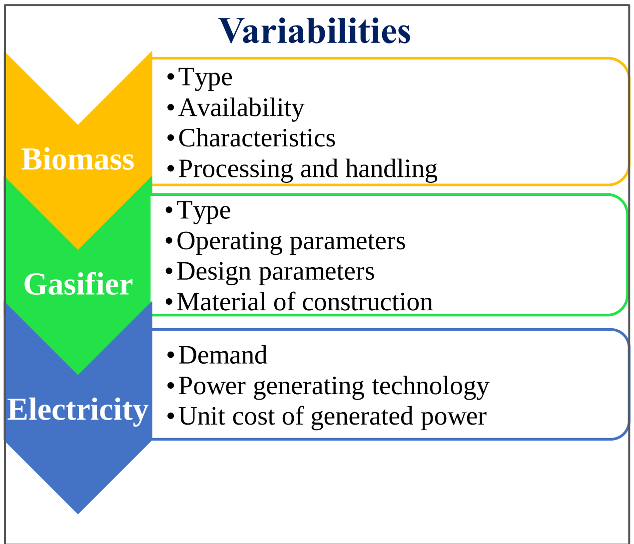

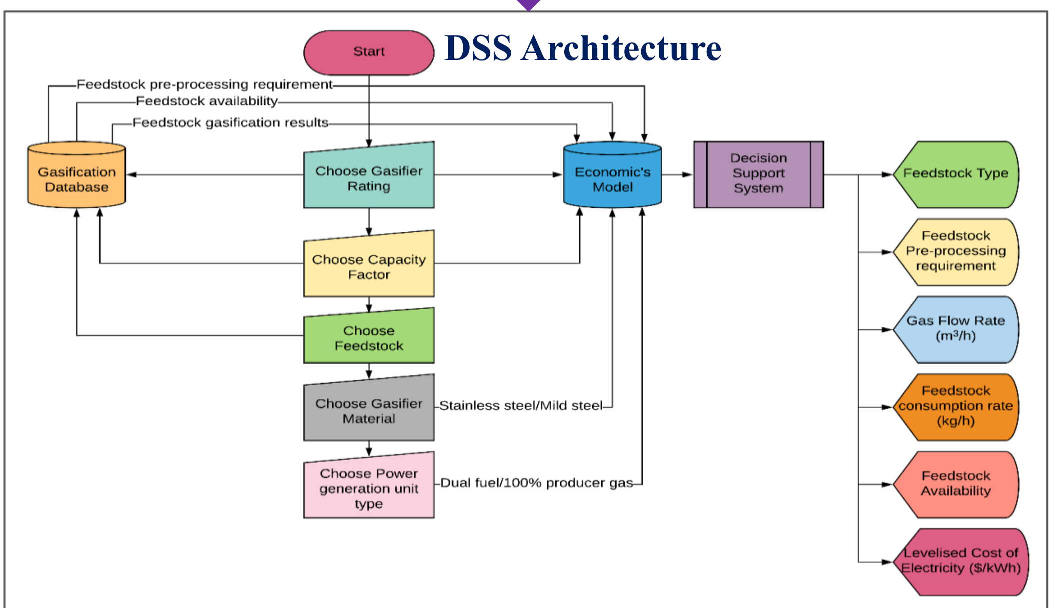

Biomass Gasification Decision Support System

Parameters	Input Values
Choose electrical power requirement (kW)	40
Choose feedstock	Rice Husk Pellet
Choose Capacity Factor	1
Choose Gasifier Material	Mild Steel
Choose Type of Engine	100% Producer Gas

Parameters	Output Values
Feedstock Type	Loose Biomass
Feedstock Pre-processing Suggestion	Feedstock pre-processing required
Gas flow rate (m^3/h)	138
Mass flow rate of feedstock (kg/h)	53
Feedstock availability	Available
Levelised Cost of Electricity ($/kWh)	0.2462

*** User input required in Green Highlighted Cells Only

ABSTRACT

Access to electricity is one of the major attributes to the standard of living which is reflected in the Human Development Index (HDI) of a country. Decentralized electricity generation (DEG) is one of the options to ensure electricity access especially in remote areas where generally grid extension is not viable. Renewable energy based DEG technologies, over the recent years, have shown a positive impact on the provisioning of electricity access. Additionally, renewable energy based DEG has an inherently lower greenhouse gas (GHG) emission in comparison to conventional electricity generation. Solar photo-voltaic (SPV), small hydro, wind turbine, biogas and biomass gasification are the technologies used. SPV has major share in the total installed DEG in the world, accounting for nearly 40%. Intermittency of solar radiation related to time of the day and climatic conditions coupled with additional storage requirements are some issues limiting total reliance on SPV systems. Specific topographical requirements for hydro and wind based DEG also limits their applicability to all regions. Biomass based electricity generation is also being widely used. The carbon neutrality of biomass is the major advantage associated with its utilization for energy generation purpose. Biochemical (anaerobic digestion) and thermo-chemical (combustion, gasification and pyrolysis) conversion pathways are widely used for biomass based energy generation. Biomass gasification is one of the routes of biomass based energy generation gaining prominence. However, in comparison to other DEG systems like SPV, small hydro and wind turbine the variabilities in biomass gasification based electricity generation is multifaceted. Variabilities are associated with aspects relating to feedstock, gasifier performance and economics. Some of the critical biomass related parameters are availability, characteristics, handling and pre-processing requirements and cost. Performance of the gasification system utilizing biomass, in turn, depends upon the characteristics of the biomass and also on the gasifier design and operating conditions. Also, the overall cost of biomass gasification based DEG is influenced by the electricity demand, electricity generation, electricity distribution, capital cost, and operation and maintenance cost. All these factors have interrelations having complex interactions. Many studies have been reported relating to feedstock

characterization, feedstock assessment, gasification performance and economic analysis of gasification based electricity generation systems. Technological perfection of gasification is also reported. Still, biomass gasification based DEG has not been deployed up to its potential. One of the attributes to the lower share of biomass gasification based DEG is the unavailability of a platform that integrates all the aspects of the system, as discussed above, and allows for decision making. Decision Support System (DSS) is one such tool that helps in organizing information, inter-linking different aspects of the information and providing the end user an interface to analyze different scenarios based on a mix of the aspects. A DSS consists of a database containing information regarding different aspects of a system, modules of the different aspects capable of inter-linking the information regarding the aspects based on their relationships and an output module which present the results in an easily interpretable form allowing for decision making. DSS has found applicability in fields including, but not limited to, evaluating engineering projects, medical diagnosis, agricultural production planning, forest management, business management, and verification of credit loan. A DSS for biomass gasification based DEG system is expected to provide a platform capable of integrating the different aspects of the system relating to biomass, gasification, electricity generation and associated economics. This will allow for management at both the supply and demand side resulting in a sustainable and efficient planning of the system.

Keeping in view of the above, the present PhD research work has been undertaken to develop a decision support system (DSS) for decentralized electricity generation (DEG) using biomass gasification with the following objectives i) to investigate biomass feedstock supply chain, ii) to investigate gasifier performance under a range of biomass feedstock variability for DSS and iii) to investigate the scope of biomass gasification based DEG using the DSS.

The parameters influencing the process of biomass to electricity via gasification route were identified based on reviews and literature survey. Parameters relating to utilization of biomass as feedstock, performance of the gasification system using the feedstock and the economics of electricity generation were identified. The DSS architecture was conceptualized to consist of three modules relating to the aspects concerning biomass parameters, gasification performance, and economics of biomass gasification based electricity generation. The modules were developed with capabilities of generating, inter-linking and storing information regarding the aspects.

Different aspects related to utilization of biomass as feedstock for gasification based electricity generation were identified viz. biomass type, availability, characteristics, pre-processing requirements, cost and environmental impact. Tools involving standard procedures for precise assessment of the parameters were identified. Considering the availability of biomass in a given region, precise information were generated using standard methodology which took into account the competitive uses of the biomass. Biomass feedstock characteristics influencing the performance of a gasifier were identified to be moisture content (MC), volatile matter (VM), fixed carbon (FC), ash content, organic constituents and inorganic constituents. Standard procedures for characterization were identified and adopted for the analysis. The parameters effecting the cost of biomass were also identified. Environmental implications of utilizing biomass as an electricity generating source were also investigated. Competitiveness of biomass based electricity generation was also assessed based on a comparative analysis involving the greenhouse gas emissions. Characterization of different biomasses available in Sonitpur District of Assam, India, was carried out to help in evaluating the prospective of biomass gasification based DEG in a representative rural area of the District.

The small-scale electricity generation through biomass gasification associated to an internal combustion engine (ICE) was identified as a competitive option in comparison to other similar technologies like biomass boiler-steam engine or steam turbine, bio-methanation followed by use in ICE and external combustion engine. The study considers downdraft gasifiers coupled to ICE and generator as the electricity generating source based on the capability of downdraft gasifiers in providing allowable quality of producer gas for utilization in ICEs combined with high char conversion, lower ash and tar carry over, quick response to load change, simple construction and easy maintenance in comparison to other types of gasifiers.

Prediction of performance is an important aspect of this study. Options for performance prediction include experimentation, use of already developed models or development of new models. There are financial and time-related limitations of physical experimentation. In this regard, mathematical models present themselves as an alternative option to get a representation of the chemical and physical phenomena occurring inside the reactor of the gasifier. Various models for predicting the gasifier performance were reviewed. Different modeling techniques have their own level of robustness and present their own level of complexity. After analyzing the relative merits of the modeling techniques, a two stage modeling approach based on ANN and Kinetic modeling were adopted for the present study.

ANN based models were formulated to predict the product gas composition in terms of concentration of four major gas species viz. CH_4, CO, CO_2 and H_2 with varying feedstock. The input parameters used in the models were C, H, O content, ash content, moisture content of the feedstock and temperature of the reduction zone. The architecture of the models consisted of one input, one hidden and one output layer. Experimental data were used to train the ANNs. The output of the ANN models were found to be in agreement with experimental data with an absolute fraction of variance (R^2) higher than 0.98 in all cases. The relative importance of the input variables were also analyzed using a standard methodology based on the Garson's equation. The developed ANNs were capable of predicting the performance of a downdraft gasifier utilizing different biomass feedstock. However, in order to complement the planning of a biomass gasification based DEG system for a region, information of gasifier performance using major feedstock of the region is required. Keeping this in view, a kinetic model was also developed.

A two zone (pyro-oxidation zone and char reduction zone) kinetic model of biomass gasification was developed to predict the performance of fixed bed downdraft gasifiers in terms of product gas composition under varying feedstock characteristics and reactor conditions. The model was validated by comparing with experimental results showing good agreement (maximum relative error less than 8%).

Technological pathway from biomass to producer gas and then gas to electricity are available. However, adoption of the pathway is affected by the associated economics. To understand the competitiveness of electricity generation, levelized cost of electricity (LCOE) is used. For biomass gasification based systems there are multifaceted variabilities in the entire demand-supply chain in comparison to conventional electricity generation systems. Thus, an economics' module capable of estimating the LCOE is developed by incorporating the variabilities in key aspects of the demand-supply chain. The module is developed to incorporate the variabilities in cost parameters related to biomass, gasifier, electricity generating unit and electricity distribution. The nature of the feedstock dictates its cost which directly depends upon the processing and handling requirements along with the transportation cost. Biomass cost parameters considered for the study are opportunity cost, collection cost, pre-processing and handling cost, and transportation cost. Cost of gasifier is based on the size of the gasifier with variations in the material of construction of the gasifier. Mild steel gasifier and stainless steel gasifiers were considered. Cost of producer gas based electricity generation is based on the type of electricity generating units. ICE based units coupled to generators are considered with variations in the type of ICE. Duel fuel engine (starting with diesel and running on producer gas) based and producer gas engine units were considered. Also, variations in the cost of electricity distribution network was considered under two scenarios viz. up to 40 kW capacity and 40-100 kW capacity. LCOE estimation was based on the annualized cost of the overall system. Annualized capital costs were estimated using the capital recovery factors of the respective components based on their useful lives and discount rate. A scale based estimation approach was developed for the analysis to incorporate cost variations relative to size of the components. The system was divided into major process areas and sub processes and their sizes were identified. Cost of a particular equipment was referred from reported literature and by consultation with manufacturers and were considered to be the base cost of the equipment. The equipment costs were adjusted to the size of the design by scaling. Also, the costs were adjusted to the common time basis using a cost index and appropriate exchange rates. This resulted in the formulation of a robust economics' module that could cater for variations in different aspects of the demand-supply chain influencing the cost.

An interface for the DSS was developed interlinking the various modules. The interface requires inputs in terms of electrical power requirement, capacity factor, type of feedstock, type of gasifier (in terms of material of construction) and the type of power generation unit. Functions were developed to interlink the user inputs with the various modules and variations within a module. The output of the modules in terms of feedstock type, feedstock pre-processing requirement, gas flow rate, feedstock consumption rate and LCOE were displayed as results in the interface. This resulted in a DSS which provided for the analysis of various combinations of the inputs to understand and take decisions regarding them.

The DSS was then utilized for investigating the scope of biomass gasifier as a rural energy option in a representative location. Jhawani village in the Bihaguri development block of the Sonitpur district of Assam, India was taken as the study area. The biomass energy potential of the study area was assessed using geographical information system (GIS). Potential electricity demand of the area was also assessed based on some realistic scenarios. Considering a realistic electricity demand growth trend and based on the prevailing demand a 40 kW size of the power plant is expected to be adequate for the region for a period of 15 years. Based on the electricity demand and biomass availability, the LCOE for various combinations of the feedstock, gasifier construction material and type of electricity generation unit was estimated using the DSS. The estimated values were compared with values for other types of renewable energy generation methods. A sensitivity analysis was undertaken to understand the parameters influencing the LCOE. The results were then utilized to suggest conditions to make biomass gasification based DEG a sustainable option for the study area.

It was attempted to develop a tool so that all the factors of the entire chain of biomass based DEG could be integrated. Impact of some critical parameters on power generation could be visualized. Variation of the fuel characteristic in terms of variations in the options for producer gas to electricity generation could be

comprehensively integrated enabling examination of the relative merits of each option. Performance of the integrated tool for a given representative rural area of India in terms of some specific biomass feedstock (Dhaincha, Rice husk pellet, Bagasse pellet, Jute stalk pellet and Bamboo), in terms of specific design of gasifier (downdraft), in terms of specific materials of construction of the gasifiers [mild steel gasifier (MSG) and stainless steel gasifier (SSG)] and options of power generation [dual fuel mode (DFP) and producer gas mode (PGP)]. The study revealed that use of Dhaincha in the MSG+PGP mode resulted in the lowest LCOE among the possible combinations. For a typical rural area it is technically and economically feasible to fulfill the demand using biomass gasification based DEG. Resources available in the region if converted using a downdraft gasifier and integrated with a producer gas engine could generate electricity to fulfill the requirements of the region at a cost which is higher than conventional grid electricity, solar PV rooftop, solar PV commercial but lower than diesel generator based electricity generation. Utility of the DSS in analyzing policy interventions are also discussed. Limitations of the study with scope for new research are also presented.