

	atmosphere into that product system, the product system is life-cycle neutral	
Offset neutrality	If the emissions of greenhouse gases are compensated for using offsets representing removals that occur outside of a product system, that product or product system is offset neutral	Airline travel by passengers who purchase offsets credits equal to emissions associated with their travels is offset neutral.
Substitution neutrality	If emissions associated with the life cycle of a product are equal to (or less than) those associated with likely substitute products, that product or product system is (at least) substitution neutral	Forest-based biomass energy systems with life-cycle emissions equal to or less than those associated with likely substitute systems are at least *substitution neutral*
Accounting neutrality	If emissions of biogenic CO2 are assigned, an emission factor of zero because net emissions of biogenic carbon are determined by calculating changes in stocks of stored carbon, that biogenic CO2 is accounting neutral	The US government calculates transfers of biogenic carbon to the atmosphere by calculating annual changes in stocks of carbon stored in forests and forest products; emissions of CO2 from biomass combustion are not counted as emissions from the energy sector

2.5 Logistics Behind Co-firing

2.5.1 Indian Commercial Vehicle Industry

The size of the Indian logistics market, which comprises air, sea, rail and road freight and warehousing sectors, is approximately worth US$300 billion. The road-freight portion of this logistics market is currently valued at US$150 billion per annum and is growing at a compound annual growth rate(CAGR) of around 12% [30].

Figure 22 shows the general structure of the Indian road transport industry. There are four major segments. First is the government regulatory body who enact the rules and regulation for possession of the trucks. The permission of the vehicle is issued by the regional transport office and other government bodies. Second segment in this industry is support and services required for the vehicle which deals with the insurance and financing. Third segment includes the key tangible section which is manufacturers, fuel, drivers and the truck builders and fourth, core actors who are the truck owners, transport agencies and the end customer.

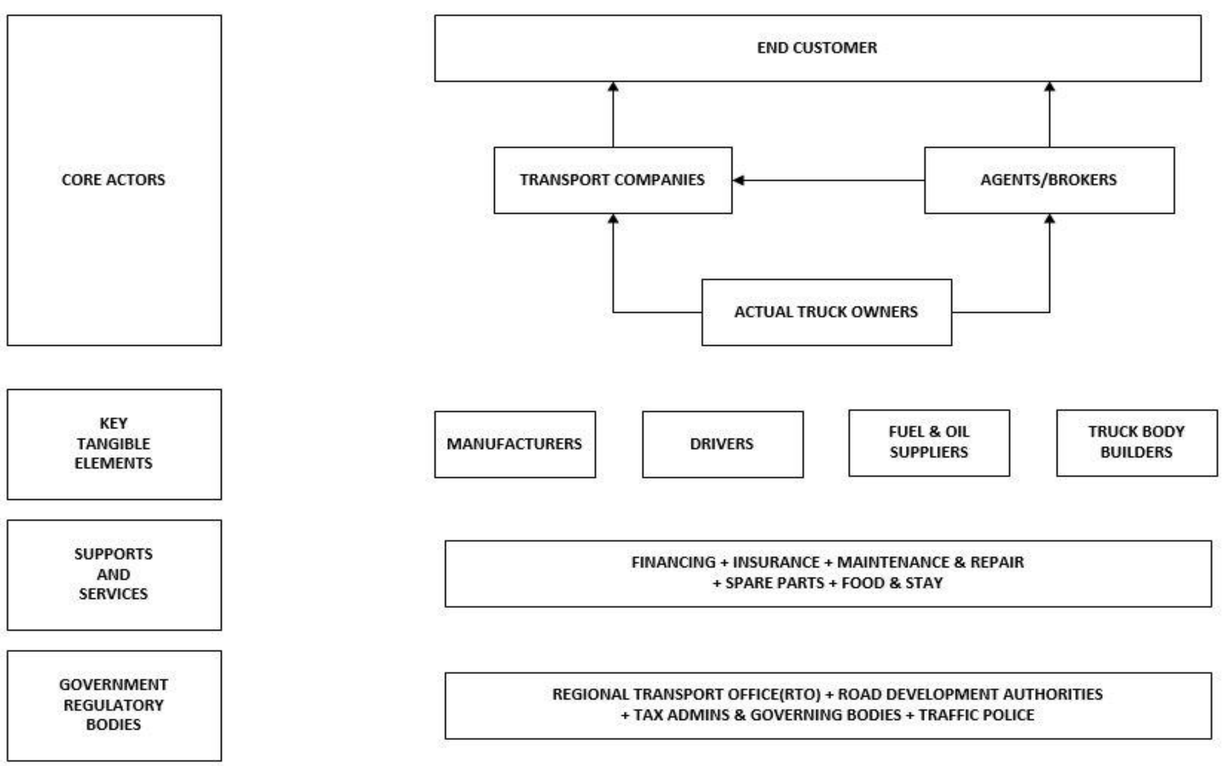


Figure 22 General Structure of Indian Road Transportation Industry

Distinguishing factor of Indian commercial vehicles market from others (US & EU) is that numbers of HCVs running on the highways are insignificant; largely due to (below-par) road infrastructure. A 16-ton commercial vehicle is considered a heavy-duty truck (in India) unlike 40T in advanced countries. But things might improve as the Indian government is focusing on infrastructure development (~30km of roads getting built every day). Within the next 5-10 years, trucks will be smarter, safer and more fuel-efficient with a higher carrying capacity. That will lead to a significant drop in per unit carrying costs of the goods being transported [30].

2.5.2 Comparison of Diesel Truck versus Electric Truck: TCO Perspective

Table 5 shown below discusses the comparison of the diesel truck vs the electric truck with a perspective of total cost of operation of 10 years.

Table 5 Comparison of Diesel Truck versus Electric Truck: TCO Perspective

Conventional Diesel Truck		Electric Truck(Tesla Semi)	
Fixed Cost		**Fixed Cost**	
Net Price	3.50	Net price except battery	11.70
Capital cost	0.32	Capital cost	1.08
Tax	0.96	Tax	0.96
Insurance	0.96	Insurance	0.96
Total Fixed Cost(MINR)	**5.74**	Battery cost	13
		Total Fixed Cost(MINR)	**27.35**

Variable Cost		**Variable Cost**	
Tires	1.65	Tires	1.65
Maintenance and Repair	0.96	Maintenance and Repair	0.48
Fuel	19.01	Electricity cost	6.23
Urea	0.67	Fuel	0.00
Engine Oil	0.09	Urea	0.00
Transmission Oil	0.06	Engine Oil	0.00
Coolant	0.01	Transmission Oil	0.00
Cost of driver	1.92	Coolant	0.00
Total Variable Cost(MINR)	**24.36**	Cost of driver	1.92
		Total Variable Cost(MINR)	10.28

Total TCO(MINR)	**30.10**	**Total TCO(MINR)**	**37.62**

With the discovery of the electric truck, Tesla formally joins the trucking company. The fate of the worldwide logistics industry, evaluated by Frost and Sullivan to add up to ~€10.6 trillion by 2020, may very well have encountered an interruption not found in the previous 100 years of trucking [30].

While doing the comparison shown in table 6, following assumptions are made:

- Average diesel price is be INR 60/lit.
- Variable cost is based on 8000 kms of monthly running
- No. of years of operation= 10 years.
- Assuming non-battery body (complete truck less batteries) costs = $100,000 in USA. And costs in India 1.8X US cost (1 United States Dollar = 65 Indian Rupees)
- The battery costs ~200$/kWh as predicted in the Bloomberg New Energy Finance study. Most companies currently offer 8-year/100,000-mile battery warranties. Manufacturers have also expanded their protection in countries that have implemented the warranty insurance conditions for California emissions, which allow battery protection on temporary zero-emission cars for at least 10 years (including EVs) [31]
- After five years and an intense 100,000 miles of driving, the Tesla Roadster pack will have an energy storage ability of around 70 percent when introduced [32]
- Average maintenance & repair cost of electric truck is 40% of conventional truck [30]

Figure 23 shows the TCO comparison of conventional diesel truck and an electric truck (Tesla semi) over the period of 10 years.

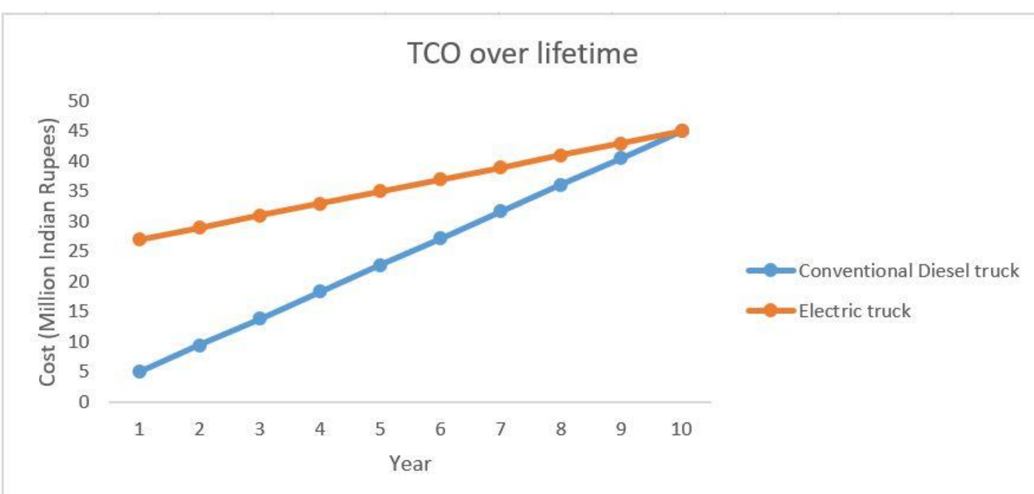


Figure 23 TCO over lifetime

Scenarios that could alter TCO comparison:

- Low fixed cost of electric truck: By starting production and sourcing from best cost countries like India, China. etc. This could swing TCO.
- Diesel price fluctuations (~60% of TCO is regarding fuel expenses for conventional truck)
- Government Initiatives: Incentives towards “electrification of automobiles” and usage of electric vehicles. (Indian government policy for electrification by 2030) can disrupt industry [30].

Frost & Sullivan’s recent research on transformations in the trucking industry has indicated four fundamental shifts, namely electrification, connectivity, autonomy and new business models, expected to drive changes in the near- and long-term [33].

Tesla Semi hits each one of the above-mentioned aspects with a full-electric drivetrain, advanced HMI technology and seamless integration with fleet systems, platooning-ready (~L3 autonomy) vehicle and potential new business models to create a viable economic case for the truck [30].

Figure 24 displays the projection of the renewable electricity generation worldwide by biomass till 2040.

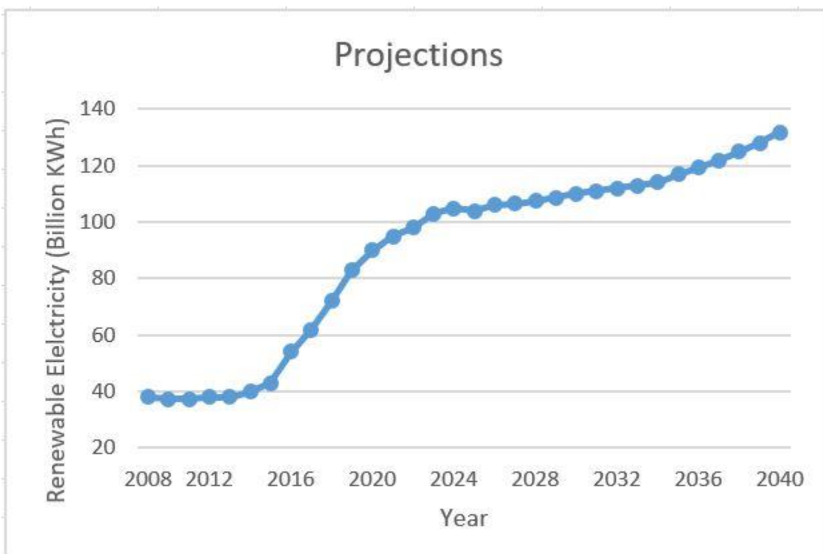


Figure 24 Renewable electricity projections

The Annual Energy Outlook (EIA, 2013a, EIA, 2013b, EIA, 2013c) projects that, electricity production worldwide from using biomass will increase from 37.26 billion kW h in 2011 to 131.89 billion kW h in 2040 [34].

Today, the average mileage that trucks can manage on Indian roads is about **4 kms a litre (9.41 mpg),** increasing their average trip expenses to over Rs 1 per tonne-km [35]. A normal 16-tonne truck can clock no more 250-400 kms a day in India, compared to trucks that can count 700-800 kms in developed countries.

2.5.3 Conventional Trucks Used

Table 6 shows the specifications and variety of conventional trucks that have been used for the study. TATA motors are one of India's major truck manufacturers and the trucks selected for this study are shown in table 6. Six different samples of TATA trucks are selected with a major characteristic difference in power, maximum speed, fuel tank capacity, fuel economy/mileage and other additional features.

Table 6 Conventional trucks used

Trucks → Specifications ↓						
Manufacturer	TATA	TATA	TATA	TATA	TATA	TATA
Name	LPT 3718	LPS 4923	LPK 3118 9S	SIGNA 4923S	LPT 709EX	LPT 407EX
Engine	5,883CC	5,883CC	5,883CC	5,883CC	3,783CC	2,956CC
Gradeability	20%	23%	33%	18.3%	25%	27%
Power	175 bhp	288 bhp	177.68 bhp	230 bhp	121.5 bhp	82.6 bhp
Max Speed	78 kmph	82.6 kmph	70 kmph	82.6 kmph	110 kmph	80 kmph
Fuel Tank (L)	400	600	300	400	160	60
Mileage	3 Km/L	3 Km/L	3 Km/L	3.2 Km/L	7.0 Km/L	8.5 Km/L
Payload	27.4 Tonnes	40 Tonnes	18.5 Tonnes	40.7 Tonnes	3.8 Tonnes	3.1 Tonnes
Gross Vehicle Weight	37 Tonnes	49 Tonnes	31 Tonnes	49 Tonnes	7.49 Tonnes	6.26 Tonnes
Axle	6x4	6x4	8x4	-	4x2	-
Wheelbase	6,750	3,880	5,580	3,880	3,400	3,400
Brakes	Air Brakes	Air Brakes	Air Brakes	Air Brakes	Air Brakes	Hydraulic
Anti-Brake System(ABS)	Yes	Yes	No	Yes	No	No
Price (1USD=65INR)	US$ 48,461.53	US$ 39,846.15	US$ 46,307.69	US$ 48,461.53	US$ 15,384.6	US$ 14,923
Price (INR)	3.15 million	2.59 million	3.01 million	3.15 million	1 million	0.97million

The major purpose of selecting these specified characteristic features is to analyze the amount of fuel that is used in the transportation of the raw biomass. This major paper aims to analyze the energy supply chain. The selection of the trucks is implemented for the transportation of the raw biomass in the paths/ process explained in section 3.2. Different fuel capacity and fuel economy/mileage relates to the amount of fuel used during the transportation and signifies the CO_2 emission.

CHAPTER 3

METHODOLOGY

In the methodology, the outline of the plant is explained. Location of the powerplant and origin of biomass is described. Plant does not exist as modelled but there is a baseline plant on which the project is modelled. The reason for the proposed model is because currently there is no EV trucks operating in India and the proposed system would help in adaption of EV trucks for the supply chain in India.

Direct emissions are radiated through the tailpipe, through evaporation from the fuel system, and during the fuelling procedure. Direct emissions include smog forming contaminations, (for example, nitrogen oxides) and greenhouse gases (GHGs), primarily carbon dioxide. Every electric vehicle produces zero direct discharges, which explicitly improves air quality in urban areas. Electric vehicles can be energized by electricity from renewable resources while gasoline/diesel must be delivered through intensive extraction and transportation forms. Electric vehicles are likewise worked to be more ecologically agreeable than conventional vehicles, as the large battery inside the EV can be recycled and reused. By picking an EV, there is a decrease of carbon footprint and pollution effect to help preserve the natural habitat. All-electric have lower maintenance and support costs when contrasted with internal combustion vehicles, since electronic system stall considerably less regularly than the mechanical systems in conventional vehicles, and the less mechanical systems on board last longer because of the better utilization of the electric motor. EVs don't require oil changes and other routine upkeep checks.

Internal combustion motors are generally inefficient at changing over ready fuel energy to propulsion as the greater part of the energy is lost as heat, and the rest while the motor is inactive. Electric engines are effective at converting stored energy into driving a vehicle. Electric drive vehicles do not consume energy while very still or drifting.

The representation of the system is categorized into two different models/paths called baseline method and method with feedback. The purpose of this system is to explain the adaption of EV trucks in India and improvement in supply chain. The modelling of the powerplant is designed to justify as the supporting background for the supply chain of EV trucks. The working of the plant is out of the project scope of research work presented in this paper. This paper focuses only on the supply chain of both the paths, baseline method and method with feedback. A cost analysis is evaluated, and carbon reduction is calculated for both the paths. Both the scenarios use a mixture of 85% coal and 15% biomass. The evaluation of the system is done by the use of EV trucks in the system for emissions reduction. There is no emissions difference between the two scenarios with regards to the powerplant.

The measure of carbon that is discharged into the environment is a major supporter of environmental change. Biomass lessens this in light of the fact that the fuel is a characteristic piece of the carbon cycle, in contrast to oil and other fossil fuels. Carbon that is discharged into the atmosphere from biomass fills is what was consumed by the plants during their lifecycles as explained in section 2.4. As explained in table 4 of carbon neutrality, as these plants are renewed, the new ones at that point absorb similar measure of carbon once more, making a neutrality that sees no new carbon made.

Baseline method is adapted from the real working co-firing biomass and coal project in Punjab. The raw biomass originates from either of the 3 unique locations mentioned in section 3.1 and after that the procedure of co-firing biomass with coal in the plant arrangement in Bahadurgarh, Haryana. The procedure produces electricity which is utilized for commercial and residential purposes. The biomass (rice husk for our situation) as well as coal comes in and is stored in the storehouse where the amount is observed. This is then co-fired where with the utilization of coal, emissions are checked.

In the method with feedback, electricity generated is supplied to the EV trucks for the supply chain of biomass from the origin to the plant location in Bahadurgarh. In this path, electricity is produced from the co-firing of the biomass and biocoal is either utilized for commercial/residential purposes or is provided to the electric vehicles (trucks-Semi Tesla) which are utilized for the logistics and supply chain of the biomass diminishing the utilization of conventional diesel trucks and decreasing the carbon discharges/emissions. These Tesla trucks will go to the origin (Location L3-mentioned in section 4.5.1) of the raw biomass plant and transport it to the plant in Bahadurgarh.

Biomass requirement for the project activity is calculated and percentage of surplus availability is determined which is mentioned in section 3.3. Total biomass required for 10MW powerplant is 271.8 MT per day and the surplus availability of biomass in the region is 89.33%. Major system requirements for a 10MW powerplant are a 50 tons per hour rated boiler and a 10MW extraction cum condensing steam turbine. Description of a monitoring plan is explained which provides a real time tracking of the process. A steam flow meter, pressure and temperature transmitter will monitor steam amount, pressure and temperature respectively. An energy monitoring system will monitor the quality of power and will analyse the performance of the generation and transmission system.

A 3D model of the powerplant is designed in SolidWorks 2016 to exhibit the design of the plant. This model acts as a supporting justification for the supply chain of the plant. It consists of 10 major components mentioned in section 3.4.4. Assumptions made for the project are explained in section 3.5. Number of hours of operation of the powerplant in a day is assumed as 24 hours and number of operating days in a year is 330. The maintenance of the plant is scheduled for 35 days to improve the quality of equipment. According to Tax club of India, the rate of depreciation of building, plant, machinery and the spare parts are mentioned.

Testing of the model is conducted by analysis of the cost and the emissions. The goal of the research work is to reduce the overall emissions while maintaining an economic value. The electricity produced by the 10MW powerplant in a month is 744MWh (mentioned in section 4.4). A simulation is executed for the sample of 6 different diesel trucks (details of trucks are mentioned in table 6) mentioned in section 4.5. Simulation is executed in Java Script which has an output of 40 different combinations. The combination of trucks with the least fuel consumption as the baseline method of supply chain. A comparison of fuel consumed, CO2 emitted and total cost of operation of these conventional diesel trucks for a period of 10 years is done with the EV trucks (Tesla Semi). Payload of 1 Tesla Semi is 36.28 tonnes and to satisfy the need of 271.8 MT of biomass per day (section 3.3), number of Tesla Semi required is 8.

Electricity consumption of 1 EV truck is 2KWh per mile and total electricity consumption of 8 Tesla Semi is 39.68MWh in a month and is mentioned in section 4.5.2. The total electricity left for residential and commercial purpose is 704.32MWh per month.

An average household in New Delhi uses 260KWh of electricity in a month and 704.32MWh of electricity can be supplied to 2,709 household. Average revenue generated from electricity form a household in New Delhi is USD 20.15 and therefore, from 2,709 households, revenue generated from electricity is USD 0.6 million in 11 months (mentioned in section 4.6).

Total emission from the powerplant is 58,221 tonnes of CO2 in a year. Total emissions from the conventional diesel trucks over the period of 10 years is 3,490.7 tonnes of CO2 and as the EV truck operates on electricity, emissions from the EV trucks is 0. Total emissions reduction over the period of 10 years by operating EV trucks is 3,490.7 tonnes of CO2 mentioned in table 22. In section 4.8, a comparison of cost of plant with baseline method of transportation with conventional trucks and with EV trucks is indicated.

3.1 Location of the Plant

Industrial Model Township (IMT), Bahadurgarh (Figure 25) or Bahadurgarh Industrial Area in NCR is a substantial industrial territory of Haryana on the western outskirt of Delhi and it lies east of Rohtak along Delhi Western Peripheral Expressway. IMT Bahadurgarh are associated with Delhi Metro on 24 Jun 2018 and situated on the arranged Delhi-Bahadurgarh-Rohtak Regional Rapid Transport System (RRTS), RRTS is a piece of Amritsar Delhi Kolkata Industrial Corridor (ADKIC) on Eastern Dedicated Freight Corridor (EDFC) [36].

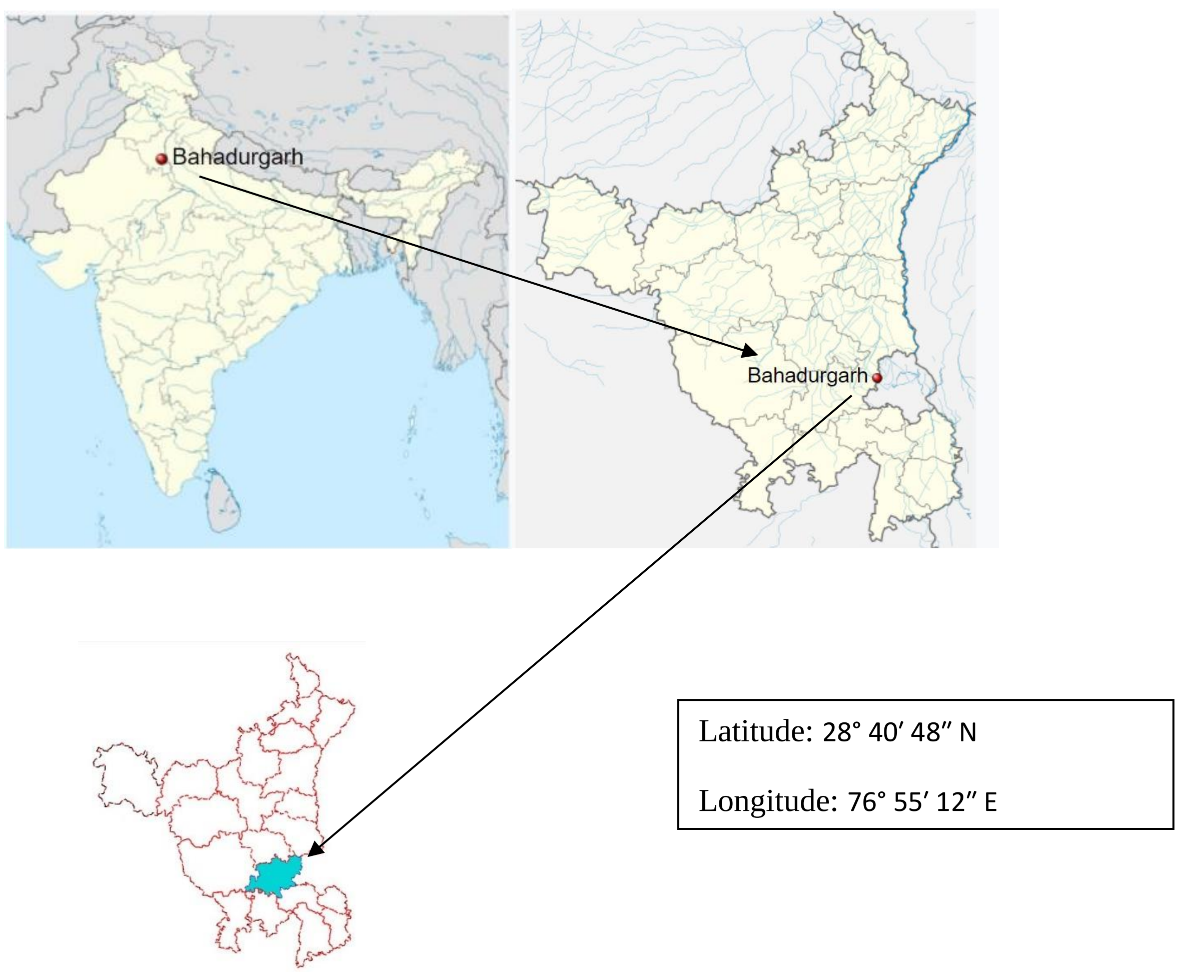


Figure 25 Bahadurgarh(location of plant)

There are three raw biomass origin locations from which the logistics and transportation of the trucks will be handled. These locations are rich in agro residues and all three locations are in different Indian states which are near to New Delhi. The agro residue generations of these states are mentioned in the literature review in the crop wise residue generated in various states of India (Table 3).

These locations are labeled as L1 which is Patiala, in the state of Punjab, L2 is Karnal in the state of Haryana and L3 is Meerut in the state of Uttar Pradesh.

L1: Patiala [37]

Patiala is the 6th most populated district in the state of Punjab (refer Figure 26). More than half of the population in Patiala lives in rural districts and hence they contribute a very large surplus of biomass.

Figure 26 Location 1 (L1): Patiala, Punjab

Patiala is approximately 275 kms from the selected plant location in Bahadurgarh, Haryana.

The total residue consumption from the farming part in the state is 2389.1 Kiloton/year, which is about 50.65% of the total generation. Of this, residential fuel and fodder together expend over 90%, while rest is utilized in thatching and manure structure [37].

Table 7 below shows the list of villages in the district of Patiala and the net surplus biomass (kiloton/year) produced in 2015.

Table 7 Net surplus biomass produced in Patiala(Kiloton/year) in 2015[37]

Villages	Area (Hectares)	Total Biomass (kilotons/year)	Total consumption (kilotons/year)	Basic Surplus Biomass (kilotons/year)	Net Surplus Biomass (kilotons/year)
Bhunerheri	37,025	560.90	284.11	288.10	278.25
Ghanour	33,135	454.33	230.13	233.34	225.38
Nabha	61,829	957.51	485.00	491.77	475.00
Patiala	36,281	555.08	281.16	285.09	275.36
Patran	39,550	597.62	302.71	306.94	296.47
Rajpura	28,065	417.90	211.67	214.63	207.31
Samana	39,802	661.21	334.92	339.59	328.02
Sanour	34,122	512.13	259.40	263.03	254.06
Total	**309,809**	**4,716.68**	**2,389.1**	**2,422.49**	**2,339.85**

- Basic Surplus Biomass [kilotons/year] = Basic Biomass Generation - (Fodder + Thatching and Other non-fuel domestic usages).
- Net Surplus Biomass [kilotons/year] =Basic Surplus Biomass (Domestic fuel use*K + Manure)

According to the present innovations, the judgmental factor K is approximately 25%, which demonstrates the potential for having the biomass utilization for residential fuel by effectiveness improvement [37].

The categorization and production of main agro residue in Patiala for the year 2015 is mentioned the table 8 shown below:

Table 8 Categorization and production of main agro residue in Patiala in 2015 [37]

Sr.	Type of agro residue crop	Residue to Product Ratio(R.P.R)	Crop Yield(Quintal)	Agri-residue prod.(Quintal/acre)
1	Paddy Straw	1.7	28	47.6
2	Paddy Husk	0.2	40	8
3	Wheat Straw	1.15	22	25.3
4	Sugarcane (Tops and Leaves	0.3	400	120
5	Maize (Stalk and Cobs)	2.5	32	80
6	Cotton (Stalks)	3.5	3	10.5
7	Rapeseed and Mustard (Straw)	2.1	4.72	9.912
8	Bajra (Stalk And Cob)	1.85	3.622	6.7
9	Gram (Stalk)	1.08	5.72	6.176
10	Barley (Stalk)	1.2	14.74	17.69
11	Jowar (Stalk)	1.65	3.52	5.809
12	Sunflower (Stalk)	2.4	7.6	18.24

L2: Karnal [38]

Karnal (refer to Figure 27) is one of the 22 districts of National Capital Region (NCR) has an abundant source of agro residue. It is approximately 140 kms from the selected plant location in Bahadurgarh, Haryana.

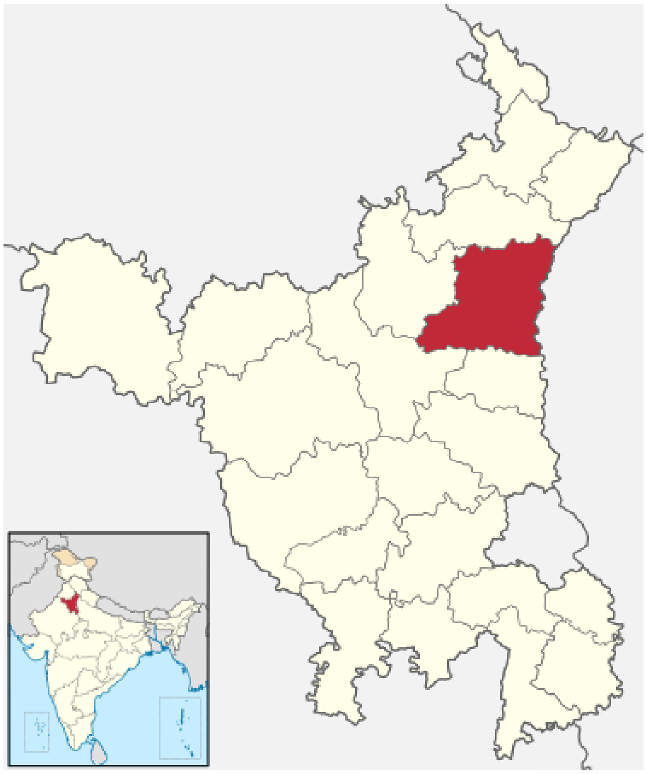


Figure 27 Location 2 (L2): Karnal, Haryana

Below, In the table 9, Karnal (Location L2) has highest amount of paddy straw in the whole of the state (599.40 kilotons a year) is highlighted. It also generates one of the highest wheat stalk and wheat pod in the state. Table 9 shows the crop residue in the state of Haryana.

Table 9 Crop residue in Haryana

District	Crop Residues (in kilotons per year)												
	Paddy Straw	**Paddy Husk**	**Maize Stalk**	**Maize Cob**	**Wheat Stalk**	**Wheat Pod**	**Sugar cane Top**	**Sugar cane Trash**	**Bajra Stalk**	**Bajra Cob**	**Cotton Stalk**	**Gram Stalk**	**Mustard Stalk**
Ambala	325.50	43.40	18.30	3.50	294.00	140.30	14.60	14.60	0.00	0.00	0.00	0.00	0.00
Bhiwani	30.00	4.00	0.00	0.00	568.80	232.30	0.00	0.00	312.00	25.00	166.30	54.60	158.40
Faridabad	116.00	16.00	0.00	0.00	646.80	242.60	4.70	4.70	34.60	3.00	0.00	0.00	0.00
Fatehabad	318.40	39.80	0.00	0.00	797.00	386.10	0.00	0.00	26.60	2.20	377.00	0.00	23.40
Gurgaon	28.70	4.00	0.00	0.00	596.40	216.50	0.00	0.00	148.60	12.50	0.00	0.00	74.40
Hisar	88.20	12.60	0.00	0.00	1,020.10	416.90	0.00	0.00	139.90	11.80	496.70	0.00	87.40
Jhajjar	38.10	5.00	0.00	0.00	482.40	188.90	0.00	0.00	64.70	5.00	0.00	0.00	49.80
Jind	288.60	44.40	0.00	0.00	1,113.60	401.00	0.00	0.00	134.20	10.20	136.20	0.00	0.00
Kaithal	488.80	78.20	0.00	0.00	791.20	337.10	0.00	0.00	9.00	0.80	0.00	0.00	0.00
Karnal	599.40	88.80	0.00	0.00	884.20	346.10	6.20	6.20	0.00	0.00	0.00	0.00	0.00
Kurukshetra	520.20	71.40	0.00	0.00	607.20	227.70	9.40	9.40	0.00	0.00	0.00	0.00	0.00
Mahendergarh	0.00	0.00	0.00	0.00	241.70	76.40	0.00	0.00	228.10	17.60	0.00	10.90	118.40
Panchkula	24.30	3.60	28.80	5.60	55.40	19.80	0.50	0.50	0.00	0.00	0.00	1.20	1.40
Panipat	259.90	37.40	0.00	0.00	410.60	191.60	2.90	2.90	0.00	0.00	0.00	0.00	0.00
Rewari	0.00	0.00	0.00	0.00	262.20	102.60	0.00	0.00	118.00	9.40	0.00	0.00	131.00
Rohtak	50.40	7.20	0.00	0.00	383.70	172.50	6.80	6.80	56.70	4.30	44.80	0.00	18.90
Sirsa	155.40	22.20	0.00	0.00	1,053.80	456.70	0.00	0.00	0.00	0.00	699.70	0.00	68.90
Sonepat	190.40	27.60	0.00	0.00	613.80	251.10	3.80	3.80	21.60	1.90	0.00	0.00	5.40
Yamunanagar	223.60	32.80	0.00	0.00	276.00	103.50	27.00	27.0	0.00	0.00	0.00	0.00	0.00
Total	**3,745.90**	**538.40**	**47.10**	**9.10**	**11,098.90**	**4,509.70**	**75.90**	**75.90**	**1,294.00**	**103.70**	**1,920.70**	**66.70**	**737.40**
Percentage of Total	**(15.17)**	**(2.18)**	**(0.19)**	**(0.04)**	**(44.94)**	**(18.26)**	**(0.31)**	**(0.31)**	**(5.24)**	**(0.42)**	**(7.78)**	**(0.27)**	**(2.99)**

L3: Meerut [39]

Meerut (refer Figure 28) is situated in western Uttar Pradesh. Being closer to the capital city and having a rich agricultural area it serves as good source of origin for agro residue for our biomass plant.

Figure 28 Meerut in Uttar Pradesh

In table 10, crop production in Meerut is 7912.6 kiloton/year and has a biomass generation of 1014.1 kiloton/year from the agro residues. From forest and wasteland, biomass generation is 4.1 kiloton/year.

Table 10 Biomass Potential in Meerut

BIOMASS POTENTIAL FROM AGRO-RESIDUES					
District	**Area (kilo hectare)**	**Crop Production (kiloton/year)**	**Biomass Generation (kiloton/year)**	**Biomass Surplus (kiloton/year)***	**Power Potential (MWe)***
Meerut	223.0	7,912.6	1,014.1	193.7	26.1

BIOMASS POTENTIAL FROM FOREST AND WASTELAND				
District	**Area (kilo hectare)**	**Biomass Generation (kiloton/year)**	**Biomass Surplus (kiloton/year)***	**Power Potential (MWe)***
Meerut	3.0	4.1	2.8	0.4

Meerut is approximately 130 kms from the selected plant location in Bahadurgarh, Haryana.

3.2 Paths/Processes

There are two major processes in the co-firing system.

- First is the baseline method which is the conventional running of the plant with co-firing biomass with coal.
- Second system is co-firing of biocoal and biomass to generate electricity. This electricity would be partially supplied to the electric vehicle trucks for their charging and the rest of the electricity would be used for the commercial purpose or for the residential use. The EV trucks that are being charged will transport and handle the logistics of the raw biomass from the origin location to the destination, i.e., the plant.

3.2.1 Baseline Method

The baseline method shown in Figure 29 is a conventional process of biomass plant which is being run. The raw biomass is being transported from the origin location to the destination plant to generate electricity which will be used for commercial processes and residential use.

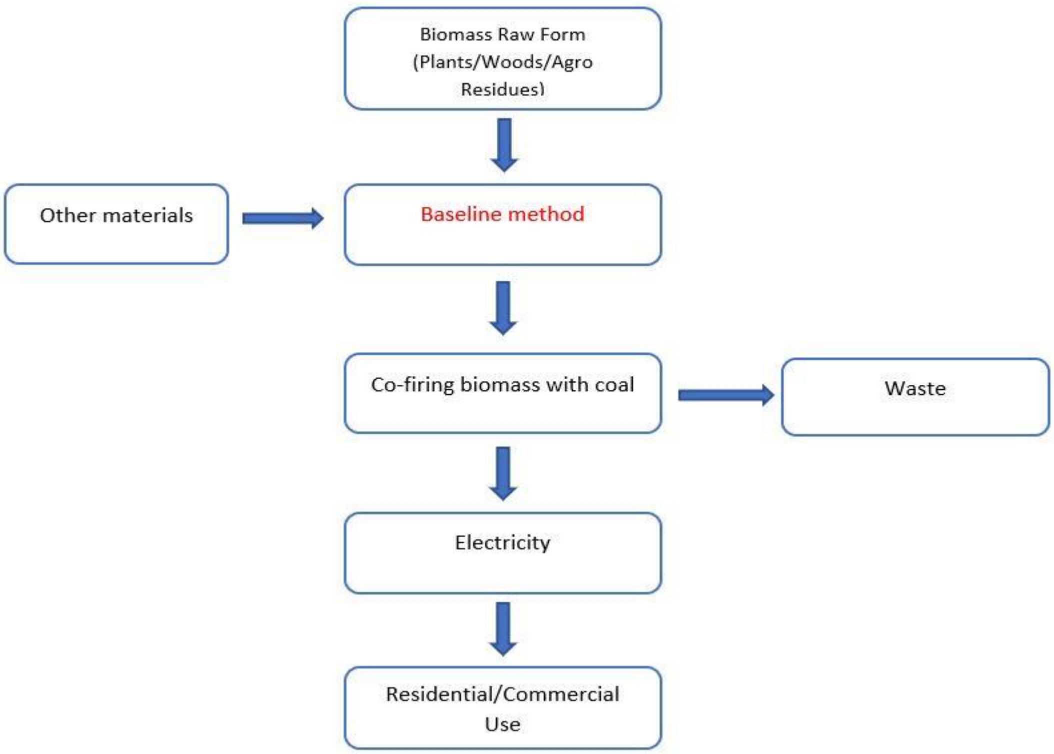


Figure 29 Baseline method of co-firing

The raw biomass comes from either of the 3 different locations and then the process of co-firing biomass with coal takes place in the plant setup in Bahadurgarh, Haryana. The process generates electricity which is used for commercial or residential purposes. The biomass (rice husk in our case) and/or coal comes in and is stored in the silo where the quantity is monitored. This is then co-fired where with the use of coal, emission reduction is monitored.

The project boundary is shown in figure 30. All the special extents of the project boundary encompass:

- All the energy generated is at the plant location whether fired with biomass, coal or a combination of both.
- All the power plant is connected physically to the electricity system (grid) that the complete project is connected to.

Within the project boundary, storage of coal and the biomass is stockpiled and the generation of electricity by co firing is conducted. The quantity of biomass (rice husk) in the case and coal is monitored. The ratio of co-firing is based on the combustion of 85% coal with 15% biomass. Electricity and transmission of the electricity to the local substation is setup and monitored.

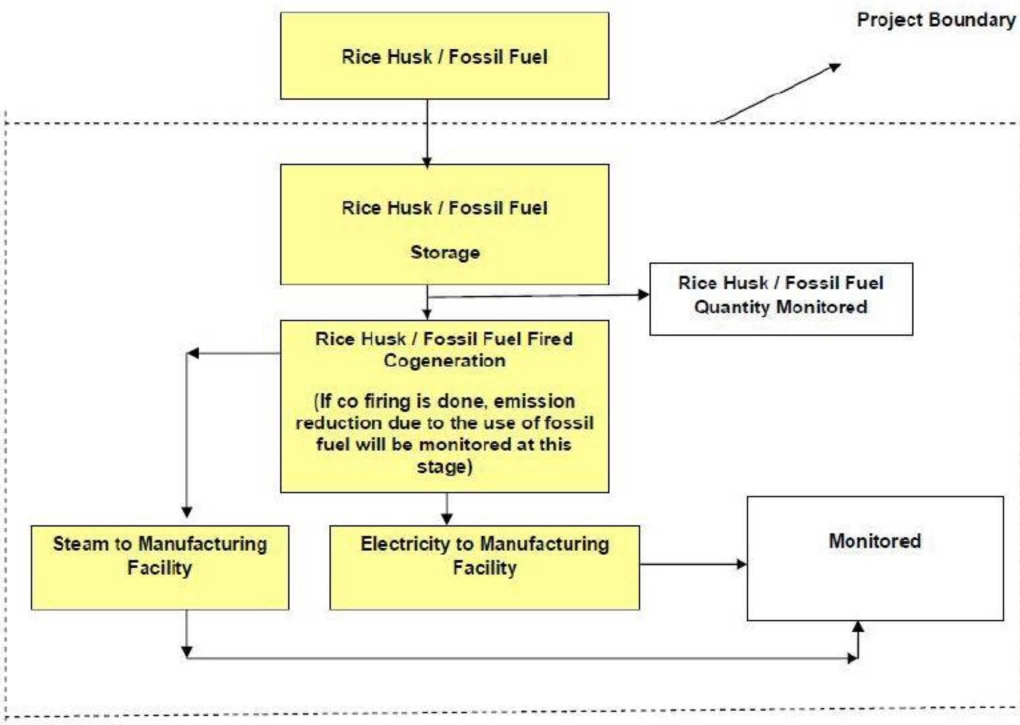


Figure 30 Project boundary

The baseline boundary with respect to methodology is shown figure 31. The cost and analysis of the plant is shown is section 4.2 and section 4.3. The analysis of emission generated by the vehicles is calculated outside the project boundary. The cost analysis of supply chain of vehicles is explained outside the methodology. The storage, and the process is contained within the project boundary.

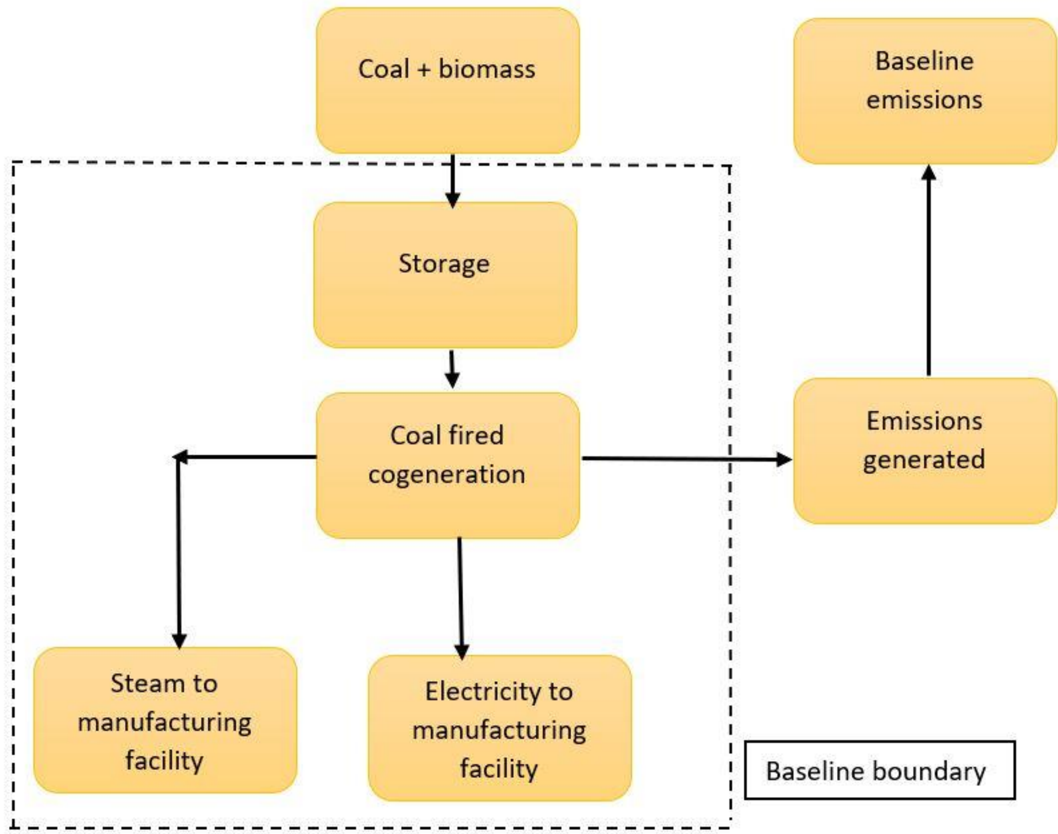


Figure 31 Baseline boundary

3.2.2 With Feedback

The second suggested path is the feedback path as shown in Figure 32. In this path, electricity which is produced from the co-firing of the biomass and biocoal is either used for commercial/residential purposes or is supplied to the electric vehicles (trucks-Tesla Semi) which are used for the supply chain of the biomass reducing the use of conventional trucks and reducing the carbon emissions. These Tesla trucks will go to the origin (Location L3-refer section 4.5.1) of the raw biomass plant and transport it to the plant in Bahadurgarh.

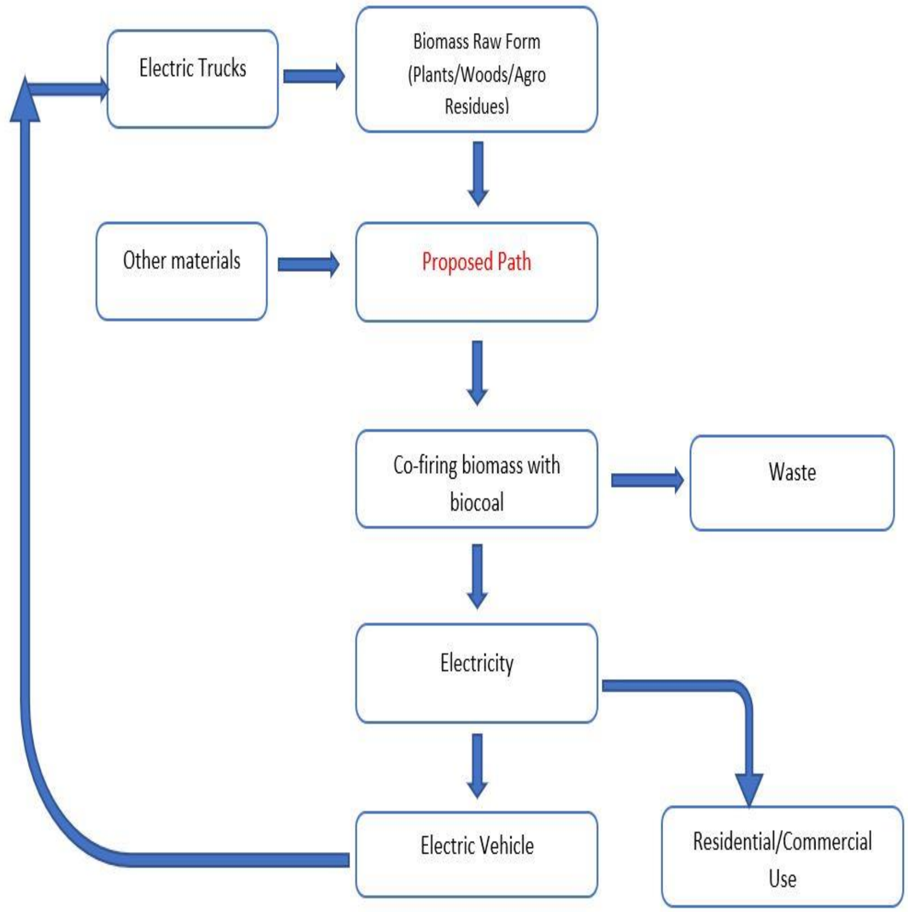


Figure 32 Path with feedback

3.3 Biomass Requirement for the Plant

For the setup of a 10MW biomass-based co-firing power plant, biomass requirement of the plant is studied. Total biomass generated in the region of plant location in Bahadurgarh is 13.69 million metric tonnes (MT) per year. Out of 13.69 million MT of biomass, the total consumption of biomass in the region is 7.18 million MT per year. As the project is a biomass-based co-firing power plant, the biomass required for a 10MW plant is 97,834 MT per year.

The following calculation shows the surplus availability of biomass with respect to the biomass generated in the region and the biomass required for the study.

Total biomass generated in the region = 13,694,237 MT/year

Total biomass consumption in the region = 7,181,423 MT/year

Biomass requirement of the project activity = 97,834 MT/year

= 8,152.83 MT/month

= 271.76 MT/day

As for the analysis of count of trucks mentioned in section 4.6, total biomass requirement for the project activity for 1 day is 271.76 MT.

Total consumption in the region including the project activity requirement is 7,279,257 MT per year. Total consumption includes the summation of the total biomass consumed in the region and the total biomass required for the project activity.

Thereby,

Surplus availability of biomass is the subtraction of the total amount of biomass generated in a year and total biomass consumed in a year and is divided by total biomass consumed. Surplus availability is formulated below:

Surplus Availability (%) = (Generation – Consumption) * 100/Consumption

Thus, Surplus Availability (%) = (13,694,237 – 7,279,257) * 100/7,279,257 = 89.33 % [20]

As per the biomass assessment studies, the amount of biomass available is 89.33 % and is more than 25% of the quantity and is consumed during the process.

The biomass requirement to run a 10MW power plant (capacity of the power plant) is 271.75MT/day.

3.4 System

A 10MW power plant will have one 50 tons per hour (TPH) rated limit boiler producing steam at 88 atmospheric absolute (ata) pressure and 517°C temperature. There will be one extraction condensing turbo-generator (TG) of 10 MW rated limit, with the extraction outlet parameters of 19.7 TPH, 9.4 ata, and 259.5 °C (It ought to be noticed that the extraction temperature of the steam from the turbine is 259.5° C and the temperature of the steam is effectively decreased to 190°C by desuperheating).

The motivation behind the project is to model a system to satisfy the energy need of the plant by successful and clean generation of energy and steam by using the biomass accessible in the area. The project is helping in preservation of natural assets like coal and high-speed diesel (HSD).
The boiler and the steam turbines installed with all necessary supporting parts is required for the efficient running of the plant [20].

3.4.1 Boiler

A 10MW power plant requires a 50TPH rated biomass fired boiler with the outlet steam pressure of 88 ata. The temperature of feed water is 135°C and the air heated outlet gas temperature is 140-150°C. The coal is ground to a fine powder, with the goal that under 2% and 70-75% is underneath 75 microns. It ought to be noticed that too fine a powder is inefficient of grinding mill plant control. Then again, too coarse a powder does not consume totally in the burning chamber and results in higher unburnt losses. Molecule residence time in the boiler is ordinarily 2 to 5 seconds, and the particles must be little enough for complete ignition to have occurred during this time. This system has numerous advantageous points, for example, capacity to fire differing nature of coal, quick reactions to changes in load and utilization of high pre-heat air temperatures.

The steam generating system for the cogeneration plant consists of one biomass fired boiler with the following operational parameters:

Steam Flow: 50 TPH

Steam pressure at superheated outlet: 88 ata

Steam temperature at superheated outlet: 517 +/-5 °C

Feed water temperature: 135°C

Air heater outlet gas temperature: 140-150 °C

The boiler is provided with superheater, desuperheater and economizer. The boiler operates with balanced draft conditions, with the help of forced and induced draft fans.

3.4.2 Steam Turbine

As the capacity of the power plant is 10MW, a 10MW rated turbo generator is required. Extraction-condensing turbines are utilized when steady power generation and steam extraction at a fixed pressure is required. Extraction pressure is controlled inside in the turbine, permitting a wide scope of extraction stream rates. Extraction can also be done inside a wide scope of working load points.

The steam generated in the boiler is fed to the 10 MW extraction cum condensing turbo generator (TG) with the following operational parameters:

Type: Extraction condensing

Rating of Turbine: 10 MW

Generator Rating 10,000 kW

Flow: 19.7 TPH

Pressure 9.4 ata

Temperature: 190 °C (It should be noted that the extraction temperature of the steam from the turbine is 259.5° C and the temperature of the steam will be reduced to 190° C by de-superheating for its usage in the process)

3.4.3 Description of the Monitoring Plan

A monitoring system is required to track the performance of the system and the equipment. It provides a real-time tracking of the process and alerts for the abnormalities that helps to identify and address the problems.

There will be a steam flow meter, pressure transmitter and temperature transmitter to record the steam amount, pressure and temperature of the steam provided to process. The enthalpy of steam provided into process will be determined from these parameters. To the extent steam/heat is concerned, the observing and check system would essentially include steam flow meters. The steam flow meter, pressure transmitter and temperature transmitter would be calibrated every year with the goal that the exactness of estimation can be guaranteed consistently.

An energy monitoring system can also enable to access the quality of the power, recognizing issues, for example, voltage sags , swells and transients. Such issues can decrease control productivity, potentially damage equipment and can cause expensive downtime. There will be two separate energy meters to record the gross power delivered and auxiliary power consumed in the task action. The net electrical energy produced will be determined by deducting the auxiliary power consumed from the gross power created in the power plant. This net power is going to be utilized for the estimation of emission decreases of the project activity. To the extent power is concerned, the checking and confirmation system for the most part of the system includes gross power generation and help control utilization meters. The gross power generation meter and helper control utilization meter will be calibrated yearly with the goal that the precision of estimation can be guaranteed consistently. The amount of biomass (rice husk) being nourished into the heater will be observed utilizing the load cell. Input amount of coal will be observed as and when utilized [20].

3.4.4 Model

In Figure 33 shown below, a process model of the way the system works is presented. Biomass collected from the origin is applied into the gasifier which is supplied with hot air and the biomass gets converted to biogas and is sent to the boiler [37]. As for the baseline method of transportation, the location of raw biomass is from Meerut (Location:L3) (Refer to table 20), the biomass will be collected and transported from Meerut (L3) to the plant location in Bahadurgarh. During this stage the biomass is torrefied by the process of torrefaction. This stage is entered as before long as the temperature surpasses 200 °C and finishes as soon the temperature moves toward becoming below 200 °C once more. The phase of torrefaction contains a warming period and a cooling period, other than a time of consistent temperature. The torrefaction temperature is this constant temperature, which is a peak temperature. Devolatilization (mass loss) begins during the warming time period, keeps during the time of consistent temperature and stops during or after the time of cooling [40]. A part of biomass is also supplied to the torrefaction reactor and after the torrefaction reaction, a by-product of biomass is obtained which is called as bio coal [26]. This bio coal is sent into the boiler where both the biogas and bio coal are co-fired and the produced steam is then sent into the turbine for the rotation of the blades which in turn, generates electricity. The combustion system feeds the biomass feedstock into the furnace or the combustion system where the biomass is burned with excess air to heat water in the boiler to create steam. This steam goes to the 10MW steam turbine (explained in section 3.4.2). This electricity passes through the medium voltage switchgear which provides isolation and protection to the circuits to the transformer and hence to the charging stations via the transformer and the transmission lines [17]. Selection of trucks and locations is done to justify the use of the specific number of trucks which would serve for the cost analysis of the baseline method and is used to calculate the CO_2 emissions and the minimum fuel used.

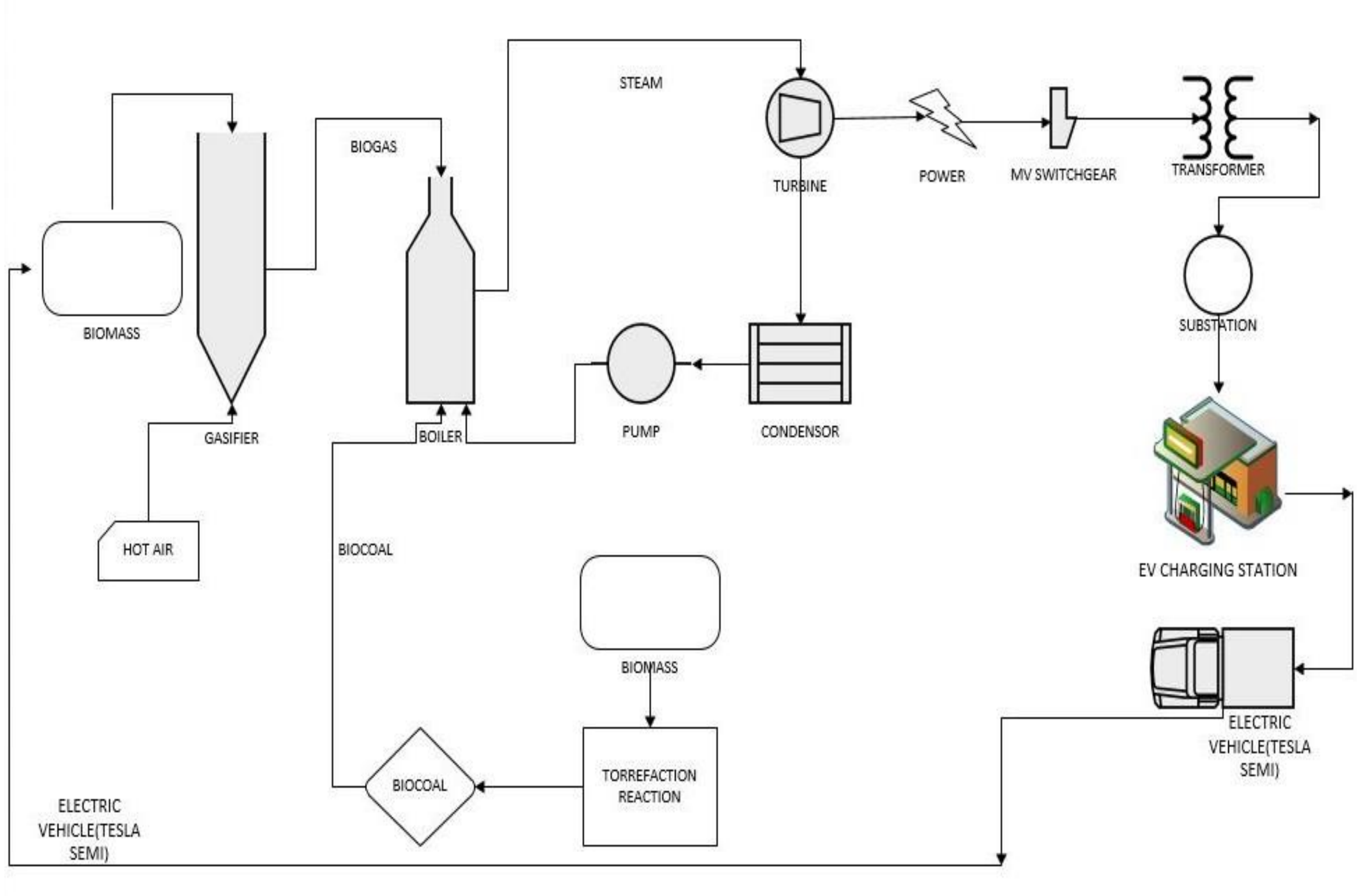


Figure 33 Industrial diagram for the prototype process

The proposed model has 10 major components which are shown in Figure 33. The analysis of the model is executed by the usage of biomass into the energy system. In section 3.2, different paths and processes have been explained. The baseline method of this energy supply chain consists of conventional diesel trucks which transport the biomass from the origin to the plant. A random simulation is conducted in section 4.5.1 which provides the data for the baseline method to analyze. The location of the biomass, fuel used, cost of fuel and the carbon emissions has been calculated and for the comparison, the process shown in figure 33 above, the usage of electric trucks (Tesla Semi) is proposed. The cost analysis and the systems with conventional trucks and EV trucks was calculated and is explained in section 4.8.

3.4.4.1 3D Model

The prototype model was designed in SolidWorks 2016 (refer to Figure 34). This shows an actual basic model of what the plant should look like with the major components. The feed conveyor near the gasifier feeds the biomass to the gasifier. Another feed conveyor feeds the bio coal to the boiler where both the biogas and bio coal are co-fired, and the created steam is then sent into the turbine for the spinning of the blades which produces power.

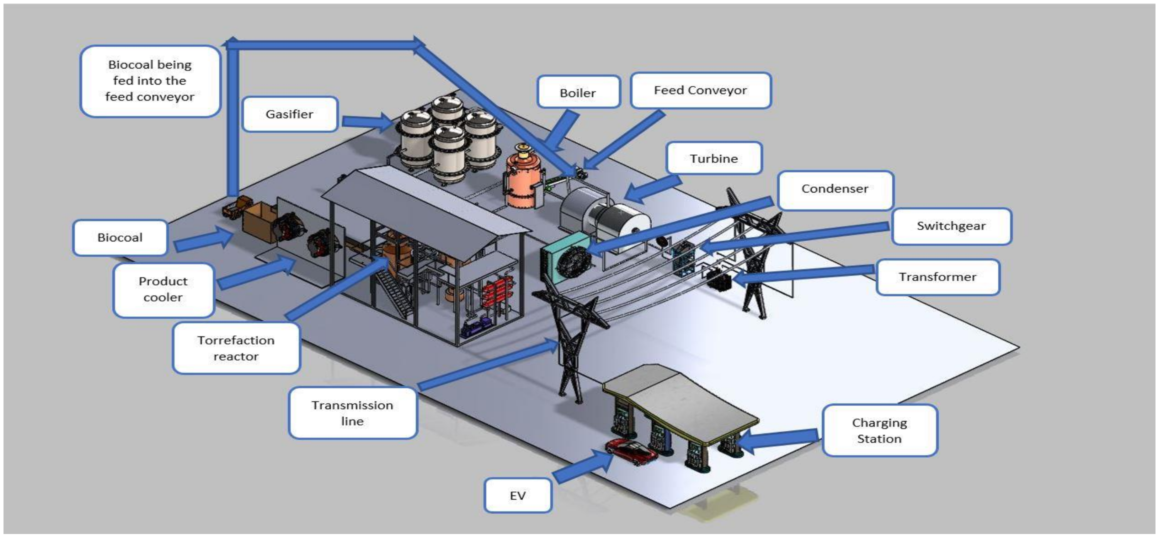


Figure 34 Isometric view of the prototype plant designed in SolidWorks 2016

3.5 Assumptions Made During the Cost Analysis

In Table 11, the assumptions taken during the project are mentioned.

The following assumptions are made in keeping note of the maintenance and the operating hours in a day. The plant will operate for 24 hours a day which generally works for three shifts of 8 hours each. Maintenance of the plant is scheduled for 35 days to make it a smooth running of plant which would help in improving the quality of equipment. All the costing which has been done is for a period of 10 years. This is also used in the simulation of the trucking combination for the plant. The complete cost and emissions are also calculated for a period of 10 years. According to the rules defined by the Tax Club India, the rate of depreciation of building is defined as 7.84%, rate of depreciation of plant and machinery a is 7.84% and rate of depreciation of spare parts is 7.69%. The discount rate of 13% is defined as per the Reserve Bank of India (RBI) for all the energy projects. The conversion rate of 1 United States Dollar is equivalent to 65 Indian Rupees as of 2017 and the cost of fuel (1 litre of diesel) is equivalent to 0.92 United States Dollar as of 2019.

Table 11 Assumptions

Parameter	Value	Unit	Comment
Number of hours of operation in a day	24	Hrs.	Total working hour in a day
Number of days of operation in a year	330	Days	35 days of maintenance/check
Cost calculation period	10	Years	-
Rate of depreciation of building	7.84 %	-	Depreciation rates for the power generating units (http://taxclubindia.com/simple/depreciation%20rates%202009-10.pdf) - Page 12 of 19
Rate of depreciation of plant and machinery	7.84%	-	Depreciation rates for the power generating units (http://taxclubindia.com/simple/depreciation%20rates%202009-10.pdf) - Page 12 of 19
Rate of depreciation of spare parts	7.69%	-	Depreciation rates for the power generating units (http://taxclubindia.com/simple/depreciation%20rates%202009-10.pdf) - Page 13 of 19
Discount Rate	13%		RBI PLR (http://rbidocs.rbi.org.in/rdocs/Wss/PDFs/82830.pdf)
Conversion Rate of USD to INR	1 USD= 65 INR	-	As of 2017
Cost of fuel(diesel)	1 L= INR 60=0.92 USD	-	As of 2019

CHAPTER 4

RESULTS

4.1 Implemented Project Cost (Plant Only)

The implemented project cost of the plant is US$ 6.72 million (refer Table 12) which includes the cost of the acquired land, plant, machinery, electric installations and fitting and all the computer installations. This cost is the fixed cost for the setup of the plant. See Appendix A for cost analysis. It was examined and assessed that the practicality of utilizing biomass to give power in co-firing and gasification plants. Additionally, to assess the effect of logistics on the bio-energy plant's productivity, the impacts of primary calculated factors, for example, explicit vehicle transport costs, vehicle limit, explicit bought biomass expenses and dispersion density have been analysed. To have a practical approach of essential components or hardware, it is important to incorporate the most recent expense of the components. In this way, the information for expenses for every equipment/segment of the plant as far as power output limit was obtained and the expense of every part is fitted utilizing power law as far as introduced limit of the plant.

Boiler is sub critical, radiant reheat, dry base, common flow, single drum, semi-outside type, direct fired, balance draft, top bolstered type having arrangement for terminating coal as the essential fuel. Turbine subsystem is tandem aggravated, flat, warm type, single shaft machine under this examination. The condenser is utilized to gather the exhaust steam from the low-weight turbine and to deliver the deepest conceivable vacuum to maximize the heat drop and the turbine output. The condensate extraction pump is connected to the condenser. The condensate extraction pump is a divergent, vertical pump, comprising of the pump body, the can, the distributor housing and the driver lantern [41].

Table 12 Implemented Project Cost (Plant only)

S. No.	Parameter	Price (US$)
1	Building	899,230.77
2	Plant & Machinery	5,748,899.57
3	Electric Fitting	3,365.85
4	Electric Installation	67,750.63
5	Computer	3,333.32
	Total	**6,722,580.14**

For the project, electricity is imported from a grid as well as created in a biomass co-fired unit. For the initial setup of the plant, the electricity is imported from the grid. Steam/heat is delivered into a biomass co-fired unit and a biomass fired boiler. This situation applies to a project that introduces another biomass cogeneration system that displaces power which generally would have been imported from a grid.

4.2 Cost of the Plant

The levelized cost of electricity is the net present estimation of the unit-cost of electrical energy over the lifetime of a creating resource considering the economic life of the plant and the costs occurred for the maintenance, operation and construction.

A levelized cost analysis (table 13) of the plant was done with variable alternatives and hence it has been summarized below:

Table 13 Cost of plant

Summary - Levelized Cost Analysis	Indian Rupee (INR) Million/TJ	United States Dollar ($)/TJ
Coal Cogen	2.5996	39,993.84
Grid Power + Coal steam	3.7205	57,328.46
Grid Power + Rice husk steam	3.8251	58,847.69
Rice Husk Cogen	2.9285	45,053.85

The levelized cost of the plant with the coal cogeneration/co-fired will be approximately 2.5996 million INR/TJ. When the energy is supplied from the electricity board, the cost of the plant increases to 3.7205 million INR/TJ.

The levelized cost analysis shows that the levelized cost of energy production of a coal-based cogeneration system to generate steam as well as power is US$39,993.84 (INR 2.5996 Million) per TJ.

The levelized cost analysis shows that the levelized cost of energy production of a rice husk-based cogeneration system to generate steam as well as power is USD 45,053.84 (INR 2.9285 million) per TJ. Execution, cost and outflows information for coal and natural gas-fired power plants is based on information a from studies completed for the International energy agency greenhouse gas innovative work program by real designing contractors and procedure licensors [41].

4.2.1 Coal Based Cogeneration System to Meet the Steam and Electricity Requirement of the Facility

In Table 14, the cost of generation from the coal cogeneration system is explained. It is differentiated into variable cost (cost of fuel) and the fixed cost. The power plant requires 50 TPH rated boiler which will generate 50,000 kilogram per hour of steam. The efficiency of the system is considered as 100% as the proposed model will be a newly set system. Total manpower cost is USD 92,307 per year. As the coal is maintained in the silo, the ash handling labour cost is none. The calorific value of coal is 4131 kilocalories per kilogram and the estimated coal consumption in the year is 65,530 MT. Interest rate of increment of manpower cost, operating and maintenance is 5.7% [20].

Table 14 Cost from coal cogeneration system

Cost of generation from Coal Cogeneration System		
VARIABLE COST		
Fuel Cost	**Unit**	**Value**
Steam Generation per hour	Kg/Hr	50,000
Specific enthalpy of steam	Kcal/Kg	819.16
Specific enthalpy of water	Kcal/Kg	135.56
Heat output	Kcal/Hr	34,180,000
Efficiency	%	100.00%
Heat input	Kcal/Hr	34,180,000
Calorific Value	Kcal/Kg	4,131
Fuel consumption	Tonne/hr	8.274
Fuel yearly consumption- Estimated	MT	65,530
FIXED COST		
Manpower cost	**Unit**	**Value**
Salary of manpower	USD/Year	92,307
Ash Handling Labour cost	USD/Year	0.00
Total manpower cost	USD/Year	92,307
Increment in manpower cost	%	5.70%
Operation & Maintenance Expenses	**Unit**	**Value**
Operation & Maintenance Expenses	USD/Year	23,077
Increment in Operating & Maintenance Expenses	%	5.70%
Depreciation	**Unit**	**Value**
Building	USD/Year	30,153
Plant & Machinery	USD/Year	398,000
Miscellaneous Fixed Assets and Preoperative cost	USD/Year	59,230
Total Depreciation	USD/Year	487,384

4.2.2 Rice Husk-based Cogeneration System to Meet the Steam and Electricity Requirement of the Facility

In Table 15, the cost of generation from rice husk cogeneration system is explained. The cost of fuel, human resource, operation, maintenance and depreciation rates are considered. The power plant requires 50 TPH rated boiler which will generate 50,000 kilogram per hour of steam. The efficiency of the system is considered as 100% as the proposed model will be a newly set system. Total manpower cost is USD 96,615 per year. As the labour is required for the ash handling for the rice husk cogeneration system, the cost of labour is USD 4,308 per year. The calorific value of rice husk is 2,767 kilocalories per kilogram and the estimated rice husk consumption in the year is 97,834 MT which is also explained in section 3.3. Interest rate of increment of manpower cost, operating and maintenance is 5.7% [20].

Table 15 Cost of generation from rice husk cogeneration system

Cost of generation from Rice Husk Cogeneration System		
VARIABLE COST		
Fuel Cost	**Unit**	**Value**
Steam Generation per hour	Kg/Hr	50,000
Specific enthalpy of steam	Kcal/Kg	819.16
Specific enthalpy of water	Kcal/Kg	135.56
Heat output	Kcal/Hr	34,180,000
Efficiency	%	100.00%
Heat input	Kcal/Hr	34,180,000
Calorific Value	Kcal/Kg	2,767
Fuel consumption	Tonne/hr	12.353
Fuel yearly consumption- Estimated	MT	97,834
FIXED COST		
Manpower cost	**Unit**	**Value**
Salary of Manpower	USD/Year	92,307
Ash Handling Labour cost	USD/Year	4,308
Total manpower cost	USD/Year	96,615
Increment in manpower cost	%	5.70%
Operation & Maintenance Expenses	**Unit**	**Value**
Operation & Maintenance Expenses	USD/Year	23,077
Increment in Operating & Maintenance Expenses	%	5.70%
Depreciation	**Unit**	**Value**
Building	USD/Year	30,153
Plant & Machinery	USD/Year	398,000
Miscellaneous Fixed Assets and Preoperative cost	USD/Year	59,230
Total Depreciation	USD/Year	487,384

4.2.3 Sensitivity Analysis

As per the Guidelines of the Investment Analysis version 5 [43], in paragraph 20 and 21, any variable which consists of 20% or more of the total project cost or total project revenues, is subjected to the variation. Hence, a range of 10% of the rice husk and the coal as well as their calorific values has been studied for the sensitivity analysis as shown in Table 16. Sensitivity analysis is an approach to anticipate the result of a choice given a specific scope of factors. From table 14, the levelized cost of the plant is estimated and the sensitivity analysis is performed on those data. Column with 0% is the baseline cost obtained from table 13. Sensitivity analysis is done for a range of +10% to -10% of the baseline cost. By making a given arrangement it can be decided how changes in a single variable influence the result.

Table 16 Sensitivity analysis

Parameter	Project Cost (Cogeneration) [in USD]				
	-10%	**-5%**	**0%**	**5%**	**10%**
Coal Cogen	39,694.5165	39,844.4898	39,994.4631	40,144.4365	40,294.4098
Grid Power + Coal steam	57,237.9595	57,237.9595	57,237.9595	57,237.9595	57,237.9595
Grid Power + Rice husk steam	58,846.9940	58,846.9940	58,846.9940	58,846.9940	58,846.9940
Rice Husk Cogen	44,754.4143	44,904.3876	45,054.3609	45,204.3342	45,354.3075

Thus, from the summary of the sensitivity analysis and the results of the levelized cost analysis, it can be noted that, in spite of having a variation of 10%, the coal generation will be 3% cheaper than the rice husk in terms of operation, but the carbon reduction is more in the rice husk cogeneration system than coal fired cogeneration system.

4.3 Emissions by the Plant

Since the project activity is a biomass (renewable) based system, it would have no project emission as carbon neutral biomass will be used. Though, in case of coal being used, CO_2 will be generated and will be calculated as per requirements as shown in Table 17.

As per the Clean development mechanism executive board, undertaking outflows could conceivably emerge from the following activities:

- CO_2 discharges from on location utilization of coal because of the project will be determined by utilizing the most recent adaptation of .Tool to calculate project or CO_2 leakage from coal combustion.
- CO_2 emissions from electricity utilization by the project using the most recent form of "tool to calculate baseline, venture and project and/or leakage emissions from electricity consumption".
- Any other huge emissions related with project within the project boundary [20].

Table 17 Emissions by plant

Baseline Emission		
Emission due to displacement of electricity		
Power generation from cogeneration plant that would be displacing grid	10	MW
No. of operating hours	24	hrs/day
Operating Days/year	330	days/yr
Power generation from cogeneration plant that would be displacing grid	79,200	MWh/yr
Auxiliary Consumption (10% of Gross Generation- http://www.ireda.gov.in/Trifforder/Proceedings/Summary/Biomass.pdf)	7920	MWh/yr
Net Generation	71,280	MWh/yr
Energy Output	256.61	TJ/yr
Emission due to displacement of thermal energy		
Average steam supplied to process from 10 MW Cogeneration plant	19.7	TPH
Enthalpy of steam @ 9.4 ata; 190 Celsius	2,805.8	kJ/kg
Enthalpy of water @ 135 Celsius	567.48	kJ/kg
Net quantity of thermal energy supplied by the project activity	0.04	TJ/hr
No. of operating hours	24	hrs/day
Operating Days/year	330	days/yr
Energy Output	349.23	TJ/yr
Emission due to displacement of Cogeneration System		
Total Energy Output	605.84	TJ/yr
Emission factor of Sub-bituminous Coal (IPCC)	96.10	Ton CO_2/TJ
Efficiency of Cogen Plant using Coal – Baseline	100.00%	%
Total Baseline Emissions	**58,221**	tCO_2/yr
Project Emissions		
Emission due to project activity	0	tCO_2/yr
Leakage		
Leakage due to transportation of biomass	0	tCO_2/yr
Emission Reduction		
Emission reduction due to project activity	**58,221**	tCO_2/yr
Total Carbon Emissions Reduction for ten years crediting period	**582,210**	tCO_2/yr

4.4 Energy Generated

The combustion system feeds the biomass feedstock into the furnace or the combustion system where the biomass is burned with excess air to heat water in the boiler to create steam. This steam goes to the 10MW steam turbine (explained in section 3.4.2). Power is generated and is passed through the medium switchgear and then the transformer. From the transformer the electricity is passed through the substations and the transmission lines for the usage.

In the generation of electricity, 1 unit (one kilowatt hour) of electricity will generate 3.6MJ energy. The total amount of energy generated by the power plant in one second will be 1 MJ. One MW power plant generates one hundred units of electricity in one hour. Therefore, a 10 MW power plant will generate one thousand units of electricity in one hour. The calculation of power generation is shown below:

1 unit of electricity = 1000W x 3600 sec = 3.6 MJ (1 unit = 1 KWh = 10^{-3}MWh)

The amount of energy generated in 1 second by a power plant = 10 MW x 1 sec = 1 MJ

10 MW power plant can generate 744,000 units per month (1000 units/hr x 24 hours x 31 days)

= ***744 MWh/month***

Total generation of electricity from a 10 MW power plant in a month is 744MWh/month. Since the plant will run for 330 days (11 months) in a year, the total electricity that will be generated from the power plant would be 8,184MWh.

4.5 Data Analysis of Truck Combination

To understand the cost analysis of the supply chain of the trucks used for the transportation of the raw material from different locations, L1: Patiala, L2: Karnal and L3: Meerut (see section 3.1) a sample of 6 different truck models were simulated and analyzed. The simulation was coded in Java script. Three major data set were truck models, payload and the price as mentioned in table 20. The total biomass requirement for the project activity in 1 day is 271.8 MT (refer section 3.3). To satisfy the weight requirement of 271.8MT, payload of each truck is mentioned, and price of each truck is provided. A random simulation was executed which resulted in 40 different combinations mentioned in table 21. Each combination resulted in the number of trucks used for the supply chain of biomass from different locations (L1, L2 and L3) and the summation of cost of all the trucks.

4.5.1 Total Number of Trucks Used

A sample of 6 different models of trucks as shown in Table 18 were selected whose specifications is mentioned in Table 6. The three different locations were selected as per the literature review of the biomass agro residue generation in the states of Punjab, Haryana and Uttar Pradesh.

Table 18 Trucks used

TRUCK	PAYLOAD (kgs)	PRICE (US$)
TATA SIGNA 4923S (T1)	40.7	48,461.53
TATA LPS 4923 (T2)	40	39,846.15
TATA LPK 3118 9S (T3)	18.5	46,307.69
TATA LPT 3718 (T4)	27.4	48,461.53
TATA LPT 709EX (T5)	3.8	15,384.60
TATA LPT 407EX (T6)	3.1	14,923.00

Selection of trucks and locations (L1: Patiala, L2: Karnal and L3: Meerut) is done to justify the use of the specific number of trucks which would serve for the cost analysis of the baseline method and will be used to calculate the CO_2 emission and the minimum fuel used.

Total biomass required for the project activity is 271.8 MT (see Section 3.3). To execute this, possible combinations of trucks that can weigh 271.8 MT of biomass in a day (when fuel used is in ascending order) is shown in table 19:

Table 19 Truck combination

All possible combination of trucks carrying the required weight	Truck Count	Distance Traveled(in Km)	Fuel Used(in Liters)
T1(2) T2(1) T3(2) T4(4) T5(1) T6(0)	10	1300	403
T1(0) T2(2) T3(0) T4(7) T5(0) T6(0)	9	1170	420
T1(4) T2(0) T3(4) T4(1) T5(2) T6(0)	11	1430	448
T1(1) T2(2) T3(5) T4(2) T5(1) T6(0)	11	1430	484
T1(1) T2(2) T3(8) T4(0) T5(0) T6(1)	12	1560	489
T1(0) T2(3) T3(8) T4(0) T5(1) T6(0)	12	1560	495
T1(1) T2(3) T3(0) T4(1) T5(0) T6(27)	32	4160	627
T1(0) T2(1) T3(1) T4(4) T5(2) T6(31)	39	5070	771
T1(2) T2(1) T3(0) T4(1) T5(3) T6(36)	43	5590	774
T1(0) T2(1) T3(4) T4(2) T5(1) T6(32)	40	5200	811
T1(1) T2(0) T3(1) T4(4) T5(1) T6(32)	39	5070	824
T1(2) T2(0) T3(3) T4(1) T5(3) T6(31)	40	5200	845
T1(0) T2(0) T3(7) T4(2) T5(1) T6(27)	37	4810	885
T1(0) T2(0) T3(1) T4(4) T5(6) T6(39)	50	6500	925
T1(0) T2(0) T3(10) T4(0) T5(0) T6(28)	38	4940	928
T1(2) T2(1) T3(5) T4(2) T5(0) T6(1)	11	1430	938
T1(1) T2(0) T3(0) T4(3) T5(9)	50	6500	973

T6(37)			
T1(1) T2(0) T3(3) T4(1) T5(8) T6(38)	51	6630	1016
T1(0) T2(1) T3(3) T4(1) T5(9) T6(37)	51	6630	1023
T1(0) T2(0) T3(2) T4(2) T5(18) T6(36)	58	7540	1058
T1(0) T2(0) T3(5) T4(0) T5(17) T6(37)	59	7670	1098
T1(0) T2(0) T3(3) T4(0) T5(30) T6(33)	66	8580	1284
T1(0) T2(4) T3(0) T4(1) T5(1) T6(26)	32	4160	1339
T1(1) T2(2) T3(3) T4(1) T5(0) T6(22)	29	3770	1348
T1(1) T2(2) T3(0) T4(1) T5(4) T6(35)	43	5590	1650
T1(0) T2(3) T3(0) T4(1) T5(5) T6(34)	43	5590	1663
T1(1) T2(1) T3(3) T4(1) T5(4) T6(30)	40	5200	1672
T1(0) T2(0) T3(4) T4(2) T5(5) T6(40)	51	6630	2041

Table 19 was created by the random number simulation in Java script. The flowchart of the java code in shown in Figure 35. Details of the trucks (payload, distances, fuel used) was fed into the code and the code was executed. The initials such as T1,T2 to T6 are defined for individual truck type which is mentioned in Table 18. From Table 19, it can be noticed that under the first column, i.e., “All possible combination of trucks carrying the required weight” it mentions the all possible truck combination that can carry 271.8MT of biomass. The numbers in the brackets around the truck’s initials (for example T1(),T2()) signifies the number of the specific trucks used for the transportation of the biomass (271.8MT). In second column of Table 19, the total truck count from individual combinations are displayed. The third column displays the distance travelled by the trucks in the individual combinations for acquiring the biomass from different locations mentioned in section 3.1 (L1,L2 and L3). The last column of the Table 19 displays the total fuel used by the Trucks in the individual combination. The fuel capacity of each model of truck is mentioned in Table 6 in section 2.5.3.

In Figure 35, the flow chart of the Java code is shown. First, a random number was mentioned in the Java code which would generate all the possible truck combinations that can carry 271.8MT of biomass from different random locations. Now, for each combination, it will count the number of trucks and will generate a random location for 3,300 (considering that the plant will operate 330 days a year and the total operation is for 10 years) iterations and will find the maximum eventuated locations. This will generate the fuel used, cost of fuel, CO_2 emitted and the cost of CO_2. It will display the total cost of trucks. All the costs are mentioned in United States Dollar. It now randomly generates one combination from all the combinations and finds the maximum time that occurred in 3300 iterations.

For, Tesla Semi trucks, it will generate the random location 3300 times and will find the maximum location eventuated from the combination. Each Tesla Semi truck has a payload of 36.28 tonnes [44] and this will give the total truck count to 8. The EV (Tesla Semi truck count has been further explained in section 4.5.2. After the measure of Semi Tesla trucks required, it will calculate the total cost in United States Dollar.

The code has been shown in appendix B: Java Code

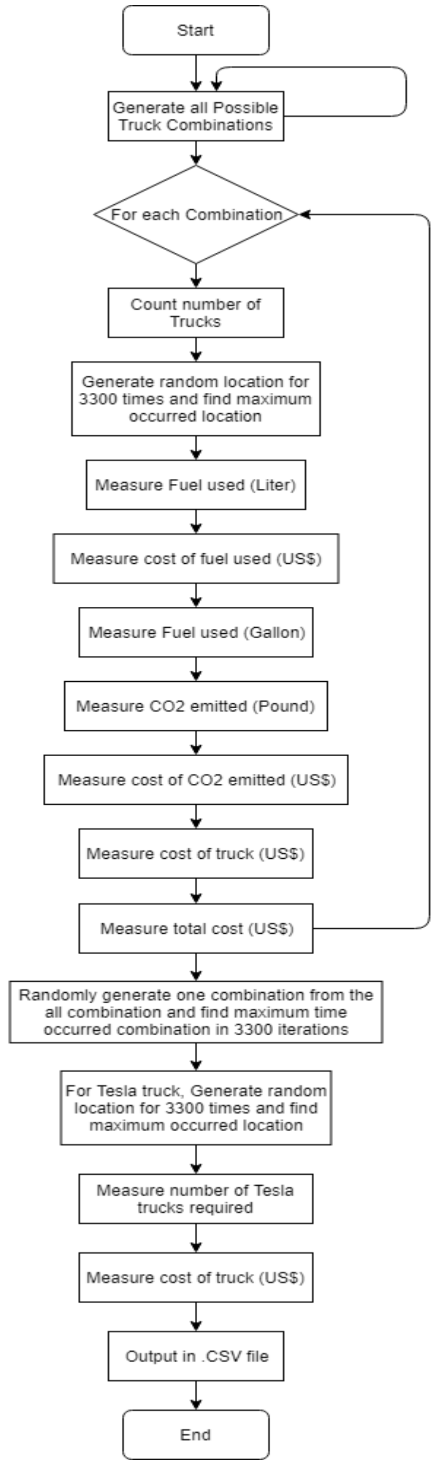


Figure 35 Flow chart of random generation of trucks

Considering the combination which has the minimum fuel used (because the aim is to reduce the CO2 emission), the truck count comes out to be 10 (Table 20). That means, this random combination of truck when it goes to Meerut (L3) generates the least amount of carbon dioxide as the least amount of fuel is used. Truck combination consists of two trucks of model TATA SIGNA 4923S, one truck of model TATA LPS 4923, two trucks of model TATA LPK 3118 9S, four trucks of model TATA LPT 3718 and one truck of model TATA LPT 709EX. The summation of payload of these 10 trucks is 271.8 MT (biomass requirement for the plant in one day). In table 6, individual fuel capacity of trucks is mentioned. Total fuel used in this combination of truck is 106 gallons. The cost of the 1 liter of fuel is taken as USD 0.92 (table 11). Total Carbon dioxide (CO2) emitted from these 10 trucks in one day is 2,332 pounds. The summation of cost of these 10 trucks is USD 0.43 million and the total distance travelled by these 10 trucks in one day is 1300 kilometers. Total cost of operation for the supply chain of transportation of biomass from Meerut (L3) to plant location in Bahadurgarh is USD 7.665 million.

Table 20 Details of combination selected for baseline

Trucks	T1(2) T2(1) T3(2) T4(4) T5(1) T6(0)
Truck Count	10
Location	L3
Fuel Used(in Gallon)	106
Cost of Fuel(in USD)	370.76
Cost of Fuel for 3300 days(in USD)	1,223,508
CO2 emitted(in pounds)	2,332
CO2 emitted in 3300 days(in pounds)	7,695,600
Cost of CO2 emitted(in USD)	1,818.96
Cost of trucks(in USD)	438,615
Total cost(fuel+CO2)(in USD) per day	2,189.72
Total distance travelled(in Kms)	1,300
Total cost(fuel+CO2)(in USD) for 3300 days	7,226,076
Total cost + Fixed price truck	7,664,691

This combination will be used for the logistics and transportation of the biomass from the origin to the plant location for the baseline method.

4.5.2 Count of EV Trucks (Tesla Semi)

In section 2.5.2, the comparison of conventional diesel truck and EV truck (Tesla Semi) is explained. The total biomass requirement for one day for project activity is 271.8MT. Each Tesla truck has a payload of 36.28 tonnes [44]. Working a diesel truck will be in any operation 20% more costly than working a Tesla truck when considering all costs, including lease installments, protection, and support. Tesla trucks have an enhanced autopilot mode which supports semi automatic features like automatic emergency braking system and auto lane keeping ability. The vehicle accompanies the capacity to legitimately coordinate with a trucking organization's fleet management for steering and planning. Greenhouse gases produced by medium-and heavy-duty trucks increased 85% from 1990 to 2016 and Tesla Semi will not add carbon to the environment. Aerodynamic shape of the Tesla Semi will reduce the air resistance by 50% as compared to the conventional diesel trucks [45].

To satisfy the load requirements of 271.8 MT/day, 8 EV Trucks (Tesla Semi) are required.

Price of 8 Tesla Semi = 1.44 million USD.

Electricity consumption of 1 Tesla Semi = 2 KWh/mile [46]

The Tesla Semi truck can run for approximately 500 miles on a single charge [46]. Considering L3 as the location for agro residue origin (Assumed for convenience in calculation because from Table 22, it can be noticed that the trucks in the combination selected for the baseline use the location L3: Meerut). Meerut (L3) in the state of Uttar Pradesh to the plant location in Bahadurgarh in Haryana is approximately 130 kms which is equivalent to 80 miles. Since, a Tesla Semi has an electricity consumption of 2 KWh/mile, to travel a distance of 80 miles, i.e., from Meerut to Bahadurgarh, it requires 160 KWh (0.16MWh) of electricity.

Therefore, electricity required for 1 Tesla Semi

for transportation from L3 to plant in 1 day = 0.16MWh

Therefore, electricity required for 8 Tesla Semi

for transportation from L3 to plant in 1 day = 0.16 MWh x 8

=1.28MWh

From section 4.4, the electricity generated from the plant is 744MWh in one month. Therefore, 8 Tesla semi requires 1.28MWh x 31 = 39.68 MWh of electricity per month required to charge completely for the complete transportation of biomass from the location L3 (Meerut).

From section 3.2.3, the path with feedback, the electricity that is generated from the plant will be used to charge the Semi Tesla (EV) trucks. Eight EV trucks will use 39.68 MWh of electricity per month to completely charge and the electricity left for commercial and residential use comes out to be 704.32 MWh per month. The calculation is shown below.

Therefore, electricity left for commercial and residential use = 744MWh - 39.68 MWh

= 704.32MWh per month

4.6 Revenue from Electricity

Each household in New Delhi consumes approximately 260 units (260 KWh) of electricity in a month [47]. The cost of 1 unit of electricity in New Delhi is INR 4.5 which is equal to USD 0.069 [47]. The residents of New Delhi have a fixed charge of INR 140 which equals to USD 2.154 per month.

Therefore, cost of electricity from 1 household= INR (260*4.5) +140(Fixed)

= INR 1310 = USD 20.15

After charging 8 Semi Tesla completely, the electricity left for usage is ***704.32MWh per month***.

Therefore, 704.32 MWh electricity can be used by approximately 2,709 household for 1 month.

Revenue generated from supplying electricity to 2,709 household in

11 months = 2,709 x 20.15 x 11 = ***USD 600,449.85***

Energy generated in the plant is 744 MWh per month and even after charging the Tesla trucks (8 count) for the location L3 (selected location from the randomization) 704.32 MWh per month of electricity is left for the commercial and residential usage. According to the data, an average household in New Delhi uses about 260 KWh of electricity in a month, and hence 2,709 households can be supplied with the electricity and the revenue generated by supplying 704.32MWh electricity is USD 0.6 million.

4.7 Payback Period

In Table 21, the payback period is calculated considering the rate of return (R) as 13%. It is the earliest time after which the capital invested can be recovered. The payback period comes out to be 10.26 years. Therefore, after the payback period there will be positive cash flow. This calculation only includes the generation of electricity and selling of electricity. Table 21 shows the calculations of cash flow, balance and present value from year 0 to year 15.

Table 21 Payback Period

Year	CF	Balance	CF PV	PV Balance
0	$6,722,580.00	$6,722,580.0000	$6,722,580.0000	$6,722,580.0000
1	$655,036.20	$6,067,543.8000	$579,678.05	$6,142,901.9469
2	$655,036.20	$5,412,507.6000	$512,989.43	$5,629,912.5194
3	$655,036.20	$4,757,471.4000	$453,972.94	$5,175,939.5747
4	$655,036.20	$4,102,435.2000	$401,745.97	$4,774,193.6059
5	$655,036.20	$3,447,399.0000	$355,527.41	$4,418,666.1999
6	$655,036.20	$2,792,362.8000	$314,626.02	$4,104,040.1769
7	$655,036.20	$2,137,326.6000	$278,430.11	$3,825,610.0681
8	$655,036.20	$1,482,290.4000	$246,398.33	$3,579,211.7417
9	$655,036.20	$827,254.2000	$218,051.62	$3,361,160.1254
10	$655,036.20	$172,218.0000	$192,966.03	$3,168,194.0932
11	$655,036.20	-$482,818.2000	$170,766.40	$2,997,427.6931
12	$655,036.20	-$1,137,854.400	$151,120.71	$2,846,306.9851
13	$655,036.20	-$1,792,890.600	$133,735.14	$2,712,571.8452
14	$655,036.20	-$2,447,926.800	$118,349.68	$2,594,222.1639
15	$655,036.20	-$3,102,963.000	$104,734.23	$2,489,487.9326
			R	13%

Payback Period	**10.26**	**years**
Discounted PP	**30.83**	**years**

4.8 Cost Analysis

4.8.1 Cost of Plant with Baseline Method of Transportation with Conventional Trucks (10 years)

The implemented project cost of the plant comes out be USD 6.72 million (Table 12), the cost of fuel used is USD 1.22 million (Table 20) and cost of the conventional diesel trucks is USD 0.43 million (Table 20). As the project is scheduled for 10 years, the total cost of operation is USD 8.384 million. About 7.695 million pounds of CO_2 is emitted (Table 20) which cost about USD 6 million. This has been formulated below:

Complete cost of plant = USD 6.722580 million

Cost of trucks = USD 438,615

Cost of fuel used (10 years) = USD 1.223508 million

Total cost of operation (10 years) = Complete cost of plant + Cost of trucks + Cost of fuel used

= ***USD 8.384733 million***

Cost of CO_2 emitted (10 years) = ***USD 6 million***

4.8.2 Cost of plant with Electric Vehicles (Tesla Semi)

The cost of 8 EV trucks (Tesla Semi) is USD 1.44 million. The cost of the plant is same and as EV runs on electricity, the emissions of CO_2 is 0 and hence the cost of CO_2 is equal to 0. The total cost of operation of the plant with EVs is USD 8.16258 million. This has been formulated below:

Complete cost of plant = USD 6.722580 million

Cost of Tesla Semi = USD 1.44 million

Cost of CO_2 emitted = USD 0

Total cost of operation (10 years) = Complete cost of plant + Cost of Trucks + Cost of fuel used

= ***USD 8.16258 million***

Cost of plant with baseline method of transportation with conventional trucks is more than the cost of plant with electric vehicles (Tesla Semi).

The total cost of operating the plant with the usage of the conventional trucks (baseline) which includes the complete cost of the plant, cost of the trucks and the cost of the fuel used for 10 years comes out to be USD 8.384 million and the cost of the CO_2 emitted for 10 years is USD 6 million, whereas the total cost of operation with the electric trucks (Tesla Semi) for 10 years comes out to be USD 8.16 million. This analysis proves that the cost of the plant with the baseline method of transportation with the conventional trucks is more than that of cost of plant with electric trucks (Tesla Semi).

4.9 Carbon Footprint/CO_2 Emissions

B20 is a commonly sold biodiesel fuel. B20 contains 20% of biodiesel and 80% of petroleum diesel fuel. Burning a gallon of B20 results in the production of 17.9 pounds of CO_2 that is emitted from the fossil fuel content [48]. When one gallon of diesel is burned, 22.4 pounds of CO_2 is produced. The cost of 1 pound of CO_2 is USD 0.78.

4.9.1 CO_2 Emission from Conventional Truck Combination and Semi Tesla

4.9.1.1 Conventional Trucks

From Table 20, it can be observed that the fuel (B20) used by 10 trucks from the selected combination to transport the raw material (biomass) from Meerut (L3) to the plant location in Bahadurgarh is 106 gallons of diesel in 1 day. Cost of 1 litre of diesel is assumed as USD 0.92 from table 11. From table 10, it is observed that biomass generation from agro residue, forest and wasteland from Meerut is 1018.2 kilotons per year. The requirement of biomass for the project activity is 271.8 MT/ day. From Meerut, biomass available for one day of operation is 3085 MT/day. Surplus availability of biomass in Meerut is 2813.2 MT/ day.

Cost of fuel used in 1 day = USD 370.76

CO_2 emitted from 106 gallons of fuel is calculated in table 22.

CO_2 emitted from 106 gallons of fuel used = 2,332 pounds of CO_2

Cost of CO_2 emitted from burning 106 gallons of fuel used = USD 1,818.96

Cost of CO_2 emitted in 3,300 days = **USD 6 million**

4.9.1.2 Tesla Semi

Since the EV trucks (Tesla Semi) operates on electricity, diesel (fuel) used by the EV is equal to 0. As the diesel (fuel) is not required to run the EV, the carbon emission (CO_2) is 0.

Fuel used by 8 Tesla Semi for 1 day = 0 gallons of diesel

CO_2 emitted = 0 pounds

Cost of CO_2 emitted in 3,300 days= **USD 0**

The amount of CO_2 emissions from conventional trucks is more than the amount of CO_2 emissions from the electric truck (Tesla Semi).

By using 10 trucks (baseline), the total amount of fuel used is 106 gallons of diesel in a day. The cost of this fuel in one day is USD 370.76 considering the mileage of each truck mentioned in Table 6. The carbon emission of 10 conventional trucks over the period of 10 years is USD 6 million, whereas for Tesla Semi is 0 USD.

In Table 22, emissions reduction by using EV trucks instead of conventional diesel trucks is calculated. Over the period of 10 years, emissions by the plant are 582,210 tonnes of CO2, emissions from the conventional diesel trucks is 3,490.7 tonnes of CO2. Total emissions from the usage of conventional trucks with the baseline method is 585,700.7 tonnes of CO2. As Tesla Semi (EV) operates on the electricity, emissions from EV is 0. Total emissions reduction over the period of 10 years by using EV instead of conventional diesel truck is 3,490.70 tonnes of CO2.

Table 22 Emissions Reduction

S. No.	**Years**	**Baseline Emissions (Tonnes of CO2) (A)**	**Emissions from conventional trucks (tonnes of CO2) (B)**	**Total Emissions from A and B (C)**	**Emissions from EV trucks (tonnes of CO2) (D)**	**Total Emissions from A and D**	**Total Emissions Reduction (Tonnes of CO2) (C-D)**
1	2018 – 19	58,221	349.07	58,570.07	0	58,221	349.07
2	2019 – 20	58,221	349.07	58,570.07	0	58,221	349.07
3	2021 – 22	58,221	349.07	58,570.07	0	58,221	349.07
4	2022 – 23	58,221	349.07	58,570.07	0	58,221	349.07
5	2023 – 24	58,221	349.07	58,570.07	0	58,221	349.07
6	2024 – 25	58,221	349.07	58,570.07	0	58,221	349.07
7	2025 – 26	58,221	349.07	58,570.07	0	58,221	349.07
8	2027 – 28	58,221	349.07	58,570.07	0	58,221	349.07
9	2028 – 29	58,221	349.07	58,570.07	0	58,221	349.07
10	2029 – 30	58,221	349.07	58,570.07	0	58,221	349.07
	Total	**582,210**	**3,490.7**	**585,700.70**	**0**	**582,210**	**3,490.7**

CHAPTER 5

CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

5.1 Conclusion

The main objective of this analysis is a demonstration of a model of co-firing biocoal with biomass into the energy supply chain for transport vehicles (delivery trucks), an improvement in cost, energy and carbon footprint/emissions which would further reduce the air pollution in the city of New Delhi. A model of an energy process is analyzed and concluded that the usage of electric trucks (Tesla Semi) instead of conventional trucks would reduce the carbon emissions and the energy supply chain related to this process is studied. A sample of 6 trucks and 3 different locations is studied and random combinations is simulated. Selection of trucks and locations is done to justify the use of the specific number of trucks which would serve for the cost analysis of the baseline method and is used to calculate the CO2 emissions and the minimum fuel used. The combination of the location and trucks used with the least fuel consumption is selected and is considered as the baseline for all the cost, energy and carbon emissions. Energy generated in the plant is 744 MWh per month and even after charging the Tesla trucks (8 count) for the location L3 (selected location from the randomization) 704.32 MWh per month of electricity is left for commercial and residential usage in an idealized plant under idealized assumptions. According to the data, an average household in New Delhi uses about 260 KWh of electricity in a month, and hence 2709 households can be supplied with the electricity and the revenue generated by supplying 704.32MWh electricity is USD 0.6 million.

The total cost of operating the plant with the usage of the conventional trucks (baseline) which includes the complete cost of the plant, the cost of the trucks and the cost of the fuel used for 10 years comes out to be USD 8.384 million and the cost of the CO2 emitted for 10 years is USD 6 million, whereas the total cost of operation with the electric trucks (Tesla Semi) for 10 years comes out to be USD 8.16 million. This analysis proves that the cost of the plant with the baseline method of transportation with the conventional trucks is more than the cost of plant with electric trucks (Tesla Semi).

By using 10 trucks (baseline), the carbon emissions over the period of 10 years is equal about USD 6 million. The emissions are 582,210 tonnes of CO2 for both the scenarios assuming 10 years of working. Therefore, the emissions for the powerplant is 582,210 tonnes of CO2, the emissions for conventional diesel trucks is 3,490.7 tonnes of CO2 and the emissions for the EV trucks is 0. Therefore, the reduction in CO2 emissions over the period of 10 years is 3,490.7 tonnes of CO2.

By usage of the proposed model and the analysis of the energy generated, cost analysis or the economics of the system/process, and the carbon emissions, it is suggested to use the Tesla Semi so that the energy supply chain improves which would be beneficial economically and environmentally.

5.2 Limitations of the Research Work

Due to the nature of the research question and the unfeasibility of the practical location, this major paper was a work of theoretical subject. This system is bounded by the powerplant and the vehicles in the supply chain of the powerplant. This model and simulation do not consider alternative use for the electricity used by the electric vehicles or this effects on overall emissions All the data that were used for the study is adapted from a practical working plant in India and the setup of a new plant in a new location was a conceptual approach. The model presented in the research paper acts as per the ideal stages which is generally difficult to achieve. The data used and calculations done for different processes were theoretically solved. The complexity of the topic was evident because of the variety of conditions within in the industry. The process of torrefaction of biomass was a hypothetical approach and usage of this torrified biomass in a co-firing plant was an intellectual viewpoint with comparison to the current application of co-firing coal and biomass. The trucks used were a sample of 6 different trucks of TATA motors. There might be some differences in the properties of similar trucks with different manufacturers. TATA was selected for being the most used transporting truck in India. The idealism of usage of Semi Tesla as the electric trucks is still in progress as the EV trucks manufactured by Tesla is in scheduled for the launch in the year 2020. Furthermore, the road conditions were not considered during the case study.

5.3 Future Research

The limitations of this paper express the topic to be addressed in the future. This model is proposed as a concept. Further work would need to validate this model with additional data or a physical prototype. The approach that is used is an intellectual theorical approach with ideal conditions. The scope of future work is stated below:

- An improved feasible practical survey of the location of the plant can lead to the change.
- After the launch of Tesla Semi trucks, these trucks can be practically run and tested for the study.
- The process of torrefaction of biomass and further co-firing of biomass and biocoal can be tested and practically implemented.
- A different diversification of diesel trucks can be used and studied the process.

REFERENCES

1. Thakur, J. (2017). Rampant construction rise in vehicles push Delhi’s dust pollution back to CWG days. [online] https://www.hindustantimes.com/. Available at: https://www.hindustantimes.com/delhi-news/delhi-s-dust-pollution-back-to-commonwealth-games-days/story-Cl9fV7ZTjXW8K9dwG5vE5N.html [Accessed 26 Mar. 2019].
2. Sequeira, J. (2008). A toxic issue: Air pollution in new delhi. Harvard International Review, 30(3), 10-11. Retrieved from https://search-proquest-com.ledproxy2.uwindsor.ca/docview/230992150?accountid=14789
3. Chatterjee, P. (2016). India takes steps to curb air pollution. [online] https://www.who.int. Available at: https://www.who.int/bulletin/volumes/94/7/16-020716/en/ [Accessed 26 Mar. 2019].
4. Irfan, U. (2018). Why India’s air pollution is so horrendous. [online] https://www.vox.com. Available at: https://www.vox.com/2018/5/8/17316978/india-pollution-levels-air-delhi-health [Accessed 26 Mar. 2019].
5. https://sustainabledevelopment.un.org/sdg11. 2017. SUSTAINABLE DEVELOPMENT GOAL 11. [ONLINE] Available at: https://sustainabledevelopment.un.org. [Accessed 30 July 2018].
6. https://www.thehindubusinessline.com. (2017). Congestion, low traffic speeds worsen pollution in Delhi. [online] Available at: https://www.thehindubusinessline.com/economy/logistics/congestion-low-traffic-speeds-worsen-pollution-in-delhi/article9768721.ece [Accessed 26 Mar. 2019].
7. http://www.pacwa.org/deforestation-effects-on-air-pollution/. 2015. Deforestation – effects on Air Pollution. [ONLINE] Available at: http://www.pacwa.org. [Accessed 30 July 2018].
8. https://www.theguardian.com/world/2017/oct/20/delhi-covered-in-toxic-haze- after-night-of-diwali-fireworks. 2017. Delhi covered in toxic haze after night of Diwali fireworks. [ONLINE] Available at: https://www.theguardian.com. [Accessed 30 July 2018].
9. Bhalla, N., O'Boyle, J. and Haun, D., 2019. Who Is Responsible for Delhi Air Pollution? Indian Newspapers’ Framing of Causes and Solutions. International Journal of Communication, 13, p.24.
10. Choudhary, S. (2018). Crop burning responsible for most of Delhi’s air pollution: study. [online]https://www.livemint.com. Available at: https://www.livemint.com/Politics/5RjnnO0IXUWJ761bU0kTLK/Crop-burning-responsible-for-most-of-Delhi-air-pollution-st.html [Accessed 26 Mar. 2019].

11. Emission of Air Pollutants from Crop Residue Burning in India - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/State-wise-distribution-of-crop-residues-burnt-in-India_fig1_277676603 [accessed 6 Mar, 2019]
12. Evans, A., Strezov, V. and Evans, T.J., 2010. Sustainability considerations for electricity generation from biomass. Renewable and sustainable energy reviews, 14(5), pp.1419-1427.
13. Fao.org. (2019). Producing energy from rice straw: an alternative to burning crop residues in India | Energy | Food and Agriculture Organization of the United Nations. [online] Available at: http://www.fao.org/energy/news/news-details/en/c/1144592/ [Accessed 27 Mar. 2019].
14. Mukerjee, P. (2016). Crop Burning: Punjab and Haryana's killer fields. [online] https://www.downtoearth.org.in. Available at: https://www.downtoearth.org.in/news/air/crop-burning-punjab-haryana-s-killer-fields-55960 [Accessed 27 Mar. 2019].
15. Chakravartty, A. and Nasim, U. (2015). Paddy burning: NGT orders fine imposition on erring farmers. [online] https://www.downtoearth.org.in. Available at: https://www.downtoearth.org.in/news/air/paddy-burning-ngt-orders-fine-imposition-on-erring-farmers-51698 [Accessed 27 Mar. 2019].
16. https://biomasspower.gov.in/About-us-3-Biomass%20Energy%20scenario-4.php. 2016. Overview of biomass power sector in India. [ONLINE] Available at: https://biomasspower.gov.in/. [Accessed 30 July 2018].
17. https://electrical-engineering-portal.com/the-role-of-medium-voltage-switchgear- in-power-system. 2014. The role of medium voltage switchgear in power system. [ONLINE] Available at: https://electrical-engineering-portal.com. [Accessed 30 July 2018].
18. Devi, S., Gupta, C., Jat, S. L., & Parmar, M. S. (2017). Crop residue recycling for economic and environmental sustainability: The case of India. The Open Agriculture Journal, 2, 486-494. Retrieved March 10, 2019.
19. https://biomasspower.gov.in/state-wise.php. 2016. Biomass Knowledge Portal Clean Green and Sustainable Energy. [ONLINE] Available at: https://biomasspower.gov.in. [Accessed 30 July 2018].
20. United Nations. (n.d.). CDM: 10 MW Biomass based Power plant in Punjab, India. Retrieved from https://cdm.unfccc.int/Projects/DB/BVQI1342000522.73/view
21. Agbor, E.U., 2015. Biomass Co-firing with Coal and Natural Gas.
22. Roni, M.S., Eksioglu, S.D., Searcy, E. and Jha, K., 2014. A supply chain network design model for biomass co-firing in coal-fired power plants. Transportation Research Part E: Logistics and Transportation Review, 61, pp.115-134.
23. https://www.nrel.gov/docs/fy00osti/28009.pdf. 2000. Biomass Cofiring: A Renewable Alternative for Utilities. [ONLINE] Available at: https://www.nrel.gov. [Accessed 31 July 2018].

24. Bhattacharjee, Somnath, 2018. Co-firing of coal & biomass waste in a conventional PF fired power station-issues & challenges. Co-firing of coal & biomass waste, [Online]. 1, 7. Available at: http://210.212.126.93:8000/ft/IPS/SessionOthers/Stations/Dadri%20Coal%20Cofiring%20of%20coal%20%20biomass%20
25. New market potential: torrefaction of woody biomass Tumuluru, Jaya Shankar;Hess, Richard Materials World; Jun 2015; 23, 6; SciTech Premium Collection pg. 41
26. http://www.btgworld.com/en/rtd/technologies/torrefaction. 2018. Torrefaction. [ONLINE] Available at: http://www.btgworld.com. [Accessed 30 July 2018].
27. http://rapsagrotech.com/benefits-of-bio-mass-briquette.html. 2018. Benefits of Bio Mass Briquette / White Coal. [ONLINE] Available at: http://rapsagrotech.com. [Accessed 30 July 2018].
28. Yi, Q., Zhao, Y., Huang, Y., Wei, G., Hao, Y., Feng, J., Mohamed, U., Pourkashanian, M., Nimmo, W. and Li, W., 2018. Life cycle energy-economic-CO 2 emissions evaluation of biomass/coal, with and without CO 2 capture and storage, in a pulverized fuel combustion power plant in the United Kingdom. Applied energy, 225, pp.258-272.
29. Carbon Neutral: Benoit, C., 2016. CO2 Neutral Biomass Fuel: Life Cycle Analysis of waste to energy systems, a case study. University of British Columbia, 49.
30. https://www.linkedin.com/pulse/conventional-diesel-vs-electric-truck-total-cost-indian-thalange/. 2017. Conventional Diesel Vs Electric Truck Total Cost of Operation Standpoint and Challenges in Indian Context. [ONLINE] Available at: https://www.linkedin.com. [Accessed 7 November 2018].
31. https://www.ucsusa.org. 2018. Electric Vehicle Battery: Materials, Cost, Lifespan. [ONLINE] Available at: https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost. [Accessed 4 September 2019].
32. https://www.tesla.com. 2006. A Bit About Batteries. [ONLINE] Available at: https://www.tesla.com/en_CA/blog/bit-about-batteries. [Accessed 4 September 2019].
33. https://www.forbes.com. 2017. The Tesla Truck: Is Elon Musk Pulling The Wool Over Our Eyes?. [ONLINE] Availableat: https://www.forbes.com/sites/sarwantsingh/2017/11/20/analysts-take-on-tesla-semi-truck-is-elon-musk-pulling-wool-over-our-eyes/#2509e6aca414. [Accessed 6 August 2019].
34. EIA, 2013a EIA, 2013. Most States have Renewable Portfolio Standards. <http://www.eia.gov/todayinenergy/detail.cfm?id= 4850> (accessed 18.11.18).
35. https://www.thehindubusinessline.com/economy/logistics/Beat-diesel-price-rise-by-cutting-logistics-costs/article20566696.ece. 2013. Beat diesel price rise by cutting logistics costs. [ONLINE] Available at: https://www.thehindubusinessline.com. [Accessed 19 November 2018].
36. En.wikipedia.org. (2019). Bahadurgarh. [online] Available at: https://en.wikipedia.org/wiki/Bahadurgarh [Accessed 10 Mar. 2019].

37. Channi, H.K., Biomass Waste Potential Assessment in the Patiala District of Punjab. International Journal of Computer Applications, 975, p.8887.
38. Chauhan, S., 2010. Biomass resources assessment for power generation: A case study from Haryana state, India. biomass and bioenergy, 34(9), pp.1300-1308.
39. https://biomasspower.gov.in. (2015). Biomass resource potential in Uttar Pradesh. [online] Available at: https://biomasspower.gov.in/uttar-pradesh.php [Accessed 30 Mar. 2019].
40. Bergman, P.C., Boersma, A.R., Zwart, R.W.R. and Kiel, J.H.A., 2005. Torrefaction for biomass co-firing in existing coal-fired power stations. Energy Centre of Netherlands, Report No. ECN-C-05-013.
41. Kumar, R., Sharma, A.K. and Tewari, P.C., 2015. Cost analysis of a coal-fired power plant using the NPV method. Journal of Industrial Engineering International, 11(4), pp.495-504.
42. Achinas, S., Achinas, V. and Euverink, G.J.W., 2017. A technological overview of biogas production from biowaste. Engineering, 3(3), pp.299-307
43. https://cdm.unfccc.int. 2010. Annex 5 GUIDELINES ON THE ASSESSMENT OF INVESTMENT ANALYSIS (Version 05). [ONLINE] Available at: https://cdm.unfccc.int/Reference/Guidclarif/reg/reg_guid03.pdf. [Accessed 17 August 2019].
44. https://gaadiwaadi.com. (2017). PepsiCo Makes Biggest Pre-Order Of 100 Tesla Semi Trucks. [online] Available at: https://gaadiwaadi.com/tesla-semi-truck-launch-details-398312/ [Accessed 1 Apr. 2019].
45. Morgan, H.(2018) https://www.cbankus.com. 2018. Tesla All-Electric Truck vs. Conventional Diesel. [ONLINE] Available at: https://www.cbankus.com/2018/10/24/tesla_truck_vs_conventional_diesel/. [Accessed 8 September 2019].
46. Howard, B. (2017). Tesla Semi: 500-Mile Range, Cheaper Than Diesel, Quick to Charge. [online] https://www.extremetech.com. Available at: https://www.extremetech.com/extreme/259195-tesla-semi-500-mile-range-cheaper-diesel-quick-charge [Accessed 1 Apr. 2019].
47. The Economic Times. (2018). DERC reduces power tariffs for consumers across all categories. [online] Available at: https://economictimes.indiatimes.com/industry/energy/power/derc-reduces-power-tariffs-for-consumers-across-all-categories/articleshow/63526509.cms [Accessed 1 Apr. 2019].
48. https://www.eia.gov/tools/faqs/faq.php?id=307&t=11. 2017. How much carbon dioxide is produced from burning gasoline and diesel fuel? [ONLINE] Available at: https://www.eia.gov/. [Accessed 19 November 2018].

APPENDICES

Appendix A : Cost Analysis

Cost of cogeneration of coal co-firing system

Cost of generation from Coal Cogeneration System

VARIABLE COST		
Fuel Cost		
Steam Generation per hour	Kg/Hr	50,000
Specific enthalpy of steam	Kcal/Kg	819.16
Specific enthalpy of water	Kcal/Kg	135.56
Heat output	Kcal/Hr	3,41,80,000
Efficiency	%	100.00%
Heat input	Kcal/Hr	3,41,80,000
Calorific Value	Kcal/Kg	4,131
Fuel consumption	Tonne/hr	8.274
Fuel yearly consumption- Estimated	MT	65,530

FIXED COST		
Man power cost		
Salary of Man Power	INR Million/Year	6.00
Ash Handling Labour cost	INR Million/Year	0.00
Total man power cost	INR Million/Year	6.00
Increment in man power cost	%	5.70%
Operation & Maintenance Expenses		
Operation & Maintenance Expenses	INR Million/Year	1.50
Increment in Operating & Maintenance Expenses	%	5.70%
Depreciation		
Building	INR Million/Year	1.96
Plant & Machinery	INR Million/Year	25.87
Miscellaneous Fixed Assets and Preoperative cost	INR Million/Year	3.85
Total Depreciation	INR Million/Year	31.68

YEAR	VARIABLE COST	FIXED COST				TOTAL COST(VAR+FIXED) (MINR/YEAR)	LEVELISED COST	
	COST OF FUEL (MINR/YEAR)	TOTAL MANPOWER	MAINTENANCE	TOTAL DEPRECIATION	TOTAL FIXED COST (MINR/YEAR)		DISCOUNTED FACTOR	DISCOUNTED VALUE
Y1	234.37	6.00	1.50	31.68	39.18	273.45	1.00	273.05
Y2	246.80	6.34	1.59	31.68	39.60	286.41	0.88	253.46
Y3	260.01	6.70	1.68	31.68	40.06	300.06	0.78	234.99
Y4	273.92	7.09	1.77	31.68	40.53	314.45	0.69	217.93
Y5	288.57	7.49	1.87	31.68	41.04	329.61	0.61	202.16
Y6	304.01	7.92	1.98	31.68	41.57	345.58	0.54	187.57
Y7	320.28	8.37	2.09	31.68	42.14	362.41	0.48	174.07
Y8	337.41	8.84	2.21	31.68	42.73	380.14	0.43	161.58
Y9	355.46	9.35	2.34	31.68	43.36	398.83	0.38	150.02
Y10	374.48	9.88	2.47	31.68	44.03	418.51	0.33	139.32
Y11	394.51	10.44	2.61	31.68	44.73	439.25	0.29	129.40
Y12	415.62	11.04	2.76	31.68	45.48	461.10	0.26	120.21
Y13	437.86	11.67	2.92	31.68	46.26	484.12	0.23	111.69
Y14	461.28	12.33	3.08	31.68	47.10	508.38	0.20	103.79
Y15	485.96	13.04	3.26	31.68	47.97	533.94	0.18	96.47
Y16	511.96	13.78	3.45	31.68	48.90	560.86	0.16	89.68
Y17	539.35	14.57	3.64	31.68	49.88	589.24	0.14	83.37
Y18	568.21	15.40	3.85	31.68	50.92	619.13	0.13	77.53
Y19	598.60	16.27	4.07	31.68	52.02	650.62	0.11	72.10
Y20	630.63	17.20	4.30	31.68	53.28	683.81	0.10	67.03

LEVELISED COST INR MILLION/YEAR
2,946

LEVELISED COST (INR Million/TJ)	2.5996

Cost of generation of rice husk co firing system

Cost of generation from Rice Husk Cogeneration System		

VARIABLE COST		
Fuel Cost		
Steam Generation per hour	Kg/Hr	50,000
Specific enthalpy of steam	Kcal/Kg	819.16
Specific enthalpy of water	Kcal/Kg	135.56
Heat output	Kcal/Hr	3,41,80,000
Efficiency	%	100.00%
Heat input	Kcal/Hr	3,41,80,000
Calorific Value	Kcal/Kg	2,767
Fuel consumption	Tonne/hr	12.353
Fuel yearly consumption- Estimated	MT	97,834

FIXED COST		
Man power cost		
Salary of Man Power	INR Million/Year	6.00
Ash Handling Labour cost	INR Million/Year	0.28
Total man power cost	INR Million/Year	6.28
Increment in man power cost	%	5.70%
Operation & Maintenance Expenses		
Operation & Maintenance Expenses	INR Million/Year	1.50
Increment in Operating & Maintenance Expenses	%	5.70%
Depreciation		
Building	INR Million/Year	1.96
Plant & Machinery	INR Million/Year	25.87
Miscellaneous Fixed Assets and Preoperative cost	INR Million/Year	3.85
Total Depreciation	INR Million/Year	31.68

YEAR	VARIABLE COST (MINR/YEAR)	FIXED COST				TOTAL COST(VAR+FIXED) (MINR/YEAR)	LEVELISED COST	
		TOTAL MANPOWER	MAINTENANCE	TOTAL DEPRECIATION	TOTAL FIXED COST (MINR/YEAR)		DISCOUNTED FACTOR	DISCOUNTED VALUE
Y1	273.93	6.28	1.50	31.68	39.45	313.39	1	313.39
Y2	287.63	6.63	1.59	31.68	39.90	327.53	0.88	289.85
Y3	302.01	7.01	1.68	31.68	40.36	342.38	0.78	268.13
Y4	317.11	7.41	1.77	31.68	40.86	357.97	0.69	248.09
Y5	332.97	7.83	1.87	31.68	41.38	374.45	0.61	229.60
Y6	349.62	8.28	1.98	31.68	41.94	391.55	0.54	212.52
Y7	367.10	8.75	2.09	31.68	42.52	409.62	0.48	196.75
Y8	385.45	9.25	2.21	31.68	43.14	428.59	0.43	182.18
Y9	404.73	9.78	2.34	31.68	43.79	448.52	0.38	168.71
Y10	424.96	10.34	2.47	31.68	44.48	469.45	0.33	156.27
Y11	446.21	10.93	2.61	31.68	45.21	491.42	0.29	144.77
Y12	468.52	11.55	2.76	31.68	45.99	514.51	0.26	134.13
Y13	491.95	12.21	2.92	31.68	46.80	538.75	0.23	124.29
Y14	516.54	12.90	3.08	31.68	47.66	564.21	0.20	115.19
Y15	542.37	13.64	3.26	31.68	48.57	590.94	0.18	106.77
Y16	569.49	14.41	3.45	31.68	49.54	619.03	0.16	98.98
Y17	597.96	15.24	3.64	31.68	50.56	648.52	0.14	91.76
Y18	627.86	16.10	3.85	31.68	51.63	679.49	0.13	85.08
Y19	659.26	17.02	4.07	31.68	52.77	712.02	0.11	78.90
Y20	692.22	17.99	4.30	31.68	53.97	746.19	0.10	73.17

LEVELISED COST INR MILLION/YEAR
3,319

LEVELISED COST (INR Million/TJ)	2.9285

Levelized Cost Analysis overall

Parameter	Value		Unit
Number of hours of operation in a day	24		Hrs
Number of days of operation in a year	330		Days
Price of Fuel	**Rs./ton**		
Rice husk	2800		
Annual escalation on rice husk	5%		
Coal	3575		
Annual escalation on coal	5.35%		
Net Calorific Value of rice husk	2767		kCal/kg
Net Calorific Value of coal	4131		kCal/kg
Cost of power from grid	4.66		Rs./kWh
Annual escalation on the grid tariff	3.04%		
Project Cost	**Cogen**	**L P Boiler + Grid**	
Cost of Building	25.00	10.00	INR Million
Cost of Plant & Machinery	330.00	132.00	INR Million
Spare Parts	50.00	20.00	INR Million
Depreciation			
Rate of depreciation for Building	7.84%		
Rate of depreciation for	7.84%		

Plant & Machinery			
Rate of depreciation for Spare Parts	7.69%		
Discount rate	13.00%		

Parameter	Value	Unit
Salary of Man Power	6.00	INR Million/Year
Fuel and Ash Handling Labour cost	0.28	INR Million/Year
Total man power cost	6.28	INR Million/Year
Increment in man power cost	5.70%	%
Operation & Maintenance Expenses	1.50	INR Million/Year
Increment in Operating & Maintenance Expenses	5.70%	%

Summary - Levelised Cost Analysis	INR Million/TJ	Percentage difference in cost of operation
Coal Cogen	2.5996	0
Grid Power + Coal steam	3.7205	43
Grid Power + Rice husk steam	3.8251	47
Rice Husk Cogen	2.9285	13

Appendix B : Java Code

```
import java.io.FileWriter;
import java.io.IOException;
import java.util.*;
import java.util.logging.Level;
import java.util.logging.Logger;
public class Paper
{
        static double dieselCost = 0.92;

        static String[] location = {"L1","L2","L3"};

        static double[] distance = {275.0,140.0,130.0};

        static double[] mileage = {3.2,3,3,3,7,8.5};

        static String[] truckname = {"TATA SIGNA 4923S","TATA LPS 4923","TATA
        LPK 3118         9S","TATA LPT 3718","TATA LPT 709EX","TATA LPT
        407EX"};
        static              double[]              truckprice              =
{48461.53,39846.15,46307.69,48461.53,15384.6,14923};
        static   String   fileName   =   "./output.csv",COMMA_DELIMITER   =
        ",",NEW_LINE_SEPARATOR = "\n";

        static FileWriter fileWriter=null;

        static List<String> combinations = new ArrayList<>();

        public static List<List<String>> combinationSum(double[] candidates, double
target)
{
        List<List<String>> result = new ArrayList<>();
        List<String> temp = new ArrayList<>();
        helper(candidates, 0, target, 0, temp, result);
        return result;
}

        private static void helper(double[] candidates, int start, double target, double sum,
        List<String> list, List<List<String>> result)
{
        if(sum>target){
```

```
        return;
}

        if(sum==target){
        result.add(new ArrayList<>(list));
        return;
}

        for(int i=start; i<candidates.length; i++){
        list.add(String.valueOf("T"+(i+1)+" "));
        helper(candidates, i, target, sum+candidates[i], list, result);
        list.remove(list.size()-1);
}
}
        public static void main(String[] args)
{
        int l1count=0,l2count=0,l3count=0;
        HashMap<String, Integer> combinationcount = new HashMap<String, Integer>();
        HashMap<String, String> combinationLocation = new HashMap<String,
String>();
        HashMap<String, Integer> combinationTruckCount = new HashMap<String,
Integer>();
        try{
        System.out.println("Writing CSV file");
        Random r = new Random();
        int truck_count=0;
        double[] candidates = {40.7,40,18.5,27.4,3.8,3.1};
        double target = 271.8;
        List<List<String>> result=combinationSum(candidates,target);

        fileWriter = new FileWriter(fileName);
        fileWriter.append("Truck,Weight,Price(US$)");
        fileWriter.append(NEW_LINE_SEPARATOR);

for(int i=0;i<candidates.length;i++)
{
        fileWriter.append(truckname[i]+" (T"+(i+1)+")");
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(candidates[i]));
        fileWriter.append(COMMA_DELIMITER);
```

```
            fileWriter.append(String.valueOf(truckprice[i]));
            fileWriter.append(COMMA_DELIMITER);
            fileWriter.append(NEW_LINE_SEPARATOR);
}

            fileWriter.append(NEW_LINE_SEPARATOR);
            fileWriter.append("Target");
            fileWriter.append(COMMA_DELIMITER);
            fileWriter.append(String.valueOf(target));
            fileWriter.append(COMMA_DELIMITER);
            fileWriter.append(NEW_LINE_SEPARATOR);
            fileWriter.append(NEW_LINE_SEPARATOR);

            fileWriter.append("Possible combinations");
            fileWriter.append(NEW_LINE_SEPARATOR);
            fileWriter.append("Trucks,Truck count,Location,Fuel used(litres),Cost of
            Fuel(US$),Fuel used(gallon),CO2 emitted(pounds),Cost of CO2
            emitted(US$),Cost of trucks(US$),Total cost(fuel+CO2+trucks)(US$), For 3300
            iterations, Max. time location visited");
            fileWriter.append(NEW_LINE_SEPARATOR);

            String temp = "";
            int t1count=0,t2count=0,t3count=0,t4count=0,t5count=0,t6count=0;
            for(int i=0;i<result.size();i++)
{
            for(int j=0;j<result.get(i).size();j++)
{
            truck_count++;
            if(result.get(i).get(j).contains("T1"))
{
            t1count++;
}
            else if(result.get(i).get(j).contains("T2"))
{
            t2count++;
}
            else if(result.get(i).get(j).contains("T3"))
{
            t3count++;
}
```

```
else if(result.get(i).get(j).contains("T4"))
{
t4count++;
}
else if(result.get(i).get(j).contains("T5"))
{
t5count++;
}
else if(result.get(i).get(j).contains("T6"))
{
t6count++;
}
}
String combination = "T1("+t1count+") T2("+t2count+") T3("+t3count+") T4("+t4count+") T5("+t5count+") T6("+t6count+")";
fileWriter.append(combination);
combinations.add(combination);
fileWriter.append(COMMA_DELIMITER);
fileWriter.append(String.valueOf(truck_count));
fileWriter.append(COMMA_DELIMITER);
combinationTruckCount.put(combination, truck_count);
int ran = r.nextInt(3-0);
fileWriter.append(location[ran]);
if(ran==0)
{
l1count++;
}
else if(ran==1)
{
l2count++;
}
else if(ran==2)
{
l3count++;
}
for(int p=0;p<3299;p++)
{
int rr = r.nextInt(3-0);
if(rr==0)
{
```

```
        l1count++;
}
        else if(rr==1)
{
        l2count++;
}
        else if(rr==2)
{
        l3count++;
}
}
        String maxloc="";
        if(l1count>l2count && l1count>l3count)
{
        maxloc="L1";
}
        else if(l2count>l3count && l2count>l1count)
{
        maxloc="L2";
}
        else
{
        maxloc="L3";
}
        fileWriter.append(COMMA_DELIMITER);
        double                          fuelUsed                          =
        Math.round(((distance[ran]/mileage[0])*t1count)+((distance[ran]/mileage[1])*t2c
        ount)+((distance[ran]/mileage[2])*t3count)+((distance[ran]/mileage[3])*t4count)
        +((distance[ran]/mileage[4])*t5count)+((distance[ran]/mileage[5])*t6count));
        double fuelUsedCost = fuelUsed * dieselCost;
        double fuelUsedGallon = Math.round(fuelUsed/3.785);
        double co2emitted = fuelUsedGallon*22;
        double cost = co2emitted*0.78;
        double                          truckcost                          =
        Math.round((truckprice[0]*t1count)+(truckprice[1]*t2count)+(truckprice[2]*t3co
        unt)+(truckprice[3]*t4count)+(truckprice[4]*t5count)+(truckprice[5]*t6count));
        double totalcost = Math.round(fuelUsedCost+cost+truckcost);
        fileWriter.append(String.valueOf(fuelUsed));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(fuelUsedCost));
```

```
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(fuelUsedGallon));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(co2emitted));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(cost));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(truckcost));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(totalcost));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append("L1("+String.valueOf(l1count)+")
        L2("+String.valueOf(l2count)+") L3("+String.valueOf(l3count)+")");
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(maxloc);
        fileWriter.append(NEW_LINE_SEPARATOR);

        combinationLocation.put(combination.trim(), maxloc);

        truck_count=0;
        t1count=0;
        t2count=0;
        t3count=0;
        t4count=0;
        t5count=0;
        t6count=0;
        l1count=0;
        l2count=0;
        l3count=0;
}
        //System.out.println(combinationLocation);
        for(int i=0;i<3300;i++)
{
        int rr = r.nextInt(combinations.size()-0);
        //System.out.println(rr);
        if(combinationcount.containsKey(combinations.get(rr)))
{
        int te = combinationcount.get(combinations.get(rr));
        te = te + 1;
        combinationcount.put(combinations.get(rr), te);
```

```
}
        else
{
        combinationcount.put(combinations.get(rr), 1);
}
        //System.out.println(combinations.get(rr));
}
        int z=0,max=0;
        String maxCombination="";
        Set set = combinationcount.entrySet();
        Iterator iterator = set.iterator();
        while(iterator.hasNext()) {
        Map.Entry mentry = (Map.Entry)iterator.next();
        if(max<(Integer)mentry.getValue())
{
        maxCombination=(String)mentry.getKey();
        max=(Integer)mentry.getValue();
}
        //System.out.print("index is: "+z+" ");
        z++;
        //System.out.print("key is: "+ mentry.getKey() + " & Value is: ");
        //System.out.println(mentry.getValue());
}
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append("Most occured combination in 3300 iterations,Number of times
        occured in 3300 iteration,Truck count, Max. time location visited");
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append(maxCombination);
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(max));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(combinationTruckCount.get(maxCombination))
);
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(combinationLocation.get(maxCombination));
        //System.out.println("maxCombination="+maxCombination);
        //System.out.println("maxValue="+max);
        double payloadTesla = 36.28;
        double teslatruckrpice = 180000;
        int ran=r.nextInt(3-0);
```

```
	if(ran==0)
{
	l1count++;
}
	else if(ran==1)
{
	l2count++;
}
	else if(ran==2)
{
	l3count++;
}
	for(int p=0;p<3299;p++)
{
	int rr = r.nextInt(3-0);
	if(rr==0)
{
	l1count++;
}
	else if(rr==1)
{
	l2count++;
}
	else if(rr==2)
{
	l3count++;
}
}
	String maxloc="";
	if(l1count>l2count && l1count>l3count)
{
	maxloc="L1";
}
	else if(l2count>l3count && l2count>l1count)
{
	maxloc="L2";
}
	else
{
	maxloc="L3";
```

```
}

        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append("Truck,Weight,Price(US$)");
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append("Tesla");
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(payloadTesla));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf(teslatruckrpice));
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append("Truck count,Location,Cost of trucks(US$), For 3300
        iterations, Max. time location visited");
        fileWriter.append(NEW_LINE_SEPARATOR);
        fileWriter.append(String.valueOf((int)Math.ceil(target/payloadTesla)));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(location[ran]);
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(String.valueOf((int)Math.ceil(target/payloadTesla)*teslatruckrp
ice));
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append("L1("+String.valueOf(l1count)+")
        L2("+String.valueOf(l2count)+") L3("+String.valueOf(l3count)+")");
        fileWriter.append(COMMA_DELIMITER);
        fileWriter.append(maxloc);

        fileWriter.flush();
        fileWriter.close();

        System.out.println("CSV file was created successfully !!!");
}
        catch (Exception ex) {
        System.err.println(ex.getMessage());
}
}
}
```

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