Biomass Gasification for Electricity Generation: An Integrated Approach for Development of Forest Residue-Based Projects in Rural India

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BIOMASS GASIFICATION FOR ELECTRICITY GENERATION: AN INTEGRATED APPROACH FOR DEVELOPMENT OF FOREST RESIDUE-BASED PROJECTS IN RURAL INDIA

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Renewable Natural Resources

by
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Bachelor of Commerce, Lucknow University India, 1995
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May 2016
To my deceased parents and dear friend, to them I owe everything I achieve in this life.
Acknowledgments

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Abstract

Biomass gasification is generally regarded as a promising technology for various advanced applications in energy production. Biomass is the only carbon-based sustainable option among the renewable energy sources. This study is focused on fostering biomass gasification for electricity generation sector in India. The study addresses four broad aspects of biomass gasification for electricity generation - feedstock properties and gasification technology, policy and regulatory framework governing the sector, financial evaluation of electricity generation from biomass gasification, and feedstock supply. The study is divided into four chapters, each of which addresses one aspect of electricity generation through biomass gasification.

Based on literature, first chapter presents a brief review of various properties of biomass feedstocks that are critical for gasification. It reviews the thermochemical conversion processes and the major issues related with biomass gasification with reference to some promising gasifier technology systems.

Based on literature, second chapter examines the importance of national and sub-national policies supporting the development of bioenergy industry (including gasification for electricity generation) in various countries. The policies and instruments deployed globally are compared with those deployed in India.

Third chapter posits a framework for conducting financial evaluation of a gasification power project. A case study of pine needle gasification power project in a remote rural area of Northern India is considered. In absence of historical data related with similar projects, a probability distribution for the Net Present Value (NPV) for the project is generated with the help of Monte Carlo Simulation. The simulation for NPV uses estimates of input variables from an existing pine needle based gasifier operating in the study area.
Continuing with the case study, fourth chapter studies the villagers’ perspective on supplying pine needles to the gasification project. A survey was administered to estimate villagers’ willingness to collect pine needles from the forests and supply it at a price to the gasification project. The willingness is modeled on demographic, livelihood, and latent factors, that are used in a Multinomial Logistic Regression Model to estimate the probability of households’ willingness to collect and supply pine needles to the project.
Chapter 1: A Review of Biomass Feedstock & Gasification Technology

Introduction

For ages, burning various kinds of fuel for energy production has been a defining phenomenon for the development of human societies. Energy derived from burning of wood and straw supported early industrialization efforts until replaced by fossil energy resources-coal, petroleum, natural gas- and hydro and nuclear power. In many parts of the world, fuelwood is still used by population that is without access to modern forms of energy. Fuelwood extraction from forests requires significant effort, especially from women and children, and fuelwood burning has been shown to be responsible for respiratory diseases among women burning fuelwood in the kitchens. Unrestricted fuelwood extraction from the forests constitutes significant forest degradations in countries where large section of population is without access to other forms of energy. These types of uses of biomass are characterized by low energy conversion efficiency and high pollutant emissions.

As the world population and demand for energy continue to grow, existing fossil fuel and biomass burning practices cannot be sustained into the future. The technological evolution of energy production from various resources is expected to nudge energy industry to adopting low emission practices. Stringent regulations on Green House Gas (GHG) emissions are likely to further stimulate this shift towards better environmental performance.

Although the technologies related with conversion of biomass to energy are still evolving and being scrutinized for their direct and indirect impact on environment, bioenergy has the potential to contribute to sustainable economic development. The stored energy in biomass can be converted to heat, power, or liquid fuel by various technologies. Historically, combustion has been the most widely used process for converting biomass to energy. Combustion converts the chemical energy stored in the biomass into heat which can be transformed into mechanical and
electrical energy with the help of heat engines. However, biomass combustion process is less desirable than other advanced conversion technologies -pyrolysis, gasification, digestion- from the perspective of emissions and inefficient use of biomass. Moreover, properties of different types of biomass determine the conversion technology. It can also be said that efficiency of conversion technology is dependent on the properties of biomass feedstock used.

This study provides a compact overview of thermochemical processes and biomass feedstock properties for such processes.

**Biomass Classification: Literature**

Plants accumulate solar energy in the form of chemical energy by the process of photosynthesis. The process of photosynthesis metabolizes carbon dioxide and water into chemical compounds which help plants to grow. The solar energy is stored in the chemical bonds-mainly in the form of glucose of the structural components of plant. At best, the photosynthesis process is able to convert only 8% of the solar energy into chemical energy.

Plants may be consumed by animals and humans, and therefore waste arising from animals and humans can also be called biomass. However, this study uses the term biomass in reference to plant based materiel. Plants that are not consumed by animals and humans are eventually broken down by micro-organism or combusted, which releases the carbon back to the atmosphere in the form of carbon dioxide. Fossil fuel is also generated from biological material including biomass that sequestered carbon thousands of years ago. When fossil fuel is combusted, the carbon that has remained sequestered for thousands of years is released into the atmosphere. The difference between fossil fuel and biomass, in this regard, lies in the time scale; biomass releases recently captured carbon, whereas fossil fuel releases carbon that has remained sequestered for thousands of years. Unlike fossil fuel, plants can reproduce and regenerate, in doing so they recapture the carbon from the atmosphere. In this sense, plants or biomass is
regarded as renewable resource. Therefore, if bioenergy production manages biomass feedstock on sustainable basis, new growth in biomass can recapture the CO₂ from the atmosphere that is released by the combustion of recently harvested biomass. This can close the carbon cycle without significantly impacting the atmospheric CO₂ level.

The related literature uses the term biomass for all organic material originating from plants (including algae, trees and crops) and animals-anything that is now alive or was alive a short time ago. From the bioenergy perspective, biomass can be loosely defined as “a general term for plant and animal resources (excluding fossil resources) and the waste arising from them.” (Yokoyama and Matsumura 2008). From this definitional perspective, biomass can include a wide variety of materials including agricultural crops, timber, aquatic plants, pulp sludge, black liquor, organic industrial waste, building and furniture waste, and municipal waste (some countries do not include municipal waste in the biomass category).

The definition of biomass varies according to the field and the categorization changes depending on purpose and application. The biological categorization is based on types of biomass existing in nature such as: categorization according to ecology of type of vegetation. In the context of bioenergy, biomass is categorized according to its origin and properties.

Khan et al. (Khan, De Jong et al. 2009) provide a classification based on origin which divides biomass in four categories:

- Primary residues: By-products of food crops and forest products (wood, straw, cereals, maize etc.)
- Secondary residues: By-products of biomass processing for production of food products or biomass materials (saw and paper mills, food and beverage industries, apricot seed etc.)
- Tertiary residues: By-products of used biomass derived commodities (waste and demolition wood etc.)
- Energy crops
Khan et al. also provide a classification system based on the properties of biomass that has six categories:

- Wood and woody fuel (hard and soft wood, demolition wood)
- Herbaceous fuels (straw, grasses, stalks etc.)
- Wastes (sewage sludge, refuse-derived fuel etc.)
- Derivatives (waste from paper and food industries etc.)
- Aquatic (Kelp etc.)
- Energy crops (specifically cultivated for energy purposes)

The Biomass Energy Centre (BEC 2014) lists five categories that are based on origin:

- Virgin wood: from forestry, arboricultural activities or from wood processing
- Energy crops: high yield crops grown specifically for energy applications
- Agricultural residues: residues from agriculture harvesting or processing
- Food waste, from food and drink manufacture, preparation and processing, and post-consumer waste
- Industrial waste and co-products from manufacturing and industrial processes

Yet another categorization provided in Asian Biomass Handbook by Yokoyama (Yokoyama and Matsumura 2008) is as follows:

- Conventional Biomass Resources: Agriculture, Forestry (Woody), Fishery, Livestock farming - Food, Materials, Medicine, Timber, Pulp, Chip
- Biomass Wastes (Derivatives): Agricultural, Forestry, Fishery, Livestock residues (wastes)- Rice straw, Cattle manure, Lumber mill, Sawdust, Sewage sludge, Black liquor
- Plantation Biomass
  - Forestry: Eucalyptus, Poplar, Willow, Oil palm
  - Herbaceous: Sugarcane, Switchgrass, Sorghum, Corn, Rapeseed
  - Aquatic: Giant kelp, Water hyacinth, and Algae

The UK Biomass Strategy (DTI 2007) identified the following biomass resources

- Conventional forestry
- Short rotation forestry
- Sawmill conversion products
- Agricultural crops and residues
- Oil bearing plants
- Animal products
- Municipal solid waste
- Industrial waste
A more recent classification is provided by European standard for solid biofuels (Alakangas 2011, García-Maraver, Popov et al. 2011). This classification is based on the biofuel origin and source. In the hierarchical classification system, the main origin-based solid biofuel groups are:

- Woody biomass (wood chips, pellets, log wood, saw dust etc.)
- Herbaceous biomass
- Fruit biomass
- Blend and mixtures

The European Committee for Standardization has published two standards for classification and 27 technical specifications for biomass that can utilized for energy production. It classifies biomass under four broad categories:

- Woody plants
- Herbaceous plants/grasses
- Aquatic plants
- Manures

Under the classification for woody plants (relevant for this study), categories of biomass originating from forest, plantation and other virgin wood are shown in Table 1. Trees, bushes, and shrubs are categorized under woody biomass, but not the fruits or seeds that some of them bear. Under the category herbaceous biomasses those plants are included that die at the end of the growing season. Herbaceous biomass category, however, include grains and cereals that grow on such plants. Herbaceous plants are further subdivided into two sub-categories: those with high and low moisture content. Barring few specific applications, most bioenergy production is focused on lower moisture content type of herbaceous and woody plant.

Aquatic plants and manure that are typically high moisture biomass are used in biochemical process, which is not part of focus of this study. Fruits, though classified as a separate group, are part of woody plants.
Table 1 Woody Biomass Classification: European Standard
Classification of Origin and Sources of Woody Biomass

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategories</th>
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<tbody>
<tr>
<td>1.1. Forest and plantation wood</td>
<td>1.1.1. Whole trees</td>
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<td>1.1.1.1. Deciduous</td>
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<td>1.1.1.2. Coniferous</td>
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<td>1.1.1.3. Short rotation coppice</td>
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<td>1.1.1.4. Bushes</td>
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<td>1.1.1.5. Blends and mixtures</td>
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<td>1.1.2. Stem wood</td>
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<td>1.1.2.1. Deciduous</td>
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<td>1.1.2.3. Blends and mixtures</td>
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<td></td>
<td>1.1.3. Logging residues</td>
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<td></td>
<td>1.1.3.1. Fresh/Green (including leaves/needles)</td>
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<tr>
<td></td>
<td>1.1.3.2. Dry</td>
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<td></td>
<td>1.1.3.3. Blends and mixtures</td>
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<td>1.1.4. Stumps</td>
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<td></td>
<td>1.1.4.1. Deciduous</td>
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<td>1.1.4.4. Bushes</td>
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<td>1.1.4.5. Blends and mixtures</td>
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<td>1.1.5. Bark (from forestry operations)</td>
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<td>1.1.6. Landscape management woody biomass</td>
</tr>
<tr>
<td>1.2. Wood processing industry by-products and residues</td>
<td>1.2.1. Chemically untreated wood residues</td>
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<td>1.2.1.1. Without bark</td>
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<td>1.2.1.2. With bark</td>
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<td>1.2.1.3. Bark (from industry operations)</td>
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<td>1.2.2. Chemically treated b wood residues</td>
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<td>1.2.2.4. Blends and mixtures</td>
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<td></td>
<td>1.2.3. Fibrous waste from the pulp and paper industry</td>
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<td></td>
<td>1.2.3.1. Chemically untreated fibrous waste</td>
</tr>
<tr>
<td></td>
<td>1.2.3.2. Chemically treated fibrous waste</td>
</tr>
<tr>
<td>1.3. Used wood</td>
<td>1.3.1. Chemically untreated wood</td>
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<td></td>
<td>1.3.1.1. Without bark</td>
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<td>1.3.1.2. Bark</td>
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<td>1.3.1.3. Blends and mixtures</td>
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<td>1.3.2. Chemically treated wood</td>
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<td></td>
<td>1.3.2.3. Blends and mixtures</td>
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<tr>
<td>1.4. Blends and mixtures</td>
<td>(Alakangas 2011)</td>
</tr>
</tbody>
</table>
Additionally, we also have mixture or blends of biomass. Blends are intentional mixing of biomass, while mixtures are unintentional mixing of biomass (McKendry 2002, Basu 2013). For commercial uses of biomass, including bioenergy production, only those types are available which do not have a deep alternative market, such as good quality timber and food grains. The production of transport fuel from cereal has established technology and is relatively easy; however, use of cereal in bioenergy production has run into problems because it diverts cereal from food market, which has economic, social, and political consequences.

The literature (McKendry 2002, Khan, De Jong et al. 2009, Alakangas 2011, Basu 2013) suggests following characteristics of biomass that are desirable in energy conversion processes:

- Easy to grow and available most of the year
- Secure and in regular supply
- High energy content
- Simple to process/sort
- Density
- Low market value
- Easy transportation
- Easy storage
- Low moisture content
- Low nitrogen emission

**Biomass Properties in the Context of Bioenergy Production**

The inherent properties of biomass influence the choice of bioenergy production process and technology. In equal measures, the choice of biomass source is influenced by specific requirements of different bioenergy production process and technology. The interaction between the biomass source and the process and technology determines the extent of use of a particular type of biomass as an energy source. The categories of biomass that are extensively used by biomass energy producers are woody and herbaceous species. Depending on the energy conversion process and technology, particular biomass properties become important during the
conversion process. Mckendry in his review of properties of biomass lists six main material properties of interest, during the biomass processing as an energy source:

   1. Moisture content (intrinsic and extrinsic)
   2. Calorific value
   3. Proportions of fixed carbon and volatiles
   4. Ash/residue content
   5. Alkali metal content
   6. Cellulose/lignin ratio

For dry biomass conversion (thermochemical) processes, the first five properties are of interest, while for wet biomass conversion (biochemical) processes, the first and sixth properties are of prime concern.

**Composition of Biomass**

Biomass contains complex organic compounds, moisture, and some amount of inorganic compounds and ash. The organic compounds in biomass comprise four principle elements: carbon, hydrogen, oxygen, and nitrogen. The inorganic compounds mainly comprise chlorine and sulfur. Sulfur is rarely present in the natural state of biomass, and is generally found in biomass originating from secondary sources such as demolition wood. The composition of biomass feedstock and its energy content are important determinants for the thermochemical conversion process, whether it is a gasifier or a combustor. For the thermochemical conversion processes, two types of composition analyses are mainly used for assessment

- Ultimate or elemental composition analysis
- Proximate composition analysis

**Ultimate Analysis:** The ultimate analysis generally reports the elemental carbon (C), hydrogen (H), nitrogen (N), sulfur (S) composition and oxygen (O) (Table 2). The composition of the hydrocarbon fuel is expressed in terms of its basic elements except for its moisture (M), and inorganic constituents, and ash.
A typical ultimate analysis is:

\[ C + H + O + N + S + ASH + M = 100\% \]

Here, C, H, O, N, and S are the mass percentages of carbon, hydrogen, oxygen, nitrogen, and sulfur, respectively, in the biomass. Not all biomass types contain all of these elements. For example, many types of biomass do not contain any sulfur (S). The moisture or water in the fuel is expressed separately as M. Therefore, in the ultimate analysis, the reported hydrogen or oxygen content does not include the hydrogen and oxygen in the moisture, but only the hydrogen and oxygen present in the organic components of the fuel (Basu 2013).

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>H</th>
<th>O</th>
<th>N</th>
<th>S</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypress</td>
<td>55</td>
<td>6.5</td>
<td>38.1</td>
<td>--</td>
<td>--</td>
<td>0.4</td>
</tr>
<tr>
<td>Ash</td>
<td>49.7</td>
<td>6.9</td>
<td>43</td>
<td>--</td>
<td>--</td>
<td>0.3</td>
</tr>
<tr>
<td>Beech</td>
<td>51.6</td>
<td>6.3</td>
<td>41.4</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Wood (average)</td>
<td>51.6</td>
<td>6.3</td>
<td>41.5</td>
<td>0</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>48.1</td>
<td>5.4</td>
<td>42.2</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>48.5</td>
<td>5.5</td>
<td>3.9</td>
<td>0.3</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Barley straw</td>
<td>45.7</td>
<td>6.1</td>
<td>38.3</td>
<td>0.4</td>
<td>0.1</td>
<td>6</td>
</tr>
<tr>
<td>Rice straw</td>
<td>41.4</td>
<td>5</td>
<td>39.9</td>
<td>0.7</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>73.1</td>
<td>5.5</td>
<td>8.7</td>
<td>1.4</td>
<td>1.7</td>
<td>9</td>
</tr>
<tr>
<td>Lignite</td>
<td>56.4</td>
<td>4.2</td>
<td>18.4</td>
<td>1.6a</td>
<td>--</td>
<td>5</td>
</tr>
</tbody>
</table>

(Yokoyama and Matsumura 2008)

The ultimate analysis is performed and reported on a dry basis, because otherwise moisture is indicated as additional hydrogen and oxygen.

Proximate Analysis: Proximate analysis reports the composition of the biomass in terms of gross contents such as moisture (M), volatile matter (VM), ash, and fixed carbon (FC) (Table 3) The VM of biomass is the condensable and non-condensable vapor released when the fuel is heated. The amount of VM depends on the rate of heating and the temperature to which biomass is heated. Ash is the solid residue form the complete combustion of biomass. It comprises silica,
aluminum, iron, calcium; small amounts of magnesium, titanium, sodium, and potassium. The ash obtained from the burning of biomass may not originate from the biomass itself. Often, the ash constituents are accumulated in the biomass harvesting and collection processes. Table 4 provides Proximate and Ultimate analysis of some types of biomass.

Table 3 Proximate Analysis of Some Biomass Feedstock (Stahl, Henrich et al. 2004)

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Moisture %</th>
<th>VM %</th>
<th>FC %</th>
<th>Ash %</th>
<th>LHV (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>20</td>
<td>82</td>
<td>17</td>
<td>1</td>
<td>18.6</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>16</td>
<td>59</td>
<td>21</td>
<td>4</td>
<td>17.3</td>
</tr>
<tr>
<td>Barley straw</td>
<td>30</td>
<td>46</td>
<td>18</td>
<td>6</td>
<td>16.1</td>
</tr>
<tr>
<td>Lignite</td>
<td>34</td>
<td>29</td>
<td>31</td>
<td>6</td>
<td>26.8</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>11</td>
<td>35</td>
<td>45</td>
<td>9</td>
<td>34</td>
</tr>
</tbody>
</table>

Moisture

Moisture is one of the major constituent of biomass. The root of a plant absorbs moisture from the ground. Capillary passages in the sapwood carry the moisture to other parts of the tree. Some of the moisture is used in photosynthesis reactions and the rest is released into the atmosphere through transpiration. For this reason, leaves contain more moisture than the trunk of the tree. Moisture in biomass is stored in spaces within the dead cells and within the cell walls.

Biomass feedstocks can be categorized into wet and dry feedstocks. The moisture content in the wet feedstock is more than 50% and sometimes up to 90%, whereas dry feedstock moisture content is significantly less than 50% by weight of the biomass (Table 4). Wet biomass is used in biochemical processes and dry feedstock typically in thermochemical processes. Some types of biomass can have moisture content as high as 90% (wet basis), for example -Water Hyacinth has moisture level at 95% on the wet basis (Basu 2013). Moisture percentage of the wood species varies from 41.27 to 70.2% on wet basis and 20% to 40% on air dry basis (Demirbas 2007).
Table 4 Proximate and Ultimate Analysis Comparison of Some Biomass with Coal

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Proximate Analysis</th>
<th>Ultimate Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture %</td>
<td>Volatile %</td>
</tr>
<tr>
<td>Wood pellets (pine)</td>
<td>4.9</td>
<td>80.4</td>
</tr>
<tr>
<td>Demolition wood pellets</td>
<td>9.1</td>
<td>69.6</td>
</tr>
<tr>
<td>Pepper plant residue</td>
<td>6.5</td>
<td>60.5</td>
</tr>
<tr>
<td>Greenhouse residue</td>
<td>2.5</td>
<td>61</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>13.9</td>
<td>77.9</td>
</tr>
<tr>
<td>Sunflower pellets</td>
<td>11.2</td>
<td>65.2</td>
</tr>
<tr>
<td>Olive cake pellets</td>
<td>11.9</td>
<td>64.2</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>6.9</td>
<td>44.6</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>4.9</td>
<td>32.3</td>
</tr>
</tbody>
</table>

Ashing at 815 °C d by difference; LLD - below the lower detection limit; N.R - Not reported.
(Khan, De Jong et al. 2009)
The heating value of a wood fuel decreases with an increase in the moisture content of the wood; therefore moisture content of biomass is an important input parameter for the assessment of a thermochemical process.

Two forms of moisture content are of interest in biomass

- Intrinsic moisture: the moisture content of the material without the weather effects.
- Extrinsic moisture: the influence of weather conditions during harvesting on the overall biomass moisture content.

Because moisture content is defined differently in each field, care is needed in reading indications of moisture content. Yokoyama et al. (Yokoyama and Matsumura 2008) define moisture content as follows.

\[
\text{Moisture content} = \left[ \frac{\text{moisture weight}}{\text{total weight}} \right] \times 100 \%
\]

Total weight = (biomass dry weight) + (moisture weight)

Using this definition, moisture content never exceeds 100%. In the forestry and ecology fields, moisture content is often defined as follows:

\[
\text{Moisture content} = \left( \frac{\text{moisture weight}}{\text{biomass dry weight}} \right) \times 100
\]

In practical terms, it is the extrinsic moisture content that is of concern, as the intrinsic moisture content is usually only applicable under laboratory conditions (McKendry 2002). Peter McKendry writes that the relationship between biomass moisture content and appropriate bio-conversion technology is straightforward, in that thermal conversion requires low moisture content feedstock (typically <50%), while bio-conversion can utilize high moisture content feedstocks. On this basis, woody and low moisture content herbaceous plant species are the most efficient biomass sources for thermal conversion to energy.
Fixed Carbon and Volatile Matter

Fixed carbon (FC) in biomass is estimated from the following equation

\[ FC = 1 - M - VM \text{ (volatile matter)} - \text{Ash} \]

The fixed carbon content is the solid carbon remaining in the char after the releases of volatiles, excluding the ash and moisture contents. For thermochemical processes, FC is an important parameter as the conversion of FC into gases determines the rate of gasification and its yield (Basu 2013).

Biomass generally has a very high volatile content. Volatile matters are subdivided into gases such as light hydrocarbons, carbon monoxide, carbon dioxide, hydrogen, moisture, and tars. The volatile content or volatile matter of biomass is that portion that volatilizes as a gas by heating biomass to 950°C for 7 min. Biomass can lose up to 90% of their masses in this first stage of combustion. A typical volatile loss during early pyrolysis of biomass is about 75% (Khan, De Jong et al. 2009). The rapid volatilization requires careful control of the thermochemical process. The significance of the VM and FC contents is that they provide a measure of the ease with which the biomass can be ignited and subsequently gasified, or oxidized, depending on how the biomass is to be utilized as an energy source.

Ash and Alkali

The chemical breakdown of a biomass, by either thermochemical or biochemical processes, produces a solid residue. When biomass is combusted in air, the solid residue is called ash. The ash content of biomass impacts the overall processing cost of the energy production. The proportion of ash in biomass diminishes the amount of available energy from the feedstock. In the thermochemical conversion process, ash present significant operational problems. During the combustion process ash can react with alkali metals (Na, K, Mg, P and Ca) to form “slag”, a
liquid form of ash at elevated temperature. Slag can lead to blockages of airways in the furnace and boiler plant and increase in the maintenance cost (McKendry 2002).

Inorganic material in biomass can be inherent or added during the biomass harvesting and processing steps. The latter often makes up a major fraction of the ash content of biomass feedstock. The ash content varies from one biomass to another. It can be from 1% (wood) to up to 30 to 40% in some types of forest residue. With high ash containing biomass feedstock incorporation of efficient dust removal system becomes important to handle particulate emissions.

**Bases of Expressing Biomass Composition**

The composition of biomass can be expressed on different bases depending on the context. The following four bases of analysis are commonly used:

- As-received (AR)
- Air-dry (AD)
- Total dry (TD)
- Dry and ash-free (DAF)

In AR basis, the constituents from both-ultimate and proximate analyses - add up to 100%. The ash and moisture content of the fuel is the same in both analyses

Ultimate: \( C + H + O + N + S + \text{ASH} + M = 100\% \)

Proximate: \( \text{VM} + \text{FC} + M + \text{ASH} = 100\% \)

When the fuel is dried in air, its surface moisture is removed while its inherent moisture is retained. Total dry basis of reporting accounts for inherent moisture as well. Dry and ash-free (DAF) reports composition of biomass without the ash and moisture. Figure 1 shows various basis of reporting biomass composition- from as-received basis that includes intrinsic and extrinsic moisture to process dried daf basis.
The heat content or calorific value of a biomass feedstock is an important factor affecting in the energy conversion process. The heat content of biomass is affected by the proportion of organic components present in it. Various researchers (McKendry 2002, Rezaiyan and Cheremisinoff 2005, Nelson, Langemeier et al. 2010, Basu 2013) have written about calorific value of various types of biomass. The calorific value (CV) of biomass expresses the energy content, or heat value, released when burnt in presence of air. The CV is measured in terms of the energy content per unit mass or volume of feedstock; hence MJ/kg for solids, MJ/l for liquids, or MJ/Nm³ for gases. The CV of biomass feedstock is expressed in two ways, the gross CV (GCV), or higher heating value (HHV) and the net CV (NCV), or lower heating value (LHV). The amount of energy recovered varies with the conversion technology.

While reporting CV of biomass, the moisture content is stated, as moisture reduces the available energy from the biomass. Usually both- HCV and NCV-are reported on the basis of dry matter tons (dmt) which assumes absence of moisture content. The higher heating value (HHV)
is defined as the amount of heat released when fuel is combusted in presence of air and the temperature of resulting products have come down to 25°C. The HHV includes the latent heat of the water vapor. The HHV therefore represents the maximum amount of energy potentially recoverable from a given biomass source (Nhuchhen and Salam 2012). The lower heating value (LHV) is defined as the net calorific value. The LHV is determined by subtracting the heat of vaporization of water vapor (generated during combustion of fuel) from the HHV (Demirbas 2007). For many kinds of fossil fuel the GHV ranges from 20 to 35 MJ/kg. However, almost all kinds of lignocellulosic biomass feedstocks fall in the range 15-19MJ/kg. The values for most woody materials are 17-19 MJ/kg; for most agricultural residues, the heating values are about 15 -17 MJ/kg (Table 5).

**Atomic Ratio**

The HHV of a biomass feedstock correlates well with the oxygen-to-carbon (O/C) ratio. When O/C ratio increases across the types of biomass feedstock from 0.86 to 1.03, the HHV reduces from 20.5 to 15MJ/kg. When the hydrogen-to-carbon (H/C) ratio of biomass increases, the HHV reduces. Fresh plant biomass like leaves has very low heating values because of its high H/C and O/C ratios. As the age of biomass based fuel increases, the H/C and O/C ratios decrease.

The higher proportion of oxygen and hydrogen, compared with carbon, reduces the energy value of a fuel, due to the lower energy contained in carbon–oxygen and carbon–hydrogen bonds, than in carbon–carbon bonds (McKendry 2002). Anthracite coal has a very high HHV and very low H/C and O/C ratios, however it carbon emission intensity is also very high. Among all hydrocarbon fuels, biomass is highest in oxygen content.
Table 5 Chemical Properties of Some Biomass Feedstock

<table>
<thead>
<tr>
<th>Material</th>
<th>Moisture Content (%)</th>
<th>HHV&lt;sup&gt;a&lt;/sup&gt; (MJ/kg)</th>
<th>FC Content (%)</th>
<th>VM Content (%)</th>
<th>Ash Content (%)</th>
<th>Alkali Metal Content (as Na and K oxides) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fir</td>
<td>6.5</td>
<td>21</td>
<td>17.2</td>
<td>82</td>
<td>0.8</td>
<td>–</td>
</tr>
<tr>
<td>Danish pine</td>
<td>8</td>
<td>21.2</td>
<td>19</td>
<td>71.6</td>
<td>1.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Willow</td>
<td>60</td>
<td>20</td>
<td>–</td>
<td>–</td>
<td>1.6</td>
<td>15.8</td>
</tr>
<tr>
<td>Poplar</td>
<td>45</td>
<td>18.5</td>
<td>–</td>
<td>–</td>
<td>2.1</td>
<td>16</td>
</tr>
<tr>
<td>Cereal straw</td>
<td>6</td>
<td>17.3</td>
<td>10.7</td>
<td>79</td>
<td>4.3</td>
<td>11.8</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>11.5</td>
<td>18.5</td>
<td>15.9</td>
<td>66.8</td>
<td>2.8</td>
<td>–</td>
</tr>
<tr>
<td>Bagasse</td>
<td>45–50</td>
<td>19.4</td>
<td>–</td>
<td>–</td>
<td>3.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>13–15</td>
<td>17.4</td>
<td>–</td>
<td>–</td>
<td>4.5</td>
<td>14</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>8–12</td>
<td>26–35</td>
<td>57</td>
<td>35</td>
<td>8</td>
<td>–</td>
</tr>
</tbody>
</table>

<sup>a</sup> Dry basis

(Demirbas 2007)
The importance of the O/C and H/C ratios on the CV of various types of fuels is illustrated in a Van Krevelen diagram (Figure 2).

**Figure 2 Krevelen Diagram for Various Solid Fuels**
(Basu 2013)

**Biomass Constituents**

Cellulose and lignin are generally recognized as the main components in biomass. The biomass feedstock can also be classified on the basis of relative proportion of cellulose, hemicellulose, and lignin.

**Cellulose/Lignin ratio**

Mckendry in his review of biomass feedstocks writes that the proportions of cellulose and lignin in biomass are important only in biochemical conversion processes. He further points out that the biodegradability of cellulose is greater than that of lignin; hence the overall conversion of the carbon-containing plant material present as cellulose is greater than for plants with a higher proportion of lignin, which an important consideration while selecting biomass for
biochemical processing. Table 6 provides proportions of lignin, cellulose, and hemi-cellulose in various types of biomass.

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Lignin (%)</th>
<th>Cellulose (%)</th>
<th>Hemi-cellulose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>27–30</td>
<td>35–40</td>
<td>25–30</td>
</tr>
<tr>
<td>Hardwood</td>
<td>20–25</td>
<td>45–50</td>
<td>20–25</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>15–20</td>
<td>33–40</td>
<td>20–25</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>5–20</td>
<td>30–50</td>
<td>10–40</td>
</tr>
</tbody>
</table>

(Demirbas 2007)

Peter Mckendry writes that for the production of ethanol, a biomass feedstock with a high, cellulose/hemi-cellulose content is needed to provide a high liter/ton yield Prabir Basu (Basu 2013) writes that the behavior of a biomass can be predicted during pyrolysis from the knowledge of these component. He writes that lignin would generally have lower oxygen and higher carbon compared to cellulose or hemicellulose, therefore, biomass with lower lignin content may be better in biochemical conversion process. However, focus of this study is on thermochemical processes, therefore cellulose/lignin ratios are not of much importance in this study. Table 7 provides the summary of various properties of biomass in the context of their utilization for energy production.

**Softwood vs Hardwood as Feedstock Options for Bioenergy**

According to CEN/TS 14961, the technical committee developing the draft standard to describe all forms of solid biofuels within Europe, the typical value of GHV for softwoods in dry basis is 20.5 MJ/kg and for hardwoods 20.2 MJ/kg (BEC 2011). On the average, hardwoods have a lower proportion of carbon and higher proportion of oxygen which tends to reduce the heat value of the biomass. This is reflected in the HHV of the softwood and hardwood.
<table>
<thead>
<tr>
<th>Properties</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
</tr>
<tr>
<td>Moisture content</td>
<td>Storage durability, Dry-matter losses, Low NCV, Self-ignition</td>
</tr>
<tr>
<td>Bulk density</td>
<td>Fuel logistics (storage, transport, handling) costs</td>
</tr>
<tr>
<td>Ash content</td>
<td>Dust particle emissions, Ash utilization/disposal costs</td>
</tr>
<tr>
<td>Particle dimension and size</td>
<td>Determines fuel feeding system, Determines combustion technology, Drying</td>
</tr>
<tr>
<td>distribution</td>
<td>properties, Dust formation, Operational safety during fuel conveying</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon C</td>
<td>GCV (positive)</td>
</tr>
<tr>
<td>Hydrogen H</td>
<td>GCV (positive)</td>
</tr>
<tr>
<td>Oxygen O</td>
<td>GCV (negative)</td>
</tr>
<tr>
<td>Chlorine Cl</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Nitrogen N</td>
<td>NOx, N2O, HCN emissions</td>
</tr>
<tr>
<td>Sulfur S</td>
<td>SOx emissions, corrosion</td>
</tr>
<tr>
<td>Fluor F</td>
<td>HF emissions, corrosion</td>
</tr>
<tr>
<td>Potassium, K</td>
<td>Corrosion (heat exchangers, super heaters), Lowering of ash melting</td>
</tr>
<tr>
<td></td>
<td>temperatures, Aerosol formation, Ash utilization (plant nutrient)</td>
</tr>
<tr>
<td>Sodium, Na</td>
<td>Corrosion (heat exchangers, super heaters), Lowering ash melting</td>
</tr>
<tr>
<td></td>
<td>temperatures, Aerosol formation</td>
</tr>
<tr>
<td>Magnesium, Mg</td>
<td>Increase of ash melting temperature, Ash utilization (plant nutrient)</td>
</tr>
<tr>
<td>Calcium, Ca</td>
<td>Increase of ash melting temperature, Ash utilization (plant nutrient)</td>
</tr>
<tr>
<td>Phosphorus, P</td>
<td>Increase in ash melting point, Ash utilization (plant nutrient)</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Emissions of pollutants, Ash utilization and disposal issues, Aerosol</td>
</tr>
<tr>
<td></td>
<td>formation</td>
</tr>
</tbody>
</table>

Note: GCV: Gross calorific value, NCV: Net calorific value (Koppejan and Van Loo 2012)
Table 8 shows the structural components of softwood and hardwood. Hardwood has higher proportion of cellulose, hemicelluloses, and extractives than softwoods, but softwoods have a higher proportion of lignin. Traditionally, hardwood has been the preferred fuel in wood stoves and fireplaces because it naturally has a lower moisture content, is a denser fuel, burns longer, and has hotter coals. Softwood is known for burning hotter initially, easy to light, having more pitch or sap, more sparks and sound as it burns, but burns up more quickly. Cypress Pacific Marketing (CPM 2015) a pellet manufacturer, claims that:

After wood chips are ground into sawdust, they are dried to a consistent moisture level. The sawdust is then compressed into pellets at a common density, about 40lbs per cubic foot. It doesn't matter if the sawdust came from a softwood species, hardwood species, or a blend; they are all compressed to the same density. If you look at BTUs of different species of wood, they are very similar. Wood pellets are about 8000 BTUs per pound at 6% moisture.

<table>
<thead>
<tr>
<th></th>
<th>C %</th>
<th>H %</th>
<th>O %</th>
<th>N %</th>
<th>S %</th>
<th>Cl %</th>
<th>HHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>51</td>
<td>6.3</td>
<td>42</td>
<td>0.1</td>
<td>0.02</td>
<td>0.01</td>
<td>20.5 MJ/Kg</td>
</tr>
<tr>
<td>Range</td>
<td>47-54</td>
<td>5.6-7</td>
<td>40-44</td>
<td>.1-.5</td>
<td>&lt;.01-.05</td>
<td>&lt;0.01–0.03</td>
<td></td>
</tr>
<tr>
<td>Hardwood</td>
<td>49</td>
<td>6.2</td>
<td>44</td>
<td>0.1</td>
<td>0.02</td>
<td>0.01</td>
<td>10.2 MJ/Kg</td>
</tr>
<tr>
<td>Range</td>
<td>48–52</td>
<td>5.9–6.5</td>
<td>41–45</td>
<td>&lt;0.1–0.5</td>
<td>&lt;0.01–0.05</td>
<td>&lt;0.01–0.03</td>
<td></td>
</tr>
</tbody>
</table>

For the thermochemical conversion processes, rather than broad categories of wood types-softwood or hardwood-particular species of either type can be a good feedstock. Although hardwood has lower proportion of lignin but it has adverse O/C and H/C ratios.

**Physical Properties of Biomass**

Some physical properties of biomass impact its pyrolysis and gasification behavior. Other properties acquire importance in term of transportation and storage costs. Some physical properties determine the type of thermochemical process needed for energy generation.
Density

The density of a biomass feedstock affects the storage requirements, the sizing of the feedstock units and how the feedstock is likely to behave during the thermo-chemical/biological processing (Table 9). For straw to be competitive as a feedstock compared with wood on the same density basis, it needs either to be baled, or processed into a cubed/pelleted form, with an attendant increase in costs (Demirbas 2007).

Table 9 Volume and Density of Some Biomass Feedstock

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Bulk Volume</th>
<th>Bulk Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m³/t, daf)</td>
<td>(t/m³, daf)</td>
</tr>
<tr>
<td>Wood</td>
<td>4.4</td>
<td>0.23</td>
</tr>
<tr>
<td>Hardwood chips</td>
<td>5.2–5.6</td>
<td>0.18–0.19</td>
</tr>
<tr>
<td>Softwood chips</td>
<td>6.2</td>
<td>0.12</td>
</tr>
<tr>
<td>Pellets</td>
<td>1.6–1.8</td>
<td>0.56–0.63</td>
</tr>
<tr>
<td>Sawdust</td>
<td>24.7–49.5</td>
<td>0.02–0.04</td>
</tr>
<tr>
<td>Straw</td>
<td>12.0–49.5</td>
<td>0.02–0.08</td>
</tr>
<tr>
<td>Loose</td>
<td>4.9–9</td>
<td>0.11–0.2</td>
</tr>
<tr>
<td>Chopped</td>
<td>24.7–49.5</td>
<td>0.02–0.08</td>
</tr>
<tr>
<td>Baled</td>
<td>0.8–10.3</td>
<td>0.10–1.25</td>
</tr>
<tr>
<td>Moduled</td>
<td>1.5–3.1</td>
<td>0.32–0.67</td>
</tr>
<tr>
<td>Cubed</td>
<td>1.4–1.8</td>
<td>0.56–0.71</td>
</tr>
</tbody>
</table>

Harvesting

Harvesting biomass represents another significant cost factors in harnessing of biomass for energy production. The harvesting process itself is energy intensive because the biomass needs to be transported to the energy production units. Moreover, the harvesting process can introduce contaminants, such as soil, which can subsequently contribute to ash and slag formation during the conversion process. The moisture content of the biomass can also be affected by the weather at the time of harvesting.
The cost of transport depends on the density and volume of the biomass. Transport cost is a function of distance covered and energy density of the biomass. Therefore, loose and voluminous biomass needs to be densified before they can be transported economically. Herbaceous biomass needs to be chopped, baled, or densified before it is transported. Woody biomass is pelletized or chipped to reduce the transportation cost.

**Biomass Feedstock Yields**

The quantity of dry matter produced by a biomass species per unit area of production, determines the potential energy production capacity, or yield, of the available land area. Biomass crop yield is measured in dmt/ha and combined with the HHV of the biomass; the energy yield of the cultivated crop can be calculated (Table 10).

<table>
<thead>
<tr>
<th>Energy Yields from Selected Biomass</th>
<th>Energy Yields from Selected Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>Crop Yield (dmt/ha/a)</td>
</tr>
<tr>
<td>Wheat (grain)/7 (straw) (14 total)</td>
<td>7.3 (straw)</td>
</tr>
<tr>
<td>Poplar</td>
<td>10–15</td>
</tr>
<tr>
<td>SRC willow</td>
<td>10–15</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>8</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>12–30</td>
</tr>
</tbody>
</table>

(Yokoyama and Matsumura 2008)

The development of dedicated plantations to grow biomass crops for energy production is likely to proceed on two paths: species with a high dmt/ha, grown ideally on good quality agricultural land e.g. set aside and species capable of reasonably high dmt/ha yields, grown on marginal land (Yokoyama and Matsumura 2008).

**Energy Production**

Demirbas and Peter Mckendry calculate the amount of biomass feedstock required for a unit of energy production. Peter calculates the yields of 15 dmt/ha/a and with 1dmt equal to 1
MWh, 1ha (based on a 3 yr. harvesting cycle) of short rotation cycle (SRC) biomass would provide 15 MWh/a. At the capacity utilization factor of 95%, a 100 KW gasifier would require approximately 55 ha of land to produce the required amount of biomass feedstock. This implies a significant land requirement even for a modest amount of energy production. The low energy conversion efficiency (20% for biomass to electricity) of current thermochemical conversion technologies presents a significant challenge for the sector.

**Thermochemical Conversion of Biomass**

There are four main types of thermo-chemical processes available for energy production:

- Combustion
- Pyrolysis
- Gasification
- Liquefaction.

The focus of this study is on the gasification processes.

**Combustion**

The burning of biomass in presence of air is called combustion. Chemically, combustion is an exothermic reaction between oxygen and hydrocarbon in biomass. The biomass is oxidized into water and carbon dioxide. Combustion is used for a wide range of outputs to convert the energy stored in the biomass into heat, mechanical power, or electricity using various items of process equipment, e.g. stoves, furnaces, boilers, steam turbines, etc. The most common practice is to burn the biomass in a boiler to generate steam which can be used to produce electricity through a steam turbine.

Combustion of biomass generates gases at temperatures around 800 to 1000 C. Although, any type of biomass can be combusted to produce gases, but in practice combustion is economically feasible only for biomass with moisture content less than 50%, unless the biomass is pre-dried. The scale of combustion plant ranges from very small scale (e.g. for domestic
heating) up to large-scale industrial plants in the range 100 to 3000 MW. Net bioenergy conversion efficiencies for biomass combustion power plants range from 20% to 40% (McKendry 2002).

**Pyrolysis**

Unlike combustion, pyrolysis takes place in the total absence of oxygen, except in cases where partial combustion of biomass is allowed that provides the thermal energy required for the initiation of pyrolysis process. Pyrolysis decomposes biomass into gas, liquid, and solid by rapidly heating biomass above 300-400°C (Table 11). Pyrolysis is primarily used to produce biofuel through a process called flash pyrolysis that converts the biomass into bio-crude with an efficiency of up to 80%. Problems with the conversion process and subsequent use of the oil, such as its poor thermal stability and its corrosively, still need to be overcome (McKendry 2002, Basu 2013).

<table>
<thead>
<tr>
<th>Process</th>
<th>Temperature (°C)</th>
<th>Catalyst</th>
<th>Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquification</td>
<td>250-330</td>
<td>Essential</td>
<td>Not required</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>300-600</td>
<td>Not required</td>
<td>Necessary</td>
</tr>
<tr>
<td>Combustion</td>
<td>700-1400</td>
<td>Not required</td>
<td>Not essential, but may help</td>
</tr>
<tr>
<td>Gasification</td>
<td>500-1300</td>
<td>Not essential</td>
<td>Necessary</td>
</tr>
</tbody>
</table>

**Gasification**

Gasification converts biomass into useful gases and chemicals. Gasification requires a medium-air, oxygen, steam, or super critical water- for reaction to take place. Currently gasification of fossil fuel is more common than that of biomass feedstock in production of syngas. However, the biomass gasification is also gathering momentum in recent years. Gasification improves over the combustion process in the following ways:
- It increases the heating value of the biomass by rejecting noncombustible components like nitrogen and water.
- It strips strip the resulting gas of sulfur such that it is not released into the atmosphere when the gas is burnt.
- It increases the H/C mass ratio in the gas.
- It reduces the oxygen content of the gas.

Whereas combustion involves mainly one process, gasification converts the energy stored in biomass to useful gases in two stages-dehydration and decarboxylation. The oxygen is removed from the biomass by either dehydration or decarboxylation reactions. The decarboxylation reaction while rejecting the oxygen through carbon dioxide also rejects carbon and thereby increasing the H/C ratio of the fuel. A positive benefit of the gasification product is that it emits less GHG when combusted (Basu 2013).

**Biomass Gasification Technologies for Power Generation**

The biomass gasification sector utilizes a range of technologies. At the end of the 1980s and the beginning of the 1990s, downdraft and updraft gasifiers with capacities of less than 100 kW and up to a few MW were developed and tested for small scale power and heat generation. In recent years, downdraft technology has dominated over the updraft technology, especially for power generation, because of its ability to handle ash content in the biomass and to limit tar generation in the gasification process (Kirkels and Verbong 2011). India and China are the major adopters of downdraft technology where most applications are at smaller scale. Most companies engaged in the biomass gasification are with limited resources and are players in the regional market only. Even for the most equipment suppliers, gasification is not their core business, and the gasification plants are not mass produced but made to order.

In the developed countries, for large applications of gasification with the power production capacity above 100 MW, the preferred technology has been atmospheric circulating fluidized beds (CFB), it can handle a high amount of feedstock, is relatively easy to scale up and
is capable of accepting a wide range in feedstock quality, both in particle size and in ash properties (Faaij 2006).

For the small scale applications of below 50MW capacity, the fixed bed gasifier has been the traditional process used for gasification. Within the fixed bed category of gasifiers, depending on the direction of airflow, the gasifiers are classified as updraft or downdraft.

The updraft gasifiers (Figure 3) are the oldest and simplest of all gasifier designs. In the updraft gasifier the feedstock is introduced at the top and the gasification medium (air, oxygen, or steam) travels upward while the bed of fuel moves downward, and the gas and solids are in countercurrent mode. The product gas leaves from near the top of the gasifier. The ash falls through the grate, which is often designed to move (rotating or reciprocating), especially in large production units to facilitate ash discharge. Updraft gasifiers are suitable for high-ash (up to 25%), high-moisture (up to 60%) biomass. They are suitable for biomass feedstock with low volatiles.
Tar production is relatively higher in an updraft gasifier, which makes it unsuitable for feedstock with high volatile content. On the other hand, an updraft gasifier utilizes combustion heat very effectively and achieves high cold-gas efficiency (McKendry 2002, Basu 2013).

In the downdraft gasifier (Figure 4), the feed and the air move in the same (concurrent) direction. The product gases flow downward and leave the gasifier from the lower section after passing through the hot zone. Since the gas passes through the hot zone, it creates suitable conditions for the tar contained in the gas for cracking, and producing a gas with low tar content.

Because the gases leave the gasifier unit at temperatures about 900–1000 C, the overall energy efficiency of a downdraft gasifier is low, due to the high heat content carried over by the hot gas. The tar content of the product gas is lower than for an updraft gasifier but the particulates content of the gas is high (McKendry 2002).

Figure 4 Downdraft Gasifier
(Basu, 2013)
Application of Gasification Technology

An overview of large operational gasification plants (of capacity over 100 MW electric equivalents, commercial industrial scale) has been presented by US DoE (Batchelor, Han et al. 2010). The study includes 144 plants and 427 gasifiers in the world. The study reports that the market is dominated by coal and petroleum based gasifiers. At least 15 different gasification technologies are in operation, of which three technologies are dominant: Sasol Lurgi, GE Energy and Shell. Since 2001 new plants have mainly been built in China. Gasifiers in Europe are mainly located in Germany.

In biomass gasification mostly wood is used as feedstock. However, peat, black liquor and rice husk gasification have also found application. Black liquor is a byproduct of the paper industry, a lignin-rich mixture of cooking chemicals and dissolved wood material. Rice husk gasification has found application in Asia (Kirkels and Verbong 2011). Canada, Finland, Sweden and the USA were initially involved in the development of biomass gasification. Each of them has large woody biomass resources. In the 1970s, especially the USA played a leading role in the development of biomass gasification technology in response to the disruption of oil supply and high oil prices. This involved research and rapid development of gasification concepts. The potential to substitute natural gas or transportation fuels was viewed as being very important. Once the energy crises abated, most financial incentives and drivers for further research in the technology that were needed to stimulate the commercial use of biomass energy were eliminated, and so were many projects and plants (Klass 1995).

However, 1990s brought increased awareness of climate change, which resulted in a renewed interest in biomass gasification. While some developments in the USA continued, European countries became increasingly involved. Germany and Austria have joint Sweden and Finland as leading countries. Especially in countries with strong support for renewables and
with availability of biomass, the development of biomass gasification has become an established practice. Since 2005, there has been a significant interest in biomass gasification (Kwant and Knoef 2004).
Chapter 2: Policy and Regulatory Framework Governing Bioenergy in India

Introduction

Bioenergy is renewable energy derived from biomass. Bioenergy takes three forms: biopower (electricity), biothermal (heat), and biofuels. Biomass can also be used to produce combined heat and power (CHP) (Bracmort 2015).

The attention accorded to bioenergy in recent times tends to obscure the fact that biomass has been a source of energy for much of the world for a long time. For the better part of the 20th century, use of biomass for modern energy production has been limited to specific situations such as using residues from pulp and paper mills and sugar cane crushing mills to run a power plant. In last two decades, the situation has changed. The urgency to address climate change, insecurities related with energy supply, and volatile fossil fuel prices have contributed to growing interest in biomass as source of energy. However, the growth in the bioenergy industry in the past decade would not have been possible without government policies and interventions aimed at meeting specific objectives.

Increasing environmental awareness in the 1960s stimulated interest in bioenergy. The energy crisis of the 1970s and 80s provided further motivation for the interest in bioenergy. In the 1990s, the growth in bioenergy originated mainly from international environmental treaties, such as the UN Framework on Climate Change in Rio (1992) and the Kyoto Protocol (1997). Increasing concerns about greenhouse gas (GHG) emission impacts continued to motivate political debate and policy reform through the 2000s (Gan, Eskeland et al. 2007). The degree of evolution of policy landscape governing the renewable energy sector has been varied in different parts of the world, as countries responded to the challenges of climate change and energy security according to their specific contexts.
In the current technological and economical sense, it is commonly agreed that bioenergy cannot replace fossil fuel on the global scale. However, bioenergy may play an important role in specific situations depending on geographical location, climate, land use, soil type, and water availability (Florin and Bunting 2009). International Energy Agency (Bioenergy 2007) states that bioenergy may meet 20% to 50% of world energy demand by 2050. Global Bioenergy Partnership (GBEP 2007) estimates these numbers at 20% by 2030, rising to between 30% and 40% by 2060, when the world’s population may have reached over 9 billion. These estimates are based on scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) with the objective of predicting future demand for energy and its potential supply from various sources. Most estimates by various agencies and researchers do not take into account the sustainability criteria that could moderate the biomass uses for energy generation. The fact that global estimates mask the regional variability in the potential of bioenergy, it introduces a degree of uncertainty to the estimates.

In addition to challenges of estimating future energy demand, the process of policy formulation that may support bioenergy sector is quite complex. The implications of bioenergy related policies span several areas including civil society, environment, and business. More specifically, the bioenergy industry has implications for forests, water resources, land uses, and biodiversity as well. The development and implementation of policy instrument is rendered even more difficult in the context of ever shifting and ill-defined targets.

**Study Objectives**

1. Review literature related with bioenergy policy framework adopted by various countries.
2. Identify major policy program and instrument in use to promote bioenergy in general and bioelectricity in particular.
3. Review bioenergy policy framework of India.
Role of Government in Industrial Development

The debate about the role of state in the economic development of a country has always been charged. The optimism of early development economists in the competence and effectiveness of state in as a primary cause of economic development was largely misplaced. On the other side of the debate, and during 1970s and 1980s, the neoclassical economists criticized government intervention in formulating industrial strategy for achieving economic development. While development economists of pre-1970s assumed imperfect markets in their arguments, those of 1980s presumed inevitability of imperfect states arguing that imperfect market is the lesser evil. Shapiro et al. (Shapiro and Taylor 1990) argue against the easy dismissal of the state and point out that virtually all cases of economic development have involved state intervention in formulating industrial strategy.

Nearly all governments intervene in the markets, by default or design, to shape its productive structure. Shapiro et al. explain that industrial strategy depends upon directed public intervention at the sectoral or firm level, aiming to stimulate particular type of economic activities. Along with the sectoral and firm level targeting, macroeconomic targeting of policies toward certain sector is also usually involved. Gerschenkron (Gerschenkron 1962) argues that different initial conditions of countries give rise to diverse institutional forms, structures, and sectoral composition in the process of economic development. He further suggests that in some cases, state has to function as substitute to the market and force industrialization, and in other cases, state’s role is restricted to creating a suitable environment for market to function properly. In general, relative economic backwardness of a country leads to more widespread state intervention. Shapiro et al. posit that there are no fixed roles for state that are independent of specific context of different countries, however, it does not mean that policy decisions are
contingent on specific contexts. Comparative analyses across countries can help explain why particular strategies work well or poorly in different context.

**Drivers for Government Action in Bioenergy Sector**

The objectives underlying the government policies can vary between countries according to their specific contexts (Table 12) arising out of energy security, socio economic conditions, population density, commitment to reduction of GHG, availability of land, biomass resources, and water resources. Most countries, with varying degrees, regard bioenergy as a partial replacement of fossil fuels and the traditional use of biomass such as fuelwood and dung. The interventions by the governments in the energy market in order to promote bioenergy is highly political and involves potential trade-offs among many variables. Various researchers such as Komor et. al., Florin et al., McCarl et.al. (Komor and Bazilian 2005, McCarl and Plieninger 2008, Florin and Bunting 2009) have enumerated the drivers underlying the governments efforts towards promoting bio energy through policies and interventions.

**Table 12 Key Motivation for Bioenergy Policy by Countries**

<table>
<thead>
<tr>
<th>Countries</th>
<th>Climate Change</th>
<th>Environment</th>
<th>Energy Security</th>
<th>Rural Development</th>
<th>Agricultural Development</th>
<th>Technology Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Mexico</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>X</td>
<td></td>
<td>X</td>
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<td>X</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
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<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Italy</td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>UK</td>
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<td>X</td>
<td>X</td>
</tr>
<tr>
<td>US</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

(GBEP 2007)
A brief discussion of the important drivers guiding the policymaking exercise in various countries follows.

**Demand for Energy**

The growing demand for energy has been one the most important reason for the increased attention being paid to bioenergy. The energy consumption globally has increased by about 1.5% annually in recent years, driven primarily by rising consumption in developing countries (REN21 2015). Access to reliable energy sources is critical to human welfare and income generation opportunities for people. The literature includes several studies on role of energy in development process. Toman et al found energy in general and electricity in particular, to be a component in production functions and a productivity enhancing factors (Toman and Jemelkova 2003). However, fossil fuel continues be the major source of energy for the world (Figure 5).

International Energy Agency in its report (IEA. 2012) points out that in recent years the growth in electricity demand has mainly come from China and India where most electricity generation is dependent on coal. Coal is a non-sustainable and non-renewable energy source which emits pollutants and GHGs including a significant amount of carbon dioxide (CO₂) when combusted.

![Figure 5 Estimated Renewable Energy Share of Global Final Energy Consumption, 2012 (REN21 2015)]
Higher demand for energy has contributed to the sustained higher fossil fuel prices for the better part of the past decade. Higher fossil fuel price has been the key factor in the growth of the bioenergy sector. International Energy Agency forecasts that the future supplies will remain cost constrained.

**Energy Security**

Many countries are dependent on large amounts of imports of petroleum and coal for their energy consumption. In order to reduce the dependence on import and enhance domestic control over energy price and supply, fossil fuel importing countries have made efforts to improve diversity of domestic energy resources (Figure 6).

![Figure 6 Estimated Renewable Electricity Share of Global Electricity Production, 2013 (REN21 2015)]

For example; the 2007 US Energy Security and Independence Act states as the first of its aims to “move the US toward greater independence and security” and introduces the Renewable Fuel Standard of the Act which is headed “Energy Security Through Increased Production of Biofuels” (Congress 2007). Bioenergy enhances the domestic energy resource diversification, thereby improves energy security. The use of domestic sources of biomass for bioenergy
production can contribute to the energy diversification by partially substituting oil, coal, and natural gas.

The high prices and constrained supply of petroleum products primarily influences the demand for liquid biofuel such as ethanol and biodiesel. Many countries use oil for heating and power generation also. Countries that use imported natural gas for electricity generation aim to reduce dependence on imported natural gas by promoting domestic bioenergy industry. Figure 7 shows electricity generation from various renewable energy sources across the world.

Figure 7 Renewable Power Capacities in World, EU-28, BRICS, and Top Six Countries, 2013 (REN21 2015)

**Rural Development**

The United Nations Development Programme (UNDP) states that “bioenergy can contribute directly to poverty alleviation by helping to meet basic needs, creating opportunities for improved productivity and better livelihoods, and preserving the natural environment on which the poor depend” (UNDP 2000). In many regions of the world, the limited access to
modern energy remains an obstacle for eradicating poverty. Renewable Energy Policy Network’s Global Status Report 2015 (REN21 2015) states that as many as 1.3 billion people still do not have access or have limited access to electricity (Figure 8), and more than 2.6 billion people depend on traditional biomass for cooking and heating (Figure 9). Increasing focus on renewables, including modern bioenergy, continues to improve the access to modern energy in many parts of the world. Access to modern bioenergy can reduce the workload on women and children involved in fuelwood and dung collection, mitigate the health impact from the indoor smoke inhalation which is responsible for approximately of 3% all deaths and diseases among women in poorest countries (WHO 2003). The access to modern energy also enables modern communication services in the poorest regions of the world creating synergy with other entrepreneurial and employment generating activities.

The improvement in the access to energy is partly a direct result of inclusion of renewable energy in national energy policies in many countries. Bioenergy industry may not generate employment on the scale or of the quality of fossil fuel based energy industry; however,
bioenergy projects tend to be more labor intensive, which may be beneficial to rural economy of developing countries. According to the Renewable Energy Network report (REN21 2015), until the year 2013, bioenergy industry has created 782,000 jobs worldwide, out of which 240,000 jobs were created in China, and 58,000 in India.

![Figure 9 World Access to Clean Cooking Energy Sources (REN21 2015)](image)

**Climate Change**

Over the last few decades, the climate change has become one of the most important global concerns. The connection between the anthropogenic emissions and concentration of greenhouse gases (GHG) is now well-established. The emerging broad consensus among the countries and the scientific communities acknowledges the necessity of reducing carbon and other emissions to much more manageable levels. An important element of the consensus is the understanding that a substantial part of the GHG emissions originate from fossil fuel based activities, and that the reduction in emissions can only be achieved if the economic growth, and expanding middle class and poverty alleviation are decoupled from GHG emissions (UN 2005). Environmental Protection Agency (EPA) indicates that coal is the source of about 42% of U.S. GHG emissions while petroleum use is of approximately equal size (McCarl and Plieninger 2005).
The modern bioenergy technology is one of the ways to decouple fossil fuel from the economic development and poverty alleviation objectives.

Bioenergy provides an important GHG emission offset because biomass growth removes CO$_2$ from the atmosphere via photosynthesis. When the biomass is used to produce energy carbon that is released had previously been sequestered from the atmosphere and is sequestered again as the biomass is regrown. If the biomass harvesting for the energy purpose is carefully managed, the net emission from bioenergy can be negligible. However, fossil fuel use releases the carbon that has remained locked in for millions of years in the atmosphere.

**Interactions and Trade-offs between Bioenergy and other Socio-economic-environmental Dimensions**

Bioenergy industry is situated among a broad range of political, socio-economical, and environmental issues (Figure 10).

![Figure 10 Interaction between Bioenergy and other Socio-economic-environmental Dimensions](image)

The industry has linkages with environment, agriculture, technology, energy demand and supply dynamics, rural poverty alleviation, fiscal situation of the government, among other
dimensions. Consequently, the industry is subject to myriad objectives and constraints, multiple institutions, and variety of organizations. As a result, promotion of bioenergy industry is an arena of complex decision making process that involves multiple trade-offs with potential of conflicts. Growth in bioenergy industry can interact with markets for agricultural products - food and feed, forest products - paper, board etc. However, the interactions are moderated by other factors such as biomass yield from the feedstock, biomass and fossil fuel price volatility. Policies related with forestry, agriculture, environment, transport, and health also interact with the bioenergy industry. Promotion of bioenergy industry also involves coordination and trade-offs with institutions, organizations, and different branches of policymaking.

**Economic and Structural Trade-off**

The trade-off associated with the growth of bioenergy industry and the technology utilized is a direct result of economic incentives such as subsidies, trade barriers, tax rebates etc. These incentives seek to provide a level of security to the investment in the bioenergy sector; however, they can also distort the energy market dynamics by sustaining bioenergy through non-market interventions. The bioenergy industry has linkages with other structural issues also such as land tenure, forest and water resources utilization policies, and agricultural policies. The policy formulation, therefore, may be subject to various lobbying and political pressures.

**Environmental and Social**

The assessment of bioenergy potential should include its linkages with large scale projects with the production of feedstock, its impact on water use, biodiversity, and climate change. The bioenergy industry raises the potential of biodiversity loss from monoculture energy plantation, soil degradation, stress on water resources, and impact of land use change on GHG emission. A careful consideration and development of scientific understanding of the above
mentioned potentially harmful environmental impact should be a necessary part of policy formulation process.

The environmental impact of use of agricultural crop as feedstock for bioenergy has been researched in much greater detail than that of lignocellulosic materials. Intensive farming for feedstock production also has an impact on biodiversity through higher use of fertilizers which may cause changes in species composition in the ecosystem. Monoculture agricultural and forestry plantation can have additional negative effect on biodiversity (Bioenergy 2009). However, it is contended that lignocellulosic crops have lesser harmful environmental impact as they require less fertilizer and are perennial. Moreover, it can help soil structure and fertility of degraded land. On the negative side, conversion of dry and arid land with sparse vegetation to high yielding lignocellulosic crops may lead to lesser availability of water in downstream areas (Bioenergy 2009). The use of agricultural and forest residue should not contribute to water stress as additional water is not used to produce residues. In general, the impact of large scale feedstock production on water supply must be considered during the policy formulation.

The extraction of biomass from natural forest for energy purposes can reduce the quantity and quality of vegetation and forest residue, and therefore biodiversity. Long-term consequences of such pressure on forests can be important. The bioenergy projects are commonly regarded as carbon neutral. However, harvesting of long-rotation forest biomass for bioenergy generation takes decades for regrowth. Forest biomass utilization for bioenergy may be carbon neutral over time if the forest regrowth sequesters as much carbon in the following rotation as was released earlier. The asynchrony between the carbon emission and sequestration has to led to concerns about the carbon neutrality of forest based bioenergy production in the short run (IEA. 2014).
The potential stress due to growth in bioenergy sector can have social implications, especially in developing countries where large numbers of people depend on agriculture and forests for their livelihood. However, the growth in bioenergy sector should not necessarily lead to stress on natural resources. There are many technological options that can handle wide variety of feedstock other than energy and agricultural crop. The lignocellulosic feedstock can be sourced from agricultural and forest residues that would not require additional use of water and land. Such feedstocks may not cause any stress if the excess amount is not extracted from the farmland and forests. The lignocellulosic feedstock can be cultivated on some suitable marginal and degraded land which in turn may contribute to water retention by reducing the rainfall evaporation.

**Land Use Change**

Higher demand for biomass feedstock may stimulate increased production. Higher demand from bioenergy industry may be achieved through intensification and extensification of bioenergy feedstock crops. Extensification involves additional land being brought into feedstock production use which may lead to increased GHG emission and loss of biodiversity (McCarl and Plieninger 2008). Various studies have substantiated the argument that land use change presents an environmental risk that may be heightened by bioenergy growth. The land use change transpires through clearing of forest land, displacement of food crop to produce a bioenergy feedstock crop, which in turn contributes to increase in prices of displaced food items. The increased GHG emission through extensification and clearing of forests and grassland are generally not included in the net carbon benefit of bioenergy use. However, the extent of “leakage” is poorly understood and the causes of land use change are complex (Florin and Bunting 2009). The promotion of bioenergy without considering its potential impact on agricultural and land use practices may result in adverse social impact. If the bioenergy feedstock
crops become very profitable, industrial scale production and land consolidation may further marginalize small land owners and farmers in developing countries. The displacement of food crop in favor of bioenergy feedstock in developed world may lead to expanded food crop production in the developing world, leading to increased GHG emission. These concerns reflect a well-documented argument that higher commodity prices and agricultural land related policies have effect on environment.

**Energy vs. Food**

The trade-off between energy and food is closely related with land use changes in response to feedstock demand from bioenergy industry. While all types of bioenergy interact with agriculture and forest product markets through the feedstock demand, the impact of liquid biofuel has raised more concerns in recent years. There is a wide range of estimates about the extent of the impact of biofuel production on food supply and prices that vary from as little as 3% (USDA 2008) to as high as 75% (Mitchell 2008). The diversion of corn from food market to production of ethanol has been a matter of debate in the US and elsewhere. The competition for usage of land for bioenergy feedstock, food production, and forestry can potentially raise the prices of some commodity. Rising food prices is a special concern for the developing and least developed countries. Although, the extent of rise in the food crops is debatable, however the rise in the food prices has indeed coincided with the growth in the bioenergy in recent years, leading to public perception as bioenergy being the chief cause. The counter argument (Florin and Bunting 2009) is that most of the world poor derive their income from the agricultural activities; therefore increase in the prices of agricultural items should enhance their income and reduce the poverty. However, this argument fails to take into account the urban poor.
Social Acceptance

Globally, the energy sector including bioenergy has to engage with public perception and social acceptance. The increasing public concern regarding the sustainability and environmental impact of current biofuel production and use may lead to an adverse perception of bioenergy industry in general. Currently, public opinion about bioenergy and biofuels in particular is polarized between those supporting it and those criticizing its potentially negative effects. The social acceptance has three interacting dimensions:

- Socio-political acceptance
- Community acceptance
- Market acceptance

The socio-political acceptance relates with acceptance of the industry and technology by public, key stakeholders, key policy-makers. The community acceptance relates with the trust and perceived distributional and procedural justice involved with the promotion of bioenergy industry. The market acceptance relates with the stance of consumers, investors and entrepreneurs towards bioenergy industry (Wüstenhagen, Wolsink et al. 2007).

General Lessons for Bioenergy Policy Making


1. The policy-making process for bioenergy is most effective if it is undertaken as a part of long-term vision for the industry. The vision should be based on the specific national and regional opportunities and strengths, availability of feedstock, state of the supporting
infrastructure, and the strength of related industries. All successful bioenergy policies tend to harness opportunities that are at least partly domestically available.

2. Bioenergy policies tend to be effective if they are specified for longer term and appear to be continuous. The bioenergy policy should aim for credibility, enforceability, simplicity, transparency, and predictability. This implies that policy making should endeavor to consider as many key factors affecting the bioenergy industry from the start. This does not imply that all policy measures need to continue indefinitely, however a clearly specified duration of the policy regime improves the policy predictability.

3. Bioenergy policies should account for the maturity of available bioenergy technologies, and provide for incentives that are consistent with the development stages of technologies. For example: bioenergy units based on different technologies have different split between capital and variable costs, the incentives should address the specific cost profiles of promising technologies.

4. Policies should provide a mechanism for access to market for various bioenergy technologies. For bio-based electricity access to grid is critical. In the initial stage of development of the industry, electricity distribution utilities may be incentivized to provide bio-based electricity units with access to market.

5. The consistent supply feedstock is critical for all bioenergy technologies. Policies should take into account the sources of feedstock; for example: agriculture and forests, the related productivity and trade-offs: food vs energy for agriculture and biodiversity vs energy for forests.

6. A successful bioenergy strategy has to consider sustainability issues related with the industry. Since sustainability linkages of the bioenergy industry are complex; the
interaction between land use change, biodiversity, water use, forest degradation, economic development, fossil fuel prices requires an integrated approach for the long term success.

7. The understanding that bioenergy policies are merely precondition but not a guarantee for success of bioenergy industry is important. Other important factors such as regional culture, absence or presence of price distortions in domestic energy market, administrative abilities, technological services, social norms, and local infrastructure are likely to impact the industry.

8. The policy measure should take into account the social acceptance as well. All three interdependent dimensions of social acceptance, namely socio-political acceptance, community acceptance and market acceptance should be taken into account.

9. Capacity building policies and programs should be used in order to create an enabling environment for the promotion of the sector. Capacity building objectives should include development of good agricultural and forestry practices, information sharing and dissemination structures, education and research, and training. Generally, capacity building policies and program need long term resource commitment from the governments.

**National Goals and Targets for Renewable Electricity**

Globally, countries are at various stages of development of bioenergy policy framework ranging from those that merely acknowledge the desirability of bioenergy sector to those with decades of experience with policy making and promotional programs for bioenergy sector. Many Latin American countries have promulgated laws related with bioenergy production and consumption. Brazil initiated its biodiesel programs in 1970s. Asian countries began formulating policies and programs more recently. Europe has been most active in putting in place the entire
ecosystem of bioenergy framework— from national goals and mandates, policy instrument and programs to institutions responsible for implementations. North America has been able to put in place several policy documents and translate them to action on ground (Figure 11).

Renewable Energy Network Report (REN 21 2015) states that by early 2015, 145 countries had at least some renewable energy supporting policies (Figure 11). This number is over nine times higher than the 15 countries that had renewable energy policies in 2005.

![Figure 11 Global Regions with Bioenergy Policies (REN21 2015)](image)

In recent years, policy makers have focused more on adapting existing policies to changing circumstances, which include streamlining and combining different policy mechanism, linking various policy instruments related with electricity, heat, and transport sector. In recent years, policy makers are also more focused on increasing the share of renewable energy in the energy mix.

In 2014, European Union leaders agreed to a region-wide goal of 27% renewable energy share by 2030(EC 2014). By the year 2014, 164 countries had targets for renewable energy
sector. Some countries had targets for specific sectors: power, heating and cooling, and transportation, but most have set a general target for renewable energy (REN21 2015). In recent years, several countries have set or revised targets for power generation from renewables (Table 13). Japan, in 2014, set a national target of 13.5% by 2020 and 20% by 2030 of total electricity generation from renewables (METI 2014). China revised its targets related with wind, biomass, and solar PV to 150 GW, 30 GW, and 70 GW respectively (REN21 2015).

European countries remain at the forefront of revising their policies and targets by adapting to changing circumstances. Renewable Portfolio Standard (RPS) or Quotas establish mandatory targets for installed capacity of renewable electricity and sourcing by utilities from renewable power generators. There is a wide range of national ambitions in various parts of the world for renewable electricity that aims at replacing fossil fuel based electricity generation by 2% to 78% by renewable electricity. Sweden aims to be the first country in the world to be free from oil by 2020 (KPMG 2010). By the early 2015, 26 countries had Quota or RPS in place at federal (national) level including China, Israel, and the United Kingdom. Seventy-two states/provinces – including 27 states and 7 union territories in India and 29 states and 3 territories in the United States-also had put Quota or RPS in place. In the United States, RPS has emerged as a preferred policy instrument for renewable energy promotion at the state level (REN21 2015). Table 13 shows that, as far as setting national level goals and targets is concerned all three categories –high income, middle income, and low income – have adopted the practice. However, many countries, including developed ones, have not chosen to obligate electricity utility companies to buy electricity generated from the renewable resources. In fact, among the major upper middle income countries only China has Quota Obligations in place.
<table>
<thead>
<tr>
<th>Countries</th>
<th>Renewable Energy Targets (Binding)</th>
<th>Electricity Utility Quota Obligations (RPS)</th>
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<td>High Income Countries</td>
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O-Existing national (could also include state/provincial),
S-existing state/provincial (but not national), R-revised (indicates state/provincial)
Adapted from REN21 2015

**Programs and Policies for Renewable Electricity Promotion**

**Renewable Portfolio Standard (RPS) and Tradable Renewable Energy Certificates (RECs)**

Quota Obligations/Renewable Portfolio Standard (RPS) is a binding renewable energy target, embedded in legislation, requiring that a minimum percentage of generation sold or
generation capacity installed be provided by renewable energy. Obligated utilities are required to ensure that the target is met. (KPMG 2010). REC is a type of financial derivative that represents the rights to the environmental and social benefits of renewable electricity generation. RECs can be traded separately from the underlying asset, which is electricity, associated with a renewable based electricity generation. RECs help procure green power over distant geographical locations. The certificates provide the flexibility in applying renewable attributes of the electricity to any entity of choice. The flexibility offered by REC improves demand and deepens the market for renewable electricity (EPA 2015). The tradable attribute of the certificates create a market for renewable energy obligation among consumers and generators. RECs also enable voluntary renewable electricity purchase. Each certificate represents the certified generation of one unit of renewable energy (typically one megawatt-hour) (KPMG 2010).

**Feed-in Tariffs (FIT)/Premiums**

Feed-in Tariffs (FIT): A policy mechanism designed to encourage the adoption of renewable energy sources. It typically includes three key provisions:

1. Guaranteed grid access
2. Long-term contracts for the electricity produced
3. Purchase prices that are based on the cost of renewable energy generation (KPMG 2010)

Premiums: Premiums are granted to operators of eligible renewable electricity plants for the electricity they feed to the grid. They are typically preferential and technology-specific amounts paid to a producer on top of the current electricity market price and are regulated by the government (KPMG 2010).

The central idea underlying feed-in tariff policies is to provide guaranteed prices for a defined period of time for electricity generated from renewable sources. The offered feed-in-tariff can be differentiated on the basis of technology type, the installed capacity, the nature of feedstock or resource, project location, and other variables. The fact that FIT can be matched
with the specific context of renewable electricity project and secures the level of tariff; it considerably reduces the investment risk, thereby improving the conditions for market growth. The future cash flow security is particularly beneficial for capital intensive projects with high ratio of fixed to variable cost.

Premium price policy instrument is market dependent FIT in which a constant premium or bonus over and above the average retail price is offered to the electricity generator. The Premium instrument typically operates in deregulated electricity markets where the retail price for electricity is allowed to fluctuate depending on supply and demand. The fixed price FIT helps lower the investment risk for the renewable electricity projects. Premium price provides incentive to generate electricity according to the demand for it, therefore is better attuned to the market mechanism (Couture and Gagnon 2010).

As of 2014, 73 countries and 35 states/provinces in Australia, Canada, China, India, and the US were offering FIT to renewable electricity generators However, EU countries have begun to shift away from FIT to Tendering. All new project support to be allocated through renewable energy Tenders by 2017 (REN21 2015).

**Tendering/Bidding**

The tendering or bidding in the renewable energy context refers to a demand auction or procurement auction in which government invites tender or bids to install specified capacity of renewable electricity. The interested project developers submit bids with specified price for unit of electricity at which they are willing to install the electricity plant with required capacity. The government chooses the winner on the basis of the bids submitted by the developers, and enters into power purchasing agreement with the successful bidder (Lucas, Ferroukhi et al. 2013). In recent years tendering (Figure 12) is being considered as a more effective policy instrument than FIT. Table 14 shows policy instruments adopted by various countries. There exists a wide range
of choices for countries to design the tendering process, and large number of criteria-apart from price- for choosing a successful winner among various renewable electricity sources.

Some of the largest tendering procurements in recent years have occurred in emerging economies (Table 14), e.g., India, Russia, South Africa, Latin America (REN 21 2015).

**Net Metering**

Net Metering allows for the flow of electricity both to and from the customer. The customers who generate electricity for captive use can supply excess electricity to the grid, offsetting electricity drawn from the grid at different time (Doris, McLaren et al. 2009) Net Metering encourages distributed generation of electricity by various types of customers who may not be in the business of electricity generation by crediting the full retail electricity price for the excess electricity fed into the grid. Net Metering policies may vary by countries, states, and technology (Table 14).
Table 14 Policy Instruments used by Countries to Promote Renewable Electricity

<table>
<thead>
<tr>
<th>Countries</th>
<th>FIT/Premium</th>
<th>Net Metering</th>
<th>REC</th>
<th>Tendering</th>
<th>Capital Subsidy/Grant/ Rebate</th>
<th>Investment/Production tax Credit</th>
<th>Public Investment/Loan/Grant</th>
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(REN21 2015)
Komor et al. (Komor and Bazilian 2005) define goals/targets, programs, and RETs as

A goal is an explicit objective, intention, or purpose. An example of a RE related goal is electricity price stability. Synonyms include policy goal, policy aim, and policy objective. A program is a government measure, mechanism, or effort- a synonym is ‘policy instrument.’ An RE technology converts an RE resource into electricity.

The most important drivers of goals underlying the governments’ policy formulation efforts can be grouped under three categories- energy goals, environmental goals, or economic goals. Komor et al postulate the relationship between goals, programs, and RETs as linear; with goals in the beginning, and programs arising out of the goals designed to meet specific goals (Figure 13 & Table 15). There are three distinct interactions involved in the linear relationship between goals to RETs. First, between goals and programs: particular goals are better addressed by some program than other. Second, between goals and technologies- some goals can be met by any RET; however, other goals may necessitate more considered approach, for example: for a developing country the goal of increasing domestic employment may be addressed better by bioenergy than by wind in the short run.

Third, between programs and RETs- most programs can be designed to work for any RET. The Table 15 summarized the mechanism-demand pull, supply push, or other means-through which programs meet national goals. Table 15 specifies the effect of a particular program on specific goals. Some policies programs and instrument provide impetus on the supply side of the energy market and some others work from the demand side. In addition, as the table illustrates, some instruments provide incentives for or mandate GHG emission reduction.

As expected, a portfolio of policy programs and instruments is required for addressing three goals related with energy production, environment, and economic development.
**Energy Goals**
- Maximum energy generation
- Quality and sustainability of energy supply
- Low energy prices

**Environmental Goals**
- Sustainability
- GHG emission reduction

**Industrial /Economic Goals**
- Local and regional economic development
- Domestic Employment

**Bioenergy Programs**
- Industrial /Economic Goals
  - Supply Push: Competitive tender
  - Supply Push: Feed-in tariff
  - Supply Push: Production credit
  - Demand Pull: Renewable obligation
  - Demand Pull: Tradable renewable credits
  - Indirect Price Support: Carbon tax
  - Indirect Price Support: Emissions trading
  - Capital Support: Grants/tax incentives
  - Technical Standards/certifications
  - Information, education, and training
  - Improved planning process
  - Research, development, and demonstration

**Support for Bioenergy Technologies**

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Figure 13 Relationship between Goals and Programs (Komor & Bazilian, 2005)
Table 15: Short-term Relationship between Goals and Policies

<table>
<thead>
<tr>
<th>Energy Goals</th>
<th>Environmental Goals</th>
<th>Industrial/Economic Goals</th>
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<tbody>
<tr>
<td></td>
<td>Maximum Electricity Generation</td>
<td>Quality and Sustainability of Electricity Supply</td>
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<td>Supply push: competitive tender</td>
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<td>Supply push: feed-in tariff</td>
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<td>Supply push: production credit</td>
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<tr>
<td>Demand pull: renewable obligation</td>
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<td>Demand pull: tradable renewable credits</td>
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<td>Indirect price support: carbon tax</td>
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<td>Indirect price support: emissions trading</td>
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<td>Capital support: grants/tax incentives</td>
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<td>Technical standards/certifications</td>
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<td>Information, education, and training</td>
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<td>Research, development and demonstration</td>
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Key: ++: program very likely to help meet goal; +: program may help meet goal; 0: program will have little direct effect on goal; - : program may conflict with goal; -- : program likely to conflict with goal.

Adapted from Komor & Bazilian, 2005

Despite the charged nature of the debate around the role of governments in industrial development, the overriding concern about the climate change has tipped the scale in favor government’s role in promoting bioenergy sector. The role of government intervention is usually accepted across the countries and multi-lateral international bodies, while the extent of intervention and targeting of particular activities (term “picking winners” is commonly used in related literature) is still debated, the interventions that are aimed at improving functioning of market, especially factor market, is not.

The proposed evolutionary framework for bioenergy policy formulation for this study is based upon the model “Market Stimulating Technology Policies (MSTP)” presented by Lall and Teubal (Lall and Teubal 1998). The MSTP is a generic model (Figure 14) that can be used to construct a policy framework for promotion of a new technology based or nascent industry. Lall and Teubal explain the idea underlying the MSTP model as:

the mechanism of the market is one of the many ways of promoting an industrial sector. Others include institutions, associations and professional bodies, bureaucracies, hierarchies, and networks.

The specific conditions and context of a country determines the most effective mechanism to promote a particular industrial sector. Moreover, over a period of time the effectiveness of a mechanism may vary. Whereas direct or indirect mobilization or market mechanism maybe necessary in the contexts where market forces are likely to function better than the non-market ones, yet the optimal allocation of resource in the initial period may necessitate policy intervention.
Figure 14 MSTP Process-flow
(Adapted from Lall and Teubal 1998)
Lall and Teubal contend that the debate about the role of governments in industrial development does not adequately cover the range of economic considerations that underlie government intervention. They state that while the categories of functional and targeted interventions are useful, there is a need to consider a third category of intervention that lies between the other two. The MSTP model proposes three categories of government interventions.

Category I (Priorities): Setting national priorities for industrial and technological development in a broader context of economic and social objectives. This level of government intervention, involves specification of broad national objectives that relate with the industry in question and its importance to the socio-economic development of the country. Within the purview of priority setting at this level is also included the establishing goals and priorities in innovation, technology, and economics of the industry.

Category 2 (Policy and Incentives): Providing signals to economic agents for industrial or technological activity where markets fail to do so adequately. The signalling process involves formulation and implementing policies at a broader program level. In this category governments may deploy “horizontal policies” and “vertical policies” to promote an industry. Horizontal policies go beyond the functional level and try to promote activities across several sectors (Table 16). For example: policies that benefit research & development institutions involved with energy sector including electricity transmission, transportation, development of information infrastructure, trading of energy derivatives etc.

Vertical policies are targeted at a selective set of activities within a particular industry (Table 17). Lall and Teubal argue that development of a particular industrial sector would involve a mixture of horizontal and vertical polices, the mix varying with the specific context of the country.
Category 3 (Institutions): Generating non-market mechanisms, institutions and organizations, including policy mechanisms, to underpin the previous two categories. This level involves the establishment and selection of institutions that would implement the priorities set at the first level through the incentives and other mechanism structured at the second level.

Table 16 Horizontal Policies

<table>
<thead>
<tr>
<th>Examples of Horizontal Policies</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grants for enterprise R&amp;D</td>
<td>Israel, Singapore, Korea</td>
</tr>
<tr>
<td>Support of R&amp;D personnel in SMEs</td>
<td>Germany in the 1980s</td>
</tr>
<tr>
<td>Teaching company scheme</td>
<td>UK</td>
</tr>
<tr>
<td>Broad technology support to SMEs</td>
<td>Most advanced countries and many developing countries</td>
</tr>
<tr>
<td>Promotion of technology transfer</td>
<td>Korea, Japan</td>
</tr>
<tr>
<td>Support of cooperative pre-competitive consortia</td>
<td>Israel, EU, Japan and several other advanced countries</td>
</tr>
</tbody>
</table>

Table 17 Vertical Policies

<table>
<thead>
<tr>
<th>Examples of Vertical Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidization and credit allocation for capital-intensive investments</td>
</tr>
<tr>
<td>Restricting FDI to build up local capabilities</td>
</tr>
<tr>
<td>Guiding or subsidizing MNCs to enter targeted activities or conduct R&amp;D</td>
</tr>
<tr>
<td>Targeting strategic technologies for promotion in national laboratories</td>
</tr>
<tr>
<td>Financing private R&amp;D in selected technologies</td>
</tr>
<tr>
<td>Targeting enterprises for R&amp;D support in particular technologies</td>
</tr>
<tr>
<td>Subsidizing joint R&amp;D by enterprises and institutions in specific areas</td>
</tr>
<tr>
<td>Building R&amp;D institutions in selected activities</td>
</tr>
<tr>
<td>Providing subsidized credit for upgrading selected activities</td>
</tr>
<tr>
<td>Intervening in technology transfer processes to build specific capabilities</td>
</tr>
</tbody>
</table>

(Lall and Teubal 1998)

Applying MSTP Model to Bioelectricity Policy Framework in India

Energy Dynamics in India

India has been one of the fastest growing economies in the world for the past two decades. India’s development goals include poverty alleviation, economic equity, and rural development. For any country, energy is a critical input for economic development and poverty alleviation (Toman and Jemelkova 2003). India’s sustained Gross Domestic Product growth rate above 7% in recent years has placed enormous demand on its conventional energy resources. For
India, demand and supply imbalance in energy sources used in production of electricity is worsening. On the supply side, India imports about 80% of its crude oil (GoI 2011). Crude oil imports are likely to continue to growth, creating serious problems for India’s future energy security. Coal based thermal power projects produce 70% of the entire supply in India (Figure 15).

![Figure 15 Generation Mix of Electricity, India (IEA. 2012)](image)

Although, India has abundant coal resources, however the impact of coal-fired electricity generation growth on CO₂ emission is a cause of concern. Despite its large reserves of coal, India experienced coal shortages in recent years; because of low productivity of monopolistic public sector coal supply companies. Consequently, India has had to rely on expensive coal imports.

Factors such as economic growth, growing population and urbanization, rise in per capita energy consumption, and improving access to energy are likely to substantially increase the total demand for electricity. However, in the last two decades (1994-2014) growth in demand for
power has outstripped the growth in power capacity installation. Even the new electricity generation capacity building is still largely coal dependent (Figure 16). Already, in the electricity sector, official peak deficits are of the order of 12.7%, which could increase over the long term (MNRE 2013). Addressing the imbalance requires serious efforts by government agencies, research organizations, finance community and other stakeholders. Other sources of electricity such as: hydro, gas, nuclear etc. have also not kept pace with the growth in power demand (GoI 2011).

![Figure 16 Electricity Generation by Non-fossil Fuels, India](IEA. 2012)

Significant accretion of gas reserves and production in recent years is likely to mitigate demand-supply gap only to a limited extent. Popular protest against large hydro power projects and nuclear power has made such projects commissioning impossible. India therefore faces severe conventional energy supply constraints (Bhide and Monroy 2011).

**Renewable Energy: National Goals and Priorities**

Historically, biomass has been a major source of energy for households in India. A major share of Indian rural population is energy poor. Energy poverty, indicated by the lack of access
to electricity and other forms of modern energy, is a direct outcome of income poverty and absence of energy sources (Coninck, Kets et al. 2012). Biomass meets the cooking energy needs of 84% of rural households and half of the urban households (Balachandra 2011).

India began its energy planning and program interventions way back in 1940s with programs for promoting biogas and the improved cook-stoves. The rural electrification programs have been around since the 1950s. However, since the oil crisis of 1973, the efforts to improve energy economy became much more organized. The Department of Non-Conventional Energy Sources was established in 1982 which was subsequently renamed as Ministry of New and Renewable Energy (MNRE). MNRE is the nodal agency of Government of India at the federal level for all policies and programs related with renewable energy. MNRE has put together a Strategic Plan for the period 2011-17 and perspective till 2022(MNRE 2011). In the strategy document MNRE states its mission and vision statements as:

- To upscale and mainstream the use of new and renewable energy sources in furtherance of the national aim of energy security and energy independence with attendant positive impact on local, national and global environment.
- Develop, demonstrate and commercialize technologies for harnessing new and renewable energy sources in close concert with corporate, scientific and technical institutions.
- Replace use of different fossil fuels wherever possible, and increase access to electricity/ lighting in remote and rural areas, through Renewable Energy Systems.
- Increase the contribution of Renewable Energy in the total energy mix of the country to 6 per cent by 2022, with about 10 per cent contribution to total electricity mix.
  - To promote renewable energy initiatives for meeting energy/lighting needs in urban and rural areas and supplementing energy needs in industry and commercial establishments
- To promote deployment of grid-interactive renewable power generation projects
- To promote research, design and development activities at premier national institutions and industries on different aspects of new and renewable energy technologies and help development of new products
- To encourage development of a robust manufacturing industry in renewable energy sector
The strategy document also provides a list of objectives and targets (Table 18).

Table 18 Year-wise Targets for Grid interactive RE Power (2011-17)

<table>
<thead>
<tr>
<th>Year</th>
<th>Biomass / Agri-waste(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative (up to 31.03.11)</td>
<td>1025</td>
</tr>
<tr>
<td>2011-2012</td>
<td>100</td>
</tr>
<tr>
<td>2012-2013</td>
<td>80</td>
</tr>
<tr>
<td>2013-2014</td>
<td>80</td>
</tr>
<tr>
<td>2014-2015</td>
<td>80</td>
</tr>
<tr>
<td>2015-2016</td>
<td>80</td>
</tr>
<tr>
<td>2016-2017</td>
<td>80</td>
</tr>
<tr>
<td>Period Total</td>
<td>500</td>
</tr>
<tr>
<td>Cumulative Total</td>
<td>1525</td>
</tr>
</tbody>
</table>

(MNRE, 2011)

Legal and Institutional Framework

The Electricity Act (EA) 2003 is the key legislation for the bioelectricity sector. EA 2003 mandates State Electricity Regulatory Commissions (SERCs) in various states to take steps to promote electricity generation from renewable resources in their respective states. SERCs are responsible for providing bioelectricity generators access to the grid, guiding public sector distribution utilities for resourcing electricity from bioelectricity units (Table 19). EA 2003 also provides for National Electricity Policy (NEP), National Tariff Policy and plan which aims, among other goals, at optimum utilization of renewable resources for electricity generation.

National Tariff Policy (NTP) 2006 provides for a minimum percentage (10%) of renewable electricity procurement by the distribution utilities. It also mandates SERCs to provide preferential tariff for renewable electricity generators. NTP 2006 also provides for competitive bidding by renewable electricity generators. As stated earlier, MNRE is the main nodal ministry that guides policy and regulations related with bioenergy in India. MNRE coordinates with Ministry of Oil, Ministry of Transportation, and other regarding biofuel policy of India, and for bioelectricity with Ministry of Power.
<table>
<thead>
<tr>
<th>Levels</th>
<th>Central Government Ministry of Power/Ministry of Finance</th>
<th>MNRE</th>
<th>CERC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Central/Federal Level</strong></td>
<td>Develops national electricity tariff policies, which also cover renewable energy</td>
<td>Develops national renewable energy laws Sets technical standards for renewable energy Conducts resource assessments for renewable energy; supports R&amp;D in renewable energy technologies Promotes effective use of information technology for renewable energy, manages database Reviews renewable energy programs to understand their effectiveness and efficiency</td>
<td>Sets guidelines for feed-in tariff design for different renewable energy technologies Regulates the regional electricity corporation mechanism Regulates interstate open access, and third-party sales</td>
</tr>
<tr>
<td></td>
<td>Provides fiscal incentives for promoting renewable energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>State Level</strong></td>
<td>State government</td>
<td>State Nodal Agency</td>
<td>SERCs</td>
</tr>
<tr>
<td></td>
<td>Develops state level renewable energy policy</td>
<td>Conducts resource assessments for various renewable energy sources Allocates renewable energy projects and progress monitors Provides facilitation services to project developers - IREDA personnel escort project developers to various government departments with the objective of facilitating and streamlining clearances Facilitates clearances and land acquisition</td>
<td>Develops feed-in tariff methodologies for different renewable energy technologies Determines RPOs and enforcement mechanism Sets regulations on intrastate wheeling, open access, and third-party sale</td>
</tr>
<tr>
<td></td>
<td>Provides fiscal incentives for promoting renewable energy sources</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Krithika and Mahajan 2014)
MNRE coordinates with the Ministry of Environment and Forests (MoEF) for environmental clearances for renewable energy projects. Since, this research is mainly focused on bioelectricity; the following section describes legal and institutional framework governing bioelectricity in India. The broad goal of MNRE is to promote and deploy new and renewable energy resources and support research and development in the related technology areas. MNRE has set up many research institutes such as Solar Energy Center, Center for Wind Energy Technology and Sardar Swaran Singh National Institute of Renewable Energy for bioenergy.

The federal bodies have state level nodal agencies in various states that coordinate with respective state governments for the implementation of various programs, schemes, and incentives. These nodal agencies channel federal level incentives, subsidies, and public investments in renewable energy projects in their respective states. The financial arm of MNRE—the Indian Renewable Energy Development Agency (IREDA) - provides financial assistance, loans to the state level projects.

Government of India and MNRE provide and offer various tax and non-tax incentives and schemes to promote renewable energy technologies. Table 20 shows various vertical polices and Table 21 shows some horizontal policies adopted by central and state governments.

<table>
<thead>
<tr>
<th>Vertical Policies/Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apart from various schemes and incentives (FIT, RPO,REC, tax benefits) MNRE is focused on:</td>
</tr>
<tr>
<td>• Areas with surplus biomass wastes (esp. rice husk, pine needles) for rural electrification/meeting unmet electricity demand.</td>
</tr>
<tr>
<td>• Promoting gasifiers for meeting captive energy needs of industry, especially rice mills.</td>
</tr>
<tr>
<td>• Encouraging Energy Servicing Companies (ESCOs), Co-operative, NGOs, Local bodies etc. availing the subsidy and balance as bank loan, equity etc.</td>
</tr>
</tbody>
</table>
Table 21 Horizontal Policies, India

<table>
<thead>
<tr>
<th>Horizontal Policies/Programs</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical capacity and skills sets</td>
<td>Research and training institutions establishment</td>
</tr>
<tr>
<td>Channels and institutional arrangements for project development and technology deployment</td>
<td>Enhancing capability through workshops, training programs Support for revenue generation activities through Public Private Partnership project</td>
</tr>
<tr>
<td>Enhancing organization capability and strength</td>
<td>Strengthening of the current Manpower and recruiting younger scientists in various nodal agencies</td>
</tr>
<tr>
<td>Equipment manufacturers and technology</td>
<td>Support available in demonstration projects in emerging technologies in partnership with private sector Results-oriented fiscal incentives rather than R&amp;D grant</td>
</tr>
<tr>
<td>Data and information capture and dissemination</td>
<td>Biomass Atlas development- satellite based remote sensing data capture for biomass availability</td>
</tr>
</tbody>
</table>

Table 22 classifies specific programs and instruments into four categories: price, quantity, capital investment, and others.

**Status of Bioelectricity in India**

MNRE sponsored biomass potential assessment project- Biomass Resource Atlas of India estimates the biomass based electricity generation at 16,000 MW per year (MNRE, 2013). According to MNRE data, until 2013, the installed capacity for bioelectricity in India was only 1220 MW. This is merely 7.6% of the total potential. Even this number is contested by various researchers on accounting of recent closure of several bioelectricity facilities. Out of all the biomass resource, only paddy husk, mustard crop, and cotton residues are widely used as feedstock for electricity generation. Other important resources such as paddy straw, wheat straw, forest residues remain underutilized. MNRE estimates that if 50% of the waste and degraded land of the country can be used for energy plantation, additional 30,000 MW can be generated.
However, energy planation in India is yet to take off. According to the Department of Land Resources (DoLR) of India, there is 63.9 million hectares of wasteland in India.

<table>
<thead>
<tr>
<th>Programs/Instruments</th>
<th>Bioenergy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targets</strong></td>
<td>*</td>
</tr>
<tr>
<td><strong>Price-based Instruments</strong></td>
<td></td>
</tr>
<tr>
<td>Feed-in tariff</td>
<td>•</td>
</tr>
<tr>
<td>Generation-based incentives</td>
<td>0</td>
</tr>
<tr>
<td>Concessional wheeling charges for captive users</td>
<td>•</td>
</tr>
<tr>
<td>Net metering</td>
<td>•</td>
</tr>
<tr>
<td>Banking</td>
<td>•</td>
</tr>
<tr>
<td>Carbon market/CDM transactions</td>
<td>•</td>
</tr>
<tr>
<td>Renewable energy certificates (REC)</td>
<td>•</td>
</tr>
<tr>
<td><strong>Quantity-based Instruments and Procurement Mechanisms</strong></td>
<td></td>
</tr>
<tr>
<td>Renewable purchase obligation (RPO)</td>
<td>•</td>
</tr>
<tr>
<td>Competitive bidding/auctions</td>
<td>•</td>
</tr>
<tr>
<td>Investment Cost Reduction/Financial Incentives</td>
<td></td>
</tr>
<tr>
<td>Accelerated depreciation</td>
<td>•</td>
</tr>
<tr>
<td>Green funds (e.g., soft loans, grants)</td>
<td>•</td>
</tr>
<tr>
<td>Capital subsidy</td>
<td>0</td>
</tr>
<tr>
<td>Equity participation</td>
<td>•</td>
</tr>
<tr>
<td>Tax exemptions</td>
<td>•</td>
</tr>
<tr>
<td>Custom/excise duty exemption</td>
<td>•</td>
</tr>
<tr>
<td>Grid connection and dispatch</td>
<td>•</td>
</tr>
<tr>
<td><strong>Other Measures</strong></td>
<td></td>
</tr>
<tr>
<td>R&amp;D funds</td>
<td>•</td>
</tr>
<tr>
<td>Single window clearance systems</td>
<td>•</td>
</tr>
</tbody>
</table>

Notes: •- Exist/ 0 -Absent

*Targets do not exist as part of a policy or a mission objective, but exist under Annual Plans of MNRE.
Adapted from (Azuela and Barroso 2011)

Most of such wastelands are classified as common property resources, collectively owned by indigenous people and villages with exclusive rights to access to the land. Ballabh et al.
Ballabh, Balooni et al. 2002) argue that scarcity of agricultural land and the economics of bioenergy crop cultivation for feedstock are considered a threat to both food production and forest biodiversity in India.

In the context of biofuel production in India, TERI (TERI 2015) reports that despite the mandatory target for ethanol at 20% by 2017, the compliance remains abysmal. As of July 2014, only 1.37 % blending of ethanol with petrol had been achieved. The competing usage of ethanol by liquor, chemical, and sugar industry is cited as main reason for low blending rates.

Natarjan et al. (Natarajan, Latva-Käyrä et al. 2015) report about missed targets and closure of bioelectricity facilities in the states of Madhya Pradesh, Tamil Nadu, and Maharashtra. The state Madhya Pradesh had set a target of achieving an installation base of 300 MW by 2014 for bioelectricity. By the end of 2013, the state had installed only 59 MW. Many planned units had not even begun the construction process because of unfavorable market conditions; many others had shelved the project. The state of Maharashtra is also experiencing similar situation, against the target of 400 MW, only 180 MW (18 plants) had been installed by the end of 2013. Out of 18 plants, 11 have temporarily or permanently shut down. The state Tamil Nadu had an installed capacity of 177MW (19 plants), half of the plant and 80% of the installed capacity is either shut down or struggling because of unavailability of feedstock, unfavorable market conditions. A UNDP review of state of bioelectricity industry in India in 2011 (Marcial T. Ocampo 2011) had reported that the industry was struggling. The review pointed out that financial delivery- government assistance and support- was very low. Controller and Auditor General of India (CAG 2015) in its audit of MNRE and state nodal agencies found several shortcomings. CAG found variations in assessment of bioelectricity potential between MNRE and state nodal agencies (SNAs) (Table 23).
Table 23 Estimated Potential and Achievement (Grid Connected) for the States Biomass Potential, as of March 2014 (MW)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>State</th>
<th>Potential</th>
<th>Achievement</th>
<th>Exploitation (in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rajasthan</td>
<td>4,595</td>
<td>101</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Punjab</td>
<td>2,675</td>
<td>140</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Maharashtra</td>
<td>1,585</td>
<td>940</td>
<td>59</td>
</tr>
<tr>
<td>4</td>
<td>Uttar Pradesh</td>
<td>1,478</td>
<td>776</td>
<td>53</td>
</tr>
<tr>
<td>5</td>
<td>Haryana</td>
<td>1,261</td>
<td>45</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Madhya Pradesh</td>
<td>1,065</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Gujarat</td>
<td>1,014</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>13,673</td>
<td>2,074</td>
<td>15</td>
</tr>
</tbody>
</table>

(MNRE 2013)

Except for two states- Punjab and Rajasthan-SNA’s assessment were significantly higher than those of MNRE. CAG reports that no efforts were made by MNRE to reconcile their potential assessment with that of the SNAs so that efforts could be made to concentrate on the States having high potential, although in some cases variation was very high; for example In Rajasthan, this difference was more than 3,500 MW. CAG also reported that estimates of Indian Institute of Science differed significantly from those of MNRE and SNA. CAG concludes by stating that estimates by MNRE and SNAs may not be correct and scientific.

CAG also found variations in capacity installation as reported by MNRE and SNAs (Table 23). CAG noted that “Sixteen States had not fixed any targets for exploitation of biomass potential during 2007-14. However, seven of these 16 States still reported capacity creation and in the case of Uttar Pradesh and Tamil Nadu it was substantial.” However, Natrajan et al. found separately that 80% of the Tamil Nadu’s and around 50% of Maharashtra’s installed capacity was not functional as opposed to the number reported by MNRE (Tables 24). CAG further notes that: “Of the eight States which had fixed targets for themselves, in six there were shortfalls in achieving the targets.
Table 24 Targets and Achievements Reported by SNAs and MNRE in Creation of Installed Capacity as on 31 March 2014 (unit MW)

<table>
<thead>
<tr>
<th>State</th>
<th>SNA Perspective</th>
<th>MNRE Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Targets</td>
<td>Achievement</td>
</tr>
<tr>
<td>(ii)</td>
<td>(iii)</td>
<td>(iv)</td>
</tr>
<tr>
<td>Andhra Pradesh³</td>
<td>No targets</td>
<td>468</td>
</tr>
<tr>
<td>Arunachal Pradesh</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Assam</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Bihar</td>
<td>10.02</td>
<td>8</td>
</tr>
<tr>
<td>Chhattisgarh</td>
<td>No targets</td>
<td>260</td>
</tr>
<tr>
<td>Gujarat</td>
<td>No targets</td>
<td>31.2</td>
</tr>
<tr>
<td>Haryana</td>
<td>242</td>
<td>60.9</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Jammu &amp; Kashmir</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Jharkhand</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Karnataka</td>
<td>581</td>
<td>613</td>
</tr>
<tr>
<td>Kerala</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>296.85</td>
<td>12</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>1,605</td>
<td>1,245.5</td>
</tr>
<tr>
<td>Meghalaya</td>
<td>No targets</td>
<td>Nil</td>
</tr>
</tbody>
</table>
(Table 24 continued)

<table>
<thead>
<tr>
<th>State</th>
<th>SNA Perspective</th>
<th>MNRE Perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Targets</td>
<td>Achievement</td>
</tr>
<tr>
<td>(ii) (iii) (iv) (v) (vi) (iv-vi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mizoram</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Nagaland</td>
<td>No targets</td>
<td>Nil</td>
</tr>
<tr>
<td>Odisha</td>
<td>No targets</td>
<td>20</td>
</tr>
<tr>
<td>Punjab</td>
<td>1,100</td>
<td>105</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>322</td>
<td>70</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>No targets</td>
<td>870</td>
</tr>
<tr>
<td>Uttar Pradesh</td>
<td>No targets</td>
<td>1,142</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>No targets</td>
<td>52</td>
</tr>
<tr>
<td>West Bengal</td>
<td>595</td>
<td>85</td>
</tr>
</tbody>
</table>

(CAG 2015)

The shortfalls were as high as 96% in Madhya Pradesh, 86% in West Bengal and 90% in Punjab and Rajasthan.” The report goes on to add that MNRE and SNAs have made no effort to reconcile the variations in their reporting about achievements of capacity installation. CAG after taking into account the explanation offered by MNRE for several variations notes:

MNRE stated (July 2015) that the variation was due to difference in capacity addition of sugar mills of the States, biomass availability, financial tie up, interest rate, State Government policies and tariff announced by State Electricity Regulatory Commission (SERC). The reply is not tenable as the audit observation is on variation in reporting of targets and achievement by MNRE and States, which should have been reconciled.
Based on the audit of MNRE and SNAs by CAG it can be concluded that although India has a comprehensive policy framework in place for bioelectricity sector, this fact has not translated into significant development of the industry.

**Causes of Underperformance of Bioelectricity Sector in India**

New technology industries do not develop in isolation; they are product of interaction between firms, government, research institutions, educational institutions, and other intermediaries. Legal and regulatory institutions largely frame rules or code of conduct for the industry that reduce uncertainty. The interaction between several entities takes place within the bounds of such framework of rules and codes. The interactions between heterogeneous entities could be suboptimal leading to imperfect outcome for the industry (Figure 17). In the context of bioelectricity sector in India, following sectoral imperfections may be contributing to the suboptimal outcome for the industry.

Higher unit cost of bioelectricity compared with fossil fuel based electricity: The coal based electricity capacity constitutes 70% of the total electricity generation of capacity of India. Vast domestic reserves of coal enable lower marginal cost of electricity. Moreover, supply-chain form coal based electricity generation has been established and operating for a long time, whereas, supply-chain for bioelectricity generation is non-existent. The competing uses of the feedstock also contribute to higher asking price for feedstock.

Infrastructural issues: In many rural areas of India, transportation of feedstock over longer distance can substantially add to the cost of operation for bioelectricity facility. Lack of appropriate transportation vehicles for feedstock hauling and poor road network keep the market for feedstock strictly local. Poor science and technology training facilities in most areas reduce the supply of trained and skilled human capital.
Figure 17 Causes underlying Underperformance of Bioelectricity Sector in India
Capability deficit: The promotional policies and schemes have failed to establish vibrant equipment manufacturer base. There not many scientist and engineers working on new design of gasifiers, digesters, catalysts etc. in the country. The capacity deficit ensures slower rate of innovations and adoption of the renewable technology.

Market distortion: Electricity market is riven with complex cross subsidization in every state. Farmers generally pay very low rate on electricity. The farmers are subsidized by higher rate charged from the industry. Urban households are also marginally subsidized by industrial users. Consequently, most public sector utilities are riven with revenue shortfall and accumulated shortfall that results in delayed payment to bioelectricity generators for the electricity fed into the grid.

Institutional and governance deficit: Promotion of bioelectricity industry interacts with social issues such aspect such as persuading farmers and villagers to supply feedstock to the bioelectricity units. Since most farmers in India have small landholding, a social cohort of feedstock cohort needs to be formed. Often persuading large number of farmers is difficult. Bioelectricity generation impacts water and forest ecosystem, potential harmful impact often lead to mistrust among people living in the vicinity. Several laws related with forest uses, agricultural land, water uses, and environment are not streamlined with the goal of promoting bioelectricity industry. For example: Forest Rights Act, 2006 gives indigenous people exclusive rights to extract minor forest products and residue from the forest.

Finance and Capital Cost: Despite the presence of IREDA, most bioelectricity generators find it difficult to raise fund for working capital and capital investment. Ones that manage to raise fund, do so at a relatively high cost, because bioelectricity sector remains an unproven enterprise.
Chapter 3: Financial Evaluation under Uncertainty of a Pine Needle Gasification Project in Uttarakhand, India

Introduction

Bio-based power production in India has not matched up to its estimated potential despite its documented and demonstrated potential in rural electrification. In India, biomass based technologies such as biomass gasification have not been able to achieve a market breakthrough comparable to other renewable energy technologies, such as wind turbines and small scale hydro power plants. The slow development of bio-based power projects is often attributed to a variety of barriers or conditions that prevent investment in in the projects. The barriers have put bio-based power production at an economic, regulatory, and institutional disadvantage relative to other forms of energy generation technologies. Barriers facing bio-based power in general and biomass gasification in particular include subsidies for conventional forms of energy, high initial capital costs coupled with feedstock price and supply risks, imperfect capital markets, lack of skills and information, poor market acceptance, technology prejudice, financing risks and uncertainties, high transactions costs, variety of regulatory and institutional factors and poor financial resources of rural households.

Several studies have identified technical as well as non-technical barriers facing the renewable energy technologies. This study is focused on power production from biomass gasification. Biomass gasification power projects (BGPP) share many barriers with other renewable energy technologies such as: higher initial cost, high transaction costs, and poor creditworthiness of projects due to various uncertainties. Financial institutions are used to appraising projects which improve financial top-lines and bottom-lines in familiar business situations. Because of non-existent historical data for BGP, many important variables required for project appraisal techniques such as; Net Present Value (NPV) and Internal Rate of Return
(IRR) cannot be used. In absence of financial assessment of BGPP, financial institutions hesitate to extend necessary funds to the projects. This study attempts to posit a base-line methodology for evaluating BGPP projects in absence of historical data. In order to evolve the methodology a case study of Pine Needle Gasification Project (PNGP) in Uttarakhand state of India is considered.

**Study Area: Uttarakhand**

Carved out of a larger state Uttar Pradesh in the year 2000, Uttarakhand is one of the newer states of India. Ninety-three percent of the state’s geographical area of 53,485 square km is mountainous. According to State of Forest Report, India (MoEF), approximately 34,650 square km area is under forest cover. The recorded forest area constitutes 64.8% of the total geographical area, although the actual cover based on remote sensing and satellite imagery information is only 44%(FSI 2011). According to Census 2011, 5.13 million males and 4.94 million females constitute the state population. The overall literacy rate of the state stands at 79.6% comprising 88.3% literacy among males and 70.7% among females.

For 70% of the households in the region, agriculture is the primary source of livelihood. The average size of farm land holding is around 0.68 hectare in the hills and 1.77 hectare in the plains. Out of the 0.9 million farming households in the state, 88% are the small and marginal farming households owning less than 2 hectares of farmland. The subsistence nature of agriculture in the hill districts affords low and unstable annual income to rural households; this has contributed to substantial out-migration of male members from the family, leaving behind a large number of female-headed households. Approximately 36.5% of the population of the state lives below the poverty line (Bhagirath Behera 2011).

Each summer, people living near and within the forests of Uttarakhand brace themselves against forest fires that threaten their livelihood along with the forest ecosystem and biological
diversity. In 1999, a fierce fire raged through the forests of Garwhal and Kumaon regions in Uttarakhand. The NSRA (National Remote Sensing Agency), Hyderabad, reported that about 22.64% (5087 square km) of the forest area was burnt while about 1225 square km was severely affected that year. While the fire of year 1999 was devastating, smaller forest fire occur regularly (Joshi & Singh). Frequent fires increase opportunities for spread of invasive species which results in slower recovery for native plant species. Along with the reduced biodiversity, the forest fires threaten the livelihood of people dependent on forest for fodder, fuel, and water. The fires usually break out between February and June in the coniferous Chir Pine forests in the 1000-1800m elevation range. The combustible pine needles (PN) carpeting the forest floor are one of the chief causes of the forest fires. In the year 2006, AVANI attempted to put the fire-causing pine needles. (PN) to productive use by using pine needles as feedstock for a gasifier.

**Pine Needle Gasification Project (PNGP)**

AVANI is a non-profit entity operating in the Kumaon region situated in middle ranges of the Central Himalaya of Uttarakhand. Since its inception in the year 1997, AVANI has helped diffuse solar technology, encouraged water resource management, and initiated a natural textiles and paint enterprise in the region. It has also contributed to the social and economic development of rural communities through projects in healthcare and micro-finance. In 2006, in order to generate electricity for its campus, AVANI installed a captive 9 KW gasifier unit using pine needles as feedstock. The cost of this gasifier was approximately US$ 8000 (Rupees4.85 lakh). The 9 KW gasifier continues to generate 7.5 KW of electricity for the AVANI campus. Local villagers are employed by AVANI on a per kg compensation based pine needles (PN) collection activity. The successful and continuous running of the 9KW plant for more than 7years has encouraged AVANI to scale-up the pine needles (PN) gasification operation.
In this study a framework for evaluating AVANI’s scaled-up project—20 distributed units of 120 KW pine needles based gasifiers power units— is posited. These 20 gasifiers would be set up on a staggered basis over a 5 year period (Table 25). Since AVANI has successfully operated downdraft gasifiers for the past 7 years, this study too considers 20 units of 120 KW downdraft gasifiers. Another reason for choosing downdraft gasifiers for this study is that at least two gasifier manufacturers—Cummins India and Ankur Gasifiers—in India have agreed to customize the gasifier based on AVANI’s experience.

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants installed</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>New plants installed</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Plants operational</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

The project conceives setting up 20 gasifier units in different locations within the same region. AVANI regards setting up 20 distributed gasifier units a more viable proposition than setting up a 2.4 MW gasifier at one location. The literature related with RET based power projects in India (Buragohain, Mahanta et al. 2010) support setting up many smaller distributed units rather than one large unit. The frequently cited reasons underlying the support for smaller units include:

- Use of locally available biomass as feedstock
- Less dependence on transportation of biomass
- More community participation in supplying biomass therefore more social support and acceptability for the projects
- Lesser negative environmental impact

Setting up of a PNGP in the rural forest regions of the state Uttarakhand requires permission from the Van Panchayats of the region. A Van Panchayat is a village elected council for village community management purpose. The Van Panchayats regulate and monitor the use of the forest by members of the local community (Baland, Bardhan et al. 2010). Each PNGP unit
would have to persuade local villagers to collect and supply PN on a per kg compensation basis. AVANI, in the process of executing various other projects - irrigation, cleaner cooking fuel, and 9KW gasifier unit- has been successful in persuading local villagers in forming self-help groups for various purposes. AVANI is confident that it will be able to persuade villagers for PN collection activity for the scaled-up project as it was in running the 9KW gasifier unit.

The gasifier would have to sign a Power Purchase Agreement (PPA) with the state owned electricity distribution utility -Uttarakhand Power Corporation Limited (UPCL). A typical PPA includes among other terms and conditions - the tariff at which the electricity is to be fed into the rural grid, specification for escalation in tariff schedule, pre-specified periods for reconsideration of tariff, the time period for which PPA would remain applicable.

Apart from generation of electricity from renewable resource the PNGP would also help address another indicator of energy poverty in the region which is dominance of fuelwood based kitchens in the households of the region. The PNGP would generate bio-charcoal as a byproduct of the gasification process. The bio-charcoal is a more efficient cooking fuel than fuelwood villagers routinely extract from the nearby forests. The charcoal would significantly reduce the amount of time spent in gathering fuelwood from the forests. Since, fuelwood gathering activity is traditionally a domain of household children and women,(Bhatt and Sachan 2004) they will be able to devote the saved time on more productive purposes.

A 120 KW unit of gasifier can satisfy the cooking fuel needs of 175 households. According to the AVANI’s estimates, a household in the region can consume approximately 2 kg of bio-charcoal per day. At a price of USD 0.08 per kg, for a monthly outlay of USD 5 is a much cheaper option compared with LPG and kerosene, a price that households should be able to afford to buy enough bio-charcoal for its cooking needs. Weaning away of the villagers from
extraction of fuel-wood from the forests to bio-charcoal can help mitigate the forest degradation, and create a smoke-free household kitchen which is one of the chief causes of respiratory problems for women of the region.

**Literature Review**

Adams et al. (Adams, Hammond et al. 2011) identify and categorize barriers facing different stakeholders - farmers/suppliers, developers/owners of projects, primary end-users, and government/policy makers - of a Renewable Energy Project (RET) in the UK. Among many financial barriers, they identify uncertain development and operational costs as being significant barriers that developers and owners face. Rosch and Kaltschmitt (Rösch and Kaltschmitt 1999) identify non-technical barriers facing biomass gasifier projects in Germany, namely-difficulties with funding; financing and insuring; unfavorable administrative conditions; organizational difficulties; lack of knowledge and adequate flow of information; and negative perception and insufficient acceptance. In South-East Asian countries Prasertsan and Sajjakulnukit (Prasertsan and Sajjakulnukit 2006) find similar barrier categories as those in UK and Germany facing the bioenergy projects, namely-institutional, policy, technical, information, public support, and financial barriers. They further find that most bioenergy projects in the region are relatively new and small; hence their transaction costs are high. These projects are also regarded risky by the financiers; therefore projects find it difficult to raise requisite finance.

Wiser and Pickle in their review (Wiser and Pickle 1998) of financing process of renewable energy power projects in USA point out that cost of projects is highly sensitive to financing terms. Wiser et al. found that a key reason why RET policies are not very effective is that project development and financing process is ignored or misunderstood when designing and implementing renewable energy policies. They show that polices which do not improve the long term stability of the renewable energy power projects increase the financing cost and reduce the
effectiveness of the project. They recommend that policy makers acknowledge financing difficulties faced by the renewable energy developers. Owen (Owen 2006) finds similar barrier facing renewable energy in Australia. In regard to financial barriers, he points out that high initial cost and imperfections in market access to fund to be major elements of the barrier.

Reddy and Painuly (Reddy and Painuly 2004), based on a survey of policy experts, industry professionals and households in India, present a taxonomy (Table 26) of barriers faced by RET projects.

Table 26 Financial Barriers

<table>
<thead>
<tr>
<th>Elements</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic viability</td>
<td>Cost reduction in RETs needed</td>
</tr>
<tr>
<td>High discount rates</td>
<td>Incentives needed in the initial stages</td>
</tr>
<tr>
<td>High payback period</td>
<td>Project becomes unviable</td>
</tr>
<tr>
<td>Small market size</td>
<td>Economy of scale cannot be achieved</td>
</tr>
<tr>
<td>High cost of capital</td>
<td>Affects economic viability.</td>
</tr>
<tr>
<td>Lack of access to capital</td>
<td>Fewer projects hence competition and market efficiency suffer</td>
</tr>
<tr>
<td>Lack of access to credit to consumers</td>
<td>Reduces market size</td>
</tr>
<tr>
<td>High up-front capital costs for investors</td>
<td>Capital costs also go up due to increased risk perception, adverse effect on competition and efficiency</td>
</tr>
<tr>
<td>Lack of financial institutions and financial instruments that support RETs</td>
<td>RET ecosystem suffers, adverse effect on competition and efficiency</td>
</tr>
</tbody>
</table>

(Reddy and Painuly 2004)

Painuly et al. expanded the financial barriers facing the RETs in India into several elements and their effect on renewable energy sector (Table 27). Much of the scholarship related with the evaluation of RET based power projects list lack of financing and coherent policy framework as a result of uncertainties and lack of information underlying RETs. The absence of benchmarks and historical data about the operation of projects such as PN gasification renders the project evaluation task quite challenging.
<table>
<thead>
<tr>
<th>Barriers</th>
<th>Actors</th>
<th>Perspectives</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness and information</td>
<td>Organization</td>
<td>Access to information</td>
<td>Lack of specific, simple, and timely information makes it difficult to take the relevant decision</td>
</tr>
<tr>
<td>Financial and economic</td>
<td>Organizational and individual</td>
<td>Access to capital</td>
<td>Low income individuals and small firms cannot invest in RETs due to their high cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heterogeneity</td>
<td>A particular RET may be cost effective on an average, but the hidden costs (operation and management cost, inconvenience, and the costs associated with gathering, and analyzing information) may be high</td>
</tr>
<tr>
<td>Market</td>
<td>Organization</td>
<td>Market failure</td>
<td>Market for RETs is subject to imperfect competition with conventional technologies Uncertainty in future prices (both conventional as well as renewable)</td>
</tr>
<tr>
<td>Technical</td>
<td>Organization</td>
<td>Risk</td>
<td>Investment in RETs represent a higher technical or financial risk than conventional technologies</td>
</tr>
<tr>
<td>Institutional and regulatory</td>
<td>Organization</td>
<td></td>
<td>No institutional mechanism for RETs. Regulatory control of utilities (supplying conventional energy) leading to prices departing from marginal costs</td>
</tr>
<tr>
<td>Behavioral</td>
<td>Individual</td>
<td></td>
<td>Consumers resist change (not interested to shift from one technology to another) Constraints on time, attention, and the ability to process information leads to decisions that are not</td>
</tr>
</tbody>
</table>
Renewable Energy Project Evaluation

A critical difference in financial evaluation of RET power projects and that of conventional power projects lies in the degree of uncertainty in forecasting financial outcomes. Before a framework for financial evaluation of a biomass gasification project is proposed in this study, it would be useful to consider the range of methodologies deployed in evaluating projects based on various RETs including biomass gasification. Various renewable energy technologies are at different stages of evolution in terms of technological maturity and acceptability, maturity of supporting vendor network and value chain, and social and governmental support. The RET based power projects also differ in their respective drivers for economic and financial feasibility, however, financial evaluation of any project is invariably measured on financial outcomes such as: cash flows, various margins of profitability, and the state of balance sheet.

Menegaki (Menegaki 2008) provides a meta-analysis of the literature on valuation methods used in evaluation of renewable energy projects. Menegaki finds that most studies embed financial evaluation within a larger framework of environmental and social cost benefit analysis. A typical cost benefit analysis comprises following steps: definition of project (gainers and losers), identification of project impact (job creation, environmental impact), selection of economically relevant impacts (quantity of goods and services that provide positive utility), physical quantification of relevant effects (benefits, cash flows), monetary valuation of relevant effects, discount of cost and benefit flows, net present value analysis, and sensitivity analysis.

The emphasis of this study is not so much on the broad environmental and social cost benefit analysis; it is, instead, on the financial outcomes- cash flows, profit and loss, balance sheet, and valuation over the entire project life. Table 28 provides a list of frequently used valuation methods in the literature.
An often-used method of valuation relates with Willingness-to-Pay (WTP) of an individual for renewable energy. A few studies have used Revealed Preference Technique (RPT) to measure WTP. This technique measures WTP through actual purchase decisions of consumers. Another frequently used method called Contingent Valuation Method is an example of Stated Preference Technique (SPT). The SPT estimates the relative preferences of the categories of potential consumers for various types of RETs or for price points for the energy services. However, in the context of developing countries the electricity consumers often do not have a choice in buying electricity from multiple electricity utilities, but only from a state-owned distributor at a state-regulated price, therefore the measurement of willingness of consumers to purchase electricity at multiple price points is not appropriate.

The methodologies used in the valuation of financial outcome adopt two approaches: risk adjusted discount rate and options theory. The two approaches complement each other and improve on the standard net present value method. The risk adjusted discount rate approach is based on Capital Asset Pricing Model (CAPM) which forms a relationship between risk and
required rate of return from a project. CAPM further partitions risk as emanating from two sources: systematic risk which arises from the state of economy that affects all assets, and unsystematic risk that is associated with specifics of a particular project. The theory underlying CAPM assumes that the asset markets are efficient and dominated by risk-averse investors.

Approaches using real option theory focus on hedging against risk that arise out of volatility in fossil fuel price, policy changes, and shift in demand and supply. Specifically, the option theory is used to value the “option” to abandon or delay the RET project when new information is available. Again, the objective of this study is not to value the option to abandon or delay the project at any stage to development or during the operation of the project.

The renewable energy industry in developing countries typically does not have large number of players and are characterized by non-market based interventions from governments. Under market conditions of small number of producers and non-market intervention, economic strength and market responsiveness of RET based project cannot be easily modeled through traditional approaches as deployed in developed countries.

Pine Needle Gasification Literature

The Himalayan mountain range stretches over 3,500 km spanning several countries including Afghanistan, Pakistan, China, India, Nepal, Bhutan, Bangladesh, and Myanmar. The Chir pine (*Pinus Roxburgii*) is the most abundant species of tree in the forests covering the Himalayan mountain range. The combined area of the pine forests in this stretch is 1.5 million hectares. The state Uttarakhand alone has pine forest area of 0.35 million hectares. The pine forests in Uttarakhand shed 2 million tons of dry mass each year. Each hectare of pine forest sheds 6 tons of pine needles (PN) or each square meter yields 0.6 kg of PN (Arvind Singh Bisht 2014). Ashfaque Ahmed in his analysis (Ahmed 2012) of forest vegetation in Uttarakhand region
found *Pinus roxburghii* to be the dominant species in terms of density of 583.2 trees/ha with mean basal area of 347.9 cm²/ tree.

Liang Jessica Fang in association with AVANI has studied (Fang and Hane-Weijman 2011) the characteristics of pine needle combustion. Jessica found that pine needles have heating value of 18 to 20 MJ/kg comparable to that of sawdust and fuel-oil but higher than that of mean heating values of various species of wood at 15.8 MJ/kg. Jessica further reports similar volatile content for pine needles to those of saw dust at 74.2% by weight but a higher fixed carbon content at 24.1% and lower ash content at 20.4%. Jessica also reports that the energy stored in pine needle volatiles are 74.2% of the total potential pine needle energy and is much larger than the approximate 60% of potential wood energy stored in wood volatiles.

Akhilesh Kumar et al. conducted an experimental analysis (Kumar and Randa 2014) of producer gas generated from Chir pine needles in a downdraft biomass gasifier. The study measures the performance of the biomass gasifier system in terms of the equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate and cold gas efficiency. This study reports similar heating value as Jessica does which is 18.89 MJ/kg, but much lower fixed carbon content at 17.76%, higher volatile matter of 82.3% by dry weight basis in proximate analysis. Akhilesh et al. study observes pine needle gasification in a downdraft gasifier at multiple equivalence ratios.

Equivalence ratio (ER) is a measure of the amount of external oxygen (or air) supplied to the gasifier. ER is obtained by dividing the actual oxygen (or air) to biomass molar ratio to the stoichiometric oxygen (or air) to biomass molar ratio. The study reports that at an equivalence ratio of 0.245, the calorific value of the producer gas is lowest at 10 MJ/Nm³. Pine needle gasification performance holds up well when compared with the performance of other feedstocks.
in downdraft gasifiers. For example Dogru et al. report (Dogru, Howarth et al. 2002) that hazelnut shell generate the producer gas with a calorific value of about 5 MJ/m$^3$. Zainal et al. using wood chips and charcoal report (Zainal, Rifau et al. 2002) calorific value to be 5.62 MJ/Nm$^3$. Babu and Seth working with wood waste generated while making furniture in the carpentry report 6.34 MJ/Nm$^3$. The comparison of the results in the Table 29 indicates that PN could potentially be a viable feedstock for the electricity generation through gasification.

### Table 29 Performance of Various Feedstocks in a Downdraft Gasifier

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Biomass</th>
<th>Optimum ER</th>
<th>CV (MJ/Nm$^3$)</th>
<th>Gas Production Rate (Nm$^3$/kg)</th>
<th>Cold Gas Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Dogru, Howarth et al. 2002)</td>
<td>Hazelnut shell</td>
<td>0.28</td>
<td>5.15</td>
<td>2.73</td>
<td>80.91</td>
</tr>
<tr>
<td>(Zainal, Rifau et al. 2002).</td>
<td>Furniture + wood charcoal</td>
<td>0.39</td>
<td>5.62</td>
<td>1.08</td>
<td>33.72</td>
</tr>
<tr>
<td>(Sheth and Babu 2009)</td>
<td>Furniture waste</td>
<td>0.21</td>
<td>6.34</td>
<td>1.62</td>
<td>56.87</td>
</tr>
<tr>
<td>(Kumar and Randa 2014)</td>
<td>Chir pine needles</td>
<td>0.25</td>
<td>10.56</td>
<td>1.6</td>
<td>89.43</td>
</tr>
</tbody>
</table>

**Policy and Regulatory Framework Governing the Gasifier Project**

There are multiple laws and regulations that govern and agencies that monitor the renewable energy sector in India. Multiple federal acts such as- the Forest Conservation Act 1978, the Water Act 1972, the Air Act 1980 for prevention and control of pollution, and the Environment Protection Act 1986- have impact on renewable energy projects at the state level. The multiplicity of interacting agencies and regulations make the coordination with and adherence to multiple regulations complex tasks.

The Ministry of Power promulgates national electricity policy and national tariff policy; both policies have direct impact on the RET based projects. Ministry of New and Renewable
Resources (MNRE) is responsible for all policies and programs promoting renewable based rural energy. India Renewable Energy Development Agency (IREDA) is the financial arm of MNRE which provides funds for the approved renewable energy projects. All federal level agencies have their state level counterparts that have direct bearing on progress of the projects in the states. Each state has a nodal agency that promotes renewables in the state, collaborates with MNRE, district agencies, manufacturers, and NGOs. Each state also has a State Electricity Regulatory Commission (SERC) responsible for determining tariffs for gasifier projects in its state. The SERCs are bound by the directives and guidelines of the Central Electricity Commission (CERC) (Table 30). Within each state and at the local level the actual implementation (dissemination, marketing, maintenance, monitoring, manufacturing, etc.) is carried out by several government and non-governmental agencies, namely, district rural development agencies, NGOs, companies, corporations, small entrepreneurs etc. (PWC 2010).

The key legislation governing the gasifier project considered in the study is the Electricity Act, 2003. The Electricity Act 2003 mandates the Central Electricity Regulatory Commission (CERC) and Uttarakhand Electricity Regulatory Commission (UERC) to promote generation of electricity from renewable resources by providing measures for connectivity with the grid and market for generated electricity The National Tariff Policy, 2006, directs UERC to purchase electricity from the gasifier units a certain minimum percentages of total electricity purchased from various electricity generators. MNRE provides grants to its state counterpart for its recurring and non-recurring promotional expenditure. Financial assistance to renewable energy projects is provided through the Indian Renewable Energy Development Agency (IREDA)-the financial arm of the MNRE-which provides loans and also channels funds and other initiatives to promote renewable energy (Krithika & Mahajan, 2014).
Table 30 Policy Framework Governing Electricity Generation from Renewables in India

<table>
<thead>
<tr>
<th>Levels</th>
<th>Central Government Ministry of Power/Ministry of Finance</th>
<th>MNRE</th>
<th>CERC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Level</td>
<td>Develops national electricity tariff policies, which also cover renewable energy</td>
<td>Develops national renewable energy laws Sets technical standards for renewable energy Conducts resource assessments for renewable energy; supports R&amp;D in renewable energy technologies Promotes effective use of information technology for renewable energy, manages database Reviews renewable energy programs to understand their effectiveness and efficiency</td>
<td>Sets guidelines for feed-in tariff design for different renewable energy technologies Regulates the regional electricity corporation mechanism Regulates interstate open access, and third-party sales</td>
</tr>
<tr>
<td>State Level</td>
<td>State government Develops state level renewable energy policy Provides fiscal incentives for promoting renewable energy sources</td>
<td>Conducts resource assessments for various renewable energy sources Allocates renewable energy projects and progress monitors Provides facilitation services to project developers - IREDA personnel escort project developers to various government departments with the objective of facilitating and streamlining clearances Facilitates clearances and land acquisition</td>
<td>Develops feed-in tariff methodologies for different renewable energy technologies Determines RPOs and enforcement mechanism Sets regulations on intrastate wheeling, open access, and third-party sale</td>
</tr>
</tbody>
</table>

(Krithika and Mahajan 2014)
Figure 18 illustrates the governance framework in which renewable energy production unit functions.

UERC notification 2013 (UERC 2013) defines a biomass gasifier based power project as:

The project shall qualify to be termed as a biomass gasifier based power project if it uses new plant and machinery and has a grid connected system that uses 100% producer gas engine, coupled with gasifier technologies approved by Ministry of New and Renewable Energy (MNRE).

The MNRE promotes multifaceted biomass gasifier power projects using locally available biomass resources including forest residues and agro-residues in rural areas. The gasifiers approved by MNRE include the tail end grid connected power projects up to 3 MW capacities such as the one this study refers to. As the state-owned Uttarakhand Power Corporation Ltd (UPCL) is the only electricity distribution utility in the state, therefore an electricity generation facility will have to enter into a PPA with the UPCL.
**Study Objectives**

1. Establish a framework for financial evaluation of a biomass gasification project using a case-study of proposed 2.4 MW (20 x 120 KW) Pine Needle Gasification project (PNGP).
2. Identify the risk factors that are likely to impact the financial viability of a PNGP within the existing policy and regulatory framework of India.
3. Derive a risk-adjusted probability distribution of profitability indicator (Net Present Value) for the PNGP.

**Methodology**

Traditionally, the capital budgeting process uses single point estimates (static) in the computations of evaluation criteria such as Net Present Value (NPV) and Internal Rate of Return (IRR). The point estimates, by simplifying the underlying uncertainty surrounding a project, render the mathematical computations straightforward, but result in unreliable evaluation criteria for making decisions. The evaluation criteria are more unreliable when used in absence of historical data, especially in the cases of RETs. In such cases the point estimates of input variables may prove to be overly optimistic or conservative.

In this study, both static and probability distributions of input variables are used to estimate NPV of the PNGP. In the static model, point estimates of cash flow variables are used to calculate the NPV of the PNGP. In the probabilistic model, point estimates are replaced by probability distributions of input variables, resulting in an estimated probability distribution of NPV rather than a single point estimate of NPV as output. As a prerequisite to developing the models, financial statements -cash flow, profit and loss, and balance sheet- are generated for each year of the entire useful life of the project.

The financial statements and NPV generated in the static model are used to identify the variables that are likely to have the most impact on the project NPV. In theory, three categories of variables impact NPV the most (Brealey & Myers, 2000)- cash inflows including those from revenue, cash outflows including those from operating costs, and the discount rate. In order to
identify specific variables that impact NPV the most, each cost/revenue variable related with operation is calculated as a proportion of the total revenue. Since revenue is an important variable determining the size of cash inflows and therefore NPV, this process helps identify the operating variables which constitute high proportion of revenue. Subsequently, “what if” scenario analysis is performed with the variables that impact NPV the most. The scenario analysis reveals the amount of change in NPV in response to unit change in a single input variable, holding all other variables constant.

In the second model (probabilistic) several scenarios are constructed from various levels of input variables. For each scenario input variables are changed simultaneously and 50,000 iterations are performed. For each scenario, the output is, therefore, a probability distribution of NPV. In the probabilistic model, in place of point estimates of input variables, statistical distribution of variables is used. A probabilistic model helps achieve better understanding of the interactions between uncertain input variables represented by a probability distribution rather than point estimates. The resulting probability distribution of NPV shows the range of possible project outcomes at different probability levels along with the variance in the outcome.

**Cash Flow Model**

The role of discounted cash flow (DCF) methods in approaches to investment decision making and valuation is well established in theory and practice. Irving Fisher (Fisher 1965) and Jack Hirshleifer (Hirshleifer 1958) posited the theoretical foundation of DCF methods. While DCF was originally conceived as a way of dealing with compounding aspect of interest rates, it found a wide range of applications in finance including capital budgeting problems. One of the traditional applications of DCF in capital budgeting literature is that in computing NPV of a project. A simple way to define NPV is that it is equal to the present value of future cash flows discounted at appropriate rates, minus the present value of the capital expenditure. The preceding
two decades (1990 to 2010) have witnessed tremendous amount of literature devoted to various approaches in computation of NPV in capital budgeting problems. The differences in various approaches have essentially been on two issues- which cash flows to discount and at what discount rates (Emhjellen and Alaouze 2003),(Jacoby and Laughton 1992).

In this study, the DCF based NPV model for valuation of the gasifier project is based on the theoretical foundations developed by Harrison et al. (Harrison and Horngren 2008), Copeland et al. (Copeland, Weston et al. 2005), and Shrieves et al. (Shrieves and Wachowicz Jr 2001).

For a single-period cash flow identity may be expressed as follows:

Sources = Uses

\[ R + \Delta D = O + \text{Int} + \text{Div} + \text{Taxes} + \Delta I + \Delta WC \]

Where

- \( R \) = operating revenue in cash
- \( \Delta D \) = net cash received from issuance of debt
- \( O \) = operating cost paid in cash
- \( \text{Int} \) = interest payment in cash
- \( \text{Div} \) = dividend paid in cash
- \( \text{Taxes} \) = total tax paid in cash

The cash flows from operating activities, financing activities, and investing activities constitute the total cash flow for the PNGP.

Operating activities include cash activities related to the main operation of the gasifier which is to produce electricity and charcoal, and sell electricity to the grid and charcoal to the local households. The electricity generating operation includes cash payments for the PN feedstock, cash payments to the employees and other related expenses.

Financing activities include cash activities related to long term debt and owners’ equity. Long term debt and owners’ equity include - the principal amount of long-term debt, equity stock
provided by the promoter and other investors, and dividend payments if any. However, interest
paid on long-term debt is included in operating activities.

Investing activities include cash activities related to creating and disposing long term
assets. Long term assets include land, building, gasifier, feedstock warehouse, the principal
amount of loans extended to other entities and other equipment that last more than a year.
However, interest received from such loans is usually included in operating activities.

The total cash flow available to the equity investors (CFE) including promoters may be
expressed as:

\[ CFE = (R - O - Dep - Int - Taxes) + Dep) - (\Delta I + \Delta WC) + \Delta D \]

\( Dep = \) annual depreciation (double declining method used in the study)

\( WC = \) working capital (calculated according to the relevant policy-fuel costs for four
months; operation and maintenance expense for one month; receivables equivalent to two
months for sale of electricity, maintenance –spare at 15% of operation and maintenance
expense).

Cash flow to the debt provider (CFD) may be expressed as:

\[ CFD = Int - \Delta D = \text{interest payment - net issuance of debt} \]

If the discount rate used in the NPV calculation is post-tax expected- return, then the cash
flow used for NPV calculation should be reduced by the tax shield afforded by the interest
payment on debt. In this study, the discount rate used in NPV is post-tax expected-return;
therefore the pre-tax cash flow to equity investor is used.

**Net Present Value**

Net present value (NPV) compares the present value of cash outflow from capital
investment in a project to the present value of the net cash inflows from the investment. In other
words, the investment is compared to the cash receipts after they are discounted by a specified expected rate of return from the investment. The NPV is calculated as:

$$\sum_{t=0}^{T} \omega_t \left\{ \left[ R_t - O_t - DEP_t - Int_t \right] + Dep_t \right\} - \left[ \Delta Investment_t + \Delta WC_t \right] + \Delta D_t \right\}$$

Where $\omega_t$ is reciprocal of expected post tax return on investment in year $t$. Essentially, NPV is calculated by discounting the pre-tax cash flows available to the equity investors by the discount rate (Emhjellen and Alaouze 2003).

**Expected Return on Investment**

Literature related with capital budgeting and valuation approaches based on NPV suggest that the discount rates, to the extent possible, should be adjusted according the nature of the project being evaluated. Smith and MacCardle (Smith and McCardle 1999) write:

Using the cost-of-capital-based discounting rule may lead to trouble when applied to projects that are significantly different from the firm as a whole. If you are going to use risk-adjusted discount rates for different projects, you should use different discount rates for different projects……you might need to go one step further and use different discount rates for different projects……as the risk of a project may change over time, depending on how uncertainties unfold and management reacts.

In this study, the static model uses a constant discount to discount the cash flows to determine NPV. In the probabilistic model, discount rates change every year depending on the assumed distribution of the expected return as defined by mean and volatility of the expected return on investment.

Damodaran (Damodaran 2012) writes:

Every risky asset market has a “risk” premium that determines how individual assets in that market are priced. In an equity market, that risk premium for dealing with the volatility of equities and bearing the residual risk is the equity risk premium. In the bond market, the risk premium for being exposed to default risk is the default spread. In real asset markets, there are equivalent (though less widely publicized markets) measures signifying risk premium.
The RET based projects are part of the real asset markets, and the risk premiums and expected rate of return for this market are not available, as there are not many assets in this still evolving biomass gasification sector in India. A study by Pricewaterhouse Coopers India (Vishnu Giri 2013) using free Cash Flow to Equity (CFE) approach for Indian equity market reports that the implied expected Indian equity market return to be approximately 15.2% post tax. The expected return as reported by the PWC India is used as the constant discount rate in the static model.

Probability density function of expected return on investment : The research in 1980s and early 1990s on economic variables such as interest rates, risk premiums, risk adjusted expected returns usually assumes these variables to be lognormally distributed, i.e., their logarithm to be normally distributed. The variables, therefore, cannot assume negative values (Levin 2004). Since then, as Levin shows, the lognormality assumption about the variables such as interest rates and risk adjusted returns has become contested. However, in cases where the historical data on distribution of expected returns is not available, assuming the expected return to be lognormally distributed is a natural way of ensuring that expected returns not take negative values (Sandmann and Sondermann 1997). In practice, International Actuarial Association often assumes the discount rates to be lognormally distributed (IAA 2002). Addressing the issue of distribution of interest rates in India, Jayanth R. Varma from Indian Institute of Ahmedabad writes about recent disagreement among scholars about appropriate model that describe the distribution of interest rates. Jayanth suggests three possible ways to address the disagreement—shift back to a normal model, combine normal and log-normal fluctuations, use interest rate plus a small constant that is lognormal (Varma 2013). The panel of experts (listed in next section) for this study suggests that keeping in view the theoretical uncertainty surrounding the appropriate
distribution model of discount rate and the nature of the PNGP, this study should assume the discount rate to be lognormally distributed.

**Data underlying Financial Statements**

In order to determine CFE for the PNGP, three financial statements - profit and loss account, balance sheet, and cash flow statement - have been drawn for each year of the entire useful life of the project. The financial statements have been drawn on the basis of generally accepted accounting principles (GAAP) as interpreted in the textbooks by Harrison et al. and Brearley et al. The financial numbers for the gasifier operations are based on the data provided by AVANI. The operational data for the 9KW system has been scaled-up for 120 KW units in consultation with the AVANI and a ten-member panel composed of eight project finance professionals who have experience with financing of RET based projects in India, and two academicians from economics and finance discipline.

The panel members include:

- Professionals from three public sector banks- State Bank of India, Punjab National Bank, Corporation Bank
- Professionals from two private sector banks- ICICI bank, HDFC bank
- Professionals from two multinational bank- Citi Bank India, HSBC India
- Professional from Indian Federal Bank- Reserve Bank of India
- Two Associate Professors from Indian Institute of Management, Indore, and O.P. Jindal University

**Monte Carlo Simulation for Investment Decision Making**

A typical capital investment project with fixed estimates (static) of model variables is evaluated in sequential but independent steps. The steps are - select evaluation criterion (usually NPV), define parameters for the project (cash flows, discount rates), perform risk analysis by measuring sensitivity of the evaluation criteria (NPV) to changing level of parameters - one parameter at a time, and finally select or reject the project on the basis of an established level of evaluation criteria. Typically, in static project appraisal techniques the basic selection criterion is
whether NPV is positive or negative. However, under conditions of uncertainty and in absence of historical data, a static appraisal technique fails to represent highly uncertain nature of cash flows, discount rates, and other related parameters.

In situations where relationship between inputs and outputs are complex and uncertain, Monte Carlo Simulation (MCS) can incorporate multiple scenarios in the process of project appraisal (Meredith and Mantel 1995). The MCS uses probability distribution, instead of static estimates of input variables. The stochastic inputs generate probability distribution of output such as NPV. The MCS helps understand not only the variability of decision making criteria NPV but also its volatility in terms of standard deviation (variance).

Jonathan Mun (Mun 2006) describes the steps of developing the model of MCS. The first step involves creating a static base-case discounted cash flow model. NPV is calculated using traditional method of forecasting cash flows for the entire period of the project, and then discounting the cash flows at appropriate risk adjusted discount rate. The next step is to identify the variables that affect NPV the most by changing the precedent variables and noting the change in NPV. The precedent variables include revenues, costs, discount rates, capital expenditure, depreciation etc. which flow through the NPV model. The precedent variables that affect the values of NPV most are the critical success drivers of the project. These critical variables are prime candidates as input variables in the MCS. Some of these input variables may be correlated; in that case a correlated MCS may be required. Typically, the correlations are obtained from historical data; however, in absence of historical data, correlation estimates provided by experienced experts can be used.

The success of any decision model depends on the reliability of the underlying inputs. The MCS may lead to more optimal decisions, as compared to static project appraisal techniques,
by revealing complex relationships among the input variables. For this study, following process is used to develop the simulation model for the gasifier project:

For this study, an Excel based visual basic program is used to run the MCS. Initially a static CFE model is built, which is used to compute single point estimate of NPV for the project. This static model is used to identify the variables which have high impact on project NP.

Once the critical variables are identified, their single-point estimates are replaced with their appropriate probability density function defined by relevant statistical terms such as mean, median, standard deviation, or range of values. These statistics of the variable probability density function would ultimately affect random values selected for the iterations in the simulation. The input variable probability function is determined with the help of available literature, the opinion of the panel, and the data from AVANI’s gasification project. If the panel suggests that the statistics defining probability density function for some variable could be uncertain then various scenarios are developed for that variable with more than one probability density function.

The next step is to decide the number of iteration for the simulation. Jonathan Mun (Mun, 2006) and Korn et al. (Korn, Korn et al. 2010) suggest minimum 10,000 iterations for the MCS. In this study 50,000 iterations are performed for each scenario. Iterations can be regarded as a separate “what-if” analysis in which inputs for critical variables are simultaneously drawn from variables’ probability density function. The random inputs for different variables are combined with the help of simulation program to compute the NPV for iterations. The resulting output is a probability density function of NPV described by a mean and a standard deviation.

**Project Evaluation Framework**

The financial statements for the PNGP is projected on the basis of the norms concerning biomass gasifiers specified in the UERC policy. The UERC policy provides normative figures for capital structure and various other financial heads such as capital cost per MW, maintenance
cost, feedstock cost per metric ton, and auxiliary power consumption. The UERC policy also specifies the principles underlying the tariff determination exercise that the state owned electricity utility UPCL undertakes before signing a PPA with biomass gasifier units. Since, there is a wide variety of biomass power projects using multiple types of feedstock; the norms suggested in the UERC policy for various costs could differ from the actual costs for a particular project.

The following sections provide a brief of the policy principles specified by the UERC underlying the tariff determination process. For each financial and operational variable the cost estimates specified in the UERC policy is compared with the costs estimates and the assumptions underlying the PNGP projections along with the justification for their difference if any. The approach framework used for the evaluation of the gasifier project is shown in Figure 19.

Figure 19 Component of PNGP Evaluation Model
Revenue

The UERC regulations are applicable to the sale of electricity to the rural grid only. A biomass gasifier unit may opt for a generic tariff offered by the UPCL or may petition the UERC for a project specific tariff; however, the project specific tariff will remain equal to or below the tariff ceiling the UERC indicates for its state. For projects opting for project specific tariff, the tariff is determined on the basis of actual capital cost instead of normative capital cost as specified in the UERC policy. This tariff is agreed upon on the basis of a detailed project report.

For this study, a base case of financial statements is projected assuming the normative tariff for the Uttarakhand state offered by the UPCL. In the simulation, the tariff is allowed to assume two values- normative subsidized tariffs offered by the UPCL and average tariff offered to fossil-fuel based power producers. The two levels considered for the purpose of projection of financial statements:

- UPCL’s total normative tariff to RET based power projects- USD .062/kwh(MNRE 2013).
- Lower tariff if preferential feed-in-tariff subsidy were to be retracted by the government- USD.04/kwh (the Panel).

The UERC policy links electricity tariff to various normative financial measures. These normative measures are evolved in consultation with MNRE and Ministry of Power in pursuance of the national goal of promoting renewable energy within the fiscal constraints of India. The UERC policy specifies a Control Period or Review Period of five years for the tariff. The tariff is reset at the end of each control period.

The tariff is applicable to the Useful Life which is specified at 20 years for a biomass gasifier project in the UERC policy (Table 31). The policy specifies a two-tier structure for the tariff- fixed tariff and variable tariff components. The policy allows a variable tariff escalation factor of 5%, subject to the condition of meeting capacity utilization factor of 80% every year.
The revenues are projected into the future assuming capacity utilization condition is met every year and the variable tariff escalation factor remains available for the entire useful life of the project.

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed tariff (USD) (per kwh)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Variable tariff (USD) (per kwh)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.08</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 31 Tariff for PNGP over the Operation Period

In order to establish the fixed cost component of the tariff the UERC takes multiple factors in account:

- Return on equity
- Interest on loan capital
- Depreciation
- Interest on working capital
- Operation and maintenance expenses

The variable cost component has three parts- Wholesale Price Index (WPI), indexed biomass feedstock cost, and transportation cost if any. The three components of the variable cost component are assigned weightages 20%, 60% and 20% respectively.

Another principle underlying the tariff design is that whether the tariff offered to the project should be front loaded- higher tariff in the initial period, or back loaded-higher tariff at later stage of the project. The front loading helps the project developer while laying extra burden on the electricity distributor the UPCL. Frontloading may not leave much incentive to the project developer to continue with the PPA at the later stages of the project. Similarly, back loading puts tremendous strain on the cash flow of the project in the initial period. Therefore, the UERC is of the view that levelised tariff is the best option. Levelised tariff in the power sector essentially refers to the average fixed and variable tariff over the entire term of the PPA adjusted for
inflation. For the purpose of projecting financial statement of the PNGP, a levelised tariff with 5% escalation in the variable tariff component has been assumed.

**Capital Structure**

Debt-equity ratio: The UERC policy specifies a normative debt-equity ratio of 70:30 (2.33). The policy further specifies that if the equity invested by the project developers is more than 30% of the capital cost, then for the purpose of determination of tariff the UERC treats equity in excess of 30% a loan. And if the equity invested by the developer is less than 30% of the capital cost, then the actual equity is to be considered for determination of tariff. For the PNGP, at the beginning of the first year debt-equity ratio is at 2.87, higher than the normative ratio of 2.33, however, by the end of the year the ratio improves to 1.8 because of profit for the first year is accreted to the reserves (Table 32).

<table>
<thead>
<tr>
<th>Year</th>
<th>Debt (USD)(000)</th>
<th>1</th>
<th>2</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt (USD)(000)</td>
<td>95.7</td>
<td>404.4</td>
<td>1,251.4</td>
<td>958.8</td>
<td>637</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Equity and reserves (USD)(000)</td>
<td>54.4</td>
<td>180</td>
<td>783.2</td>
<td>1,059.4</td>
<td>1,390.3</td>
<td>6,989.7</td>
<td>7,761.3</td>
<td></td>
</tr>
<tr>
<td>Debt-equity ratio (end of the year)</td>
<td>1.8</td>
<td>2.2</td>
<td>1.6</td>
<td>0.9</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**Loan and Finance Charges**

Loan tenure: For the purpose of determination of tariff, the UERC policy assumes loan tenure of 12 years.

Interest rate: The UERC policy assumes the interest rate to be average of State Bank of India (SBI) Base Rate prevalent during the first six months of the previous year plus 300 basis points. Loan tenure and interest rate for the financial statements for the PNGP is assumed at 10% per annum, as the SBI’s base rate in recent years have been hovering around 9% per annum.
(Table 33) (SBI 2015). For the study, the loan disbursement is assumed to be in instalments over a seven year period. The loan is repaid over a period of eleven years, including the disbursal period.

In the simulation, on the basis of the opinions of the Panel members, SBI’s base rate is assumed to vary lognormally with a long term mean of 10% with two levels of standard deviations - 1% and 4%. The 1% standard deviation represents an outlook of stable expected interest rate regime in the economy over the useful life of the project, whereas a standard deviation of 4% represents a volatile interest rate regime over the useful life of the project.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Base Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>9.7</td>
</tr>
<tr>
<td>2014</td>
<td>9.8</td>
</tr>
<tr>
<td>2013</td>
<td>9.7</td>
</tr>
<tr>
<td>2012</td>
<td>9.75</td>
</tr>
<tr>
<td>2011</td>
<td>8.5</td>
</tr>
<tr>
<td>2010</td>
<td>7.5</td>
</tr>
</tbody>
</table>

(SBI 2015)

Working Capital

The UERC policy computation for the working capital requirement adds up following components:

- Fuel costs for four months equivalent at 80% utilization factor (CUF);
- Operation & Maintenance expense for one month;
- Receivables equivalent to two months of fixed and variable charges for sale of electricity calculated at 80% CUF;
- Maintenance spare at 15% of operation and maintenance expense

In order to address the uncertainty with the payment schedule from the state-owned UPCL, the working capital computation for the PNGP considers four months of receivables rather than that for two months to provide a layer of safety for the project.
Return on Equity

For the purpose of tariff calculations the UERC policy draft assumes pre-tax 20% per annum for the first 10 years, and pre-tax 24% per annum 11th year onwards. The return on equity is one of the final outcomes of the drawing of financial statements. However, according to the Panel, the project would be considered viable by financial institutions and equity investors if the return on equity from the project is above pre-tax 18% per annum.

Operational Cost

Feedstock cost: For the year 2014, the UERC policy indicates a Biomass Fuel Price (P) as USD 30.5 per MT, which is indexed for different years of tariff period based on annual inflation rate, Indexed Energy Charge Component (IRC) - an inflationary index wholesale price index (WPI) for specific category of biomass, and transportation cost (price for high speed diesel: Pd) with 20%, 60% and 20% respective weightages in the following formula

\[ P(n) = P(n-1) \times (0.2 \times \frac{WPI(n)}{WPI(n-1)}) + 0.6 \times (1+IRC(n-1)) + 0.2 \times \frac{Pd(n)}{Pd(n-1)} \]

However, as the indices- WPI and IRC for nth year are determined only after close of nth year, and in some cases much later, the project developer is allowed to increase the variable tariff based on normative escalation factor of 5% on previous year’s variable tariff. AVANI’s experience in operating the 9KW gasifier indicates that the pine needle cost per kg- including the cost of collection, loss in the process of handling, and cost of densifying the needles in preparation of feedstock- is USD 0.017 (Table 34).

Operation and Maintenance Cost

The UERC policy specifies a normative operational and maintenance cost of USD 71,667/MW per annum. These expenses are allowed to escalate at 5.72% p.a. to arrive at O&M expenses for the subsequent years.
Table 34 Pine Needles Quantity and Cost (120 KW units)

<table>
<thead>
<tr>
<th>Feedstock Quantity and Cost (per 120 kw unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine needle consumption (Kg/KWh)</td>
</tr>
<tr>
<td>Pine needle consumption per plant p.a.</td>
</tr>
<tr>
<td>Pine needle loss</td>
</tr>
<tr>
<td>Pine needle collections (kg/year)</td>
</tr>
<tr>
<td>Pine needle availability (kg/sq.km p.a.)</td>
</tr>
<tr>
<td>Sq. Km of pine forest land to be covered for needles collection</td>
</tr>
<tr>
<td>Landed cost of pine needle including densification/kg (USD)</td>
</tr>
</tbody>
</table>

The financial statement for the PNGP estimates operation and maintenance cost to be USD 75,173 per MW in the 7th year when all 20 units are operational (Table 35).

Table 35 Maintenance Cost for PNGP

<table>
<thead>
<tr>
<th>Operation and Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Number of operational units</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Installed capacity</td>
</tr>
<tr>
<td>Total plant engineer cost (USD)</td>
</tr>
<tr>
<td>Total plant operator cost (USD)</td>
</tr>
<tr>
<td>Total maintenance cost (USD)</td>
</tr>
<tr>
<td>Total O&amp;M cost (USD)</td>
</tr>
<tr>
<td>O&amp;M cost/MW (USD)</td>
</tr>
</tbody>
</table>

Depreciation

The UERC policy specifies the capital cost to be the base value for the calculation of depreciation. It assumes the salvage value of the capital asset at 10% of the original capital cost and the maximum depreciation allowed up to 90% of the capital cost of the asset. Depreciation per annum is based on Differential Depreciation Approach’ over loan tenure and for the period beyond the loan tenure until the useful life it is computed on ‘Straight Line Method’.

For the PNGP, the salvage value is conservatively assumed at 5% of the capital cost of the assets. In the 20th year, the accumulated depreciation of the capital asset stands at 83% of the
original cost. Furthermore, a double declining differential approach is assumed for the entire useful life of the project. Over the entire useful period, the total depreciation charged is same under every depreciation approaches, however, double declining methods, compared with straight line method, allows higher profits in the initial years and lower profits in the later years.

**Capital Cost**

The normative capital cost as specified in the UERC policy is USD 0.92 million per MW which includes all capital work including plant and machinery, civil work, erection and commissioning, financing and interest cost during construction, and electricity evacuation infrastructure up to rural grid inter-connection point. Therefore, at 2.4 MW installed capacity (20X120 KW) total capital investment in the project is USD 2.2 million. For the PNGP, the estimate for the capital cost per MW in the financial projections including: plant and machinery, civil work, erection and commissioning, financing and interest during construction, electricity evacuation infrastructure up to rural grid inter-connection point, the cost of downdraft gasifier is USD 0.89 million/MW. MNRE offers a capital subsidy of USD 300 per KW and Uttarakhand government offers additional 20% capital subsidy over MNRE subsidy at USD 60 per KW.

**Site Selection**

As mentioned before, the site selection process would involve the Van Panchayats of the villages, and would also require an agreement with them in setting up self-help groups with villagers for the purpose of collecting pine needles for the gasifier unit. AVANI is quite confident that it would be able to persuade the Van Panchayats to agree with the plan. The confidence stems from the relationships AVANI has been able to forge with the local community over the past decade, and from the fact that the gasifier project would significantly contribute to the local economy in the way of providing employment and efficient cooking fuel to the local households. The RET based projects on forest land have to obtain an approval from the Ministry
of Environment and Forests (MoEF), which is a two stage process- approval from the Divisional Forest Officer and subsequently from the regional office of MoEF. The site selection process would have to take into account several other factors as well including:

- Non-diversion of agricultural land for other purposes
- Distance of pine forests
- Proximity of the rural grid from the PNGP, as the distance of the rural grid impacts the capital cost of the project because the electricity feed-in infrastructure up to the grid is responsibility of the PNGP

**Assumptions underlying the Evaluation Framework**

- AVANI will be able to find suitable sites for the 20 gasifiers and get approval for siting from Village Panchayats.
- The down draft gasifiers would function at 80% capacity utilization factor for the entire useful life of the project.
- Sufficient number of villagers would agree to form a self-help group to collect pine needles and supply to AVANI at a reasonable price.

**Summary Financial Statements for the PNGP**

Table 36 shows a summary of base-case financial projections for the PNGP in which variable tariff grows at the yearly rate of 5% per annum provided in the UERC policy. In the base-case, cost of pine needle is assumed to be constant for the entire useful life of the project. In short, no unexpected shocks to the project are built into the base-case scenario. In such an unlikely scenario, at the end of 7th year of operation, when all 20 units are functioning, the revenue is estimated to be USD 1.4 million, the corresponding operating cost, including the pine needle cost, is estimated at USD 0.6 million. The operating margin for the 7th year therefore works out to 49.9%. Reserves and surplus at the end of the useful period of the project is estimated at USD 11.2 million. For the base case scenario, the NPV calculated by discounting Operating Cash Flow at the discount rate of 15.2% post tax (see literature review section). For the base-case scenario. IRR and discounted Payback period are calculated as well. The NPV for this scenario is USD 1.7 million, and the IRR is 25% which is more than the return
<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of operational units</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Revenue (USD)</td>
<td>56,015</td>
<td>260,981</td>
<td>531,786</td>
<td>1,461,273</td>
<td>1,500,656</td>
<td>1,542,008</td>
<td>2,088,137</td>
<td>2,158,863</td>
</tr>
<tr>
<td>Total operating cost</td>
<td>27,774</td>
<td>121,812</td>
<td>243,624</td>
<td>609,061</td>
<td>609,061</td>
<td>609,061</td>
<td>609,061</td>
<td>609,061</td>
</tr>
<tr>
<td>Operating margin</td>
<td>28,241</td>
<td>139,169</td>
<td>288,162</td>
<td>607,176</td>
<td>637,919</td>
<td>670,198</td>
<td>1,479,076</td>
<td>1,549,803</td>
</tr>
<tr>
<td>Operating margin (%)</td>
<td>50.42%</td>
<td>53.33%</td>
<td>54.19%</td>
<td>49.92%</td>
<td>51.16%</td>
<td>52.39%</td>
<td>69.86%</td>
<td>70.83%</td>
</tr>
<tr>
<td>EBITDA</td>
<td>28,241</td>
<td>139,169</td>
<td>283,762</td>
<td>841,212</td>
<td>880,595</td>
<td>921,947</td>
<td>1,468,076</td>
<td>1,538,803</td>
</tr>
<tr>
<td>EBITDA margin (%)</td>
<td>50.42%</td>
<td>53.33%</td>
<td>53.36%</td>
<td>57.57%</td>
<td>58.68%</td>
<td>59.79%</td>
<td>70.31%</td>
<td>71.28%</td>
</tr>
<tr>
<td>PBT</td>
<td>39,762</td>
<td>56,979</td>
<td>124,866</td>
<td>564,494</td>
<td>648,294</td>
<td>735,474</td>
<td>1,425,266</td>
<td>1,500,273</td>
</tr>
<tr>
<td>PAT</td>
<td>27,833</td>
<td>39,885</td>
<td>87,406</td>
<td>395,146</td>
<td>453,806</td>
<td>514,832</td>
<td>997,686</td>
<td>1,050,191</td>
</tr>
<tr>
<td>PAT margin (%)</td>
<td>49.69%</td>
<td>15.28%</td>
<td>16.44%</td>
<td>27.04%</td>
<td>30.24%</td>
<td>33.39%</td>
<td>47.78%</td>
<td>48.65%</td>
</tr>
<tr>
<td>Net fixed assets</td>
<td>96,333</td>
<td>375,700</td>
<td>723,463</td>
<td>1,364,206</td>
<td>1,227,785</td>
<td>1,105,007</td>
<td>385,292</td>
<td>346,763</td>
</tr>
<tr>
<td>Secured loans</td>
<td>95,755</td>
<td>404,455</td>
<td>785,105</td>
<td>1,251,397</td>
<td>958,803</td>
<td>636,949</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Share capital</td>
<td>33,333</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Reserves and surplus</td>
<td>27,833</td>
<td>67,719</td>
<td>155,125</td>
<td>1,339,079</td>
<td>1,792,885</td>
<td>2,307,717</td>
<td>10,174,063</td>
<td>11,224,254</td>
</tr>
<tr>
<td>Cash flow from operating activities</td>
<td>31,813</td>
<td>63,217</td>
<td>169,852</td>
<td>666,929</td>
<td>680,925</td>
<td>695,864</td>
<td>1,031,634</td>
<td>1,079,414</td>
</tr>
<tr>
<td>Cash flow from investment activities</td>
<td>-107,037</td>
<td>-321,111</td>
<td>-428,148</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cash flow from financing activities</td>
<td>119,513</td>
<td>384,922</td>
<td>302,139</td>
<td>-411,122</td>
<td>-388,474</td>
<td>-385,548</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
expected on long term finance including equities. The discounted payback period is 6 years. Based on these three measures of the base case scenario, the PNGP is very profitable.

**Sensitivity Analysis**

Table 37 shows that for a 120 KW unit, pine needles account for 37% and interest charges for 14.76% of the revenues. Various profitability and viability measures would shift in unfavorable direction if pine needles and interest rates experience unfavorable volatility. Conversely, the gasifier project could be more profitable if the movement in these costs is in favorable direction.

<table>
<thead>
<tr>
<th>Major Cost-heads as % of Revenue for a 120 KW Unit</th>
<th>USD</th>
<th>% of Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total revenue</td>
<td>64,870</td>
<td>100%</td>
</tr>
<tr>
<td>Pine needle cost</td>
<td>24,235</td>
<td>37.36%</td>
</tr>
<tr>
<td>Charcoal cost</td>
<td>2,555</td>
<td>3.94%</td>
</tr>
<tr>
<td>Employee cost</td>
<td>5,999</td>
<td>9.25%</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>3,021</td>
<td>4.66%</td>
</tr>
<tr>
<td>Interest cost</td>
<td>9,575</td>
<td>14.76%</td>
</tr>
</tbody>
</table>

As described in the methodology section, sensitivity analysis is used to determine how changes in an input variable impact a particular output variable under a given set of assumptions. For the purpose of financial evaluation of the PNGP, the output variable is NPV. Table 13 shows that pine needle cost is 37.36% of the revenue, therefore it is likely to have high impact on the cash flows of the PNGP which in turn determines NPV. Similarly, interest cost is 14.76% of the revenue; therefore it is likely to have some impact on the NPV. In order gain better understanding of the sensitivity of NPV, two other variables are also considered- changes in the project capital cost and the changes in capital subsidy.
Table 38 shows that, keeping other input variable constant, a 25% increase from the current cost in the cost of pine needle results in 29% decrease in NPV. If the pine needle cost goes up by 86%, NPV decreases by 100%, i.e. it turns negative. Current cost of the pine needle is 0.017$ per kg, if it goes up to 0.034$ per kg, NPV for the project is negative.

Table 38 NPV Sensitivity for Pine Needle Cost

<table>
<thead>
<tr>
<th>Percent Change in Cost of Pine Needle</th>
<th>-10%</th>
<th>-5%</th>
<th>Current</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
<th>25%</th>
<th>86%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in NPV</td>
<td>12%</td>
<td>6%</td>
<td>0</td>
<td>-6%</td>
<td>-12%</td>
<td>-18%</td>
<td>-23%</td>
<td>-29%</td>
<td>-100%</td>
</tr>
</tbody>
</table>

Table 39 shows that if the expected rate of return increase 2.5 times of the current rate, NPV decreases by 50% from the current level. However, 150% increase in interest rate is unlikely because of various financial support provided by the IREDA.

Table 39 NPV Sensitivity for Expected Rate of Return

<table>
<thead>
<tr>
<th>Interest Rate</th>
<th>10%</th>
<th>12.5%</th>
<th>15%</th>
<th>17.5%</th>
<th>20%</th>
<th>22.5%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in NPV</td>
<td>0</td>
<td>-11.1%</td>
<td>-20.9%</td>
<td>-29.5%</td>
<td>-37.1%</td>
<td>-44%</td>
<td>-50%</td>
</tr>
</tbody>
</table>

Table 40 shows that if the fixed cost goes up by 25% from the current level then the NPV decreases by 12.5%. Table 17 shows that even if capital subsidy provided by the government is retracted, NPV decreases by only 14.89%.

Table 40 NPV Sensitivity for Fixed Cost

<table>
<thead>
<tr>
<th>Percent Change in Fixed Cost</th>
<th>Current</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in NPV</td>
<td>0</td>
<td>-2.5%</td>
<td>-5%</td>
<td>-7.5%</td>
<td>-10%</td>
<td>-12.5%</td>
</tr>
</tbody>
</table>

The project NPV is most sensitive to the cost of pine needle (Table 41). The interest cost, fixed cost, and capital subsidy are not likely to change much from the current level as they are supported and incentivized by various government schemes. The cost of pine needle is dependent
on the local factors which promoter cannot control. As stated in the literature review section, the discount rate in the NPV model is an important factor that impacts the NPV level. Therefore, for the simulation cost of pine needle and discount rates are allowed to change simultaneously.

<table>
<thead>
<tr>
<th>Percent Change in Capital Subsidy</th>
<th>Current</th>
<th>-10%</th>
<th>-20%</th>
<th>-30%</th>
<th>-50%</th>
<th>-80%</th>
<th>-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in NPV</td>
<td>0</td>
<td>-1.49%</td>
<td>-2.98%</td>
<td>-4.47%</td>
<td>-7.45%</td>
<td>-11.91%</td>
<td>-14.89%</td>
</tr>
</tbody>
</table>

**Simulation Set-up**

At the simulation stage, three variables are allowed to change simultaneously—pine needle cost, discount rate, and the tariff for electricity sale. The Panel is of the opinion that the growth in the variable tariff should be considered at an average rate of 5% over the 20 years period as provided in the UPCL policy, however, the possibility that promotional tariff offered to any RET based projects—including those based on biomass—could be discontinued sometime in the future cannot be ruled out.

As stated in the literature review section, NPV is computed as:

\[ \sum_{t=0}^{T} \omega_t \{ [R_t - O_t - DEP_t - Int_t] + Dep_t \} - [\Delta Investment_t + \Delta WC_t] + \Delta D_t \]

Where \( \omega_t \) is inverse of expected post-tax return on investment in year \( t \).

In order to observe the effect of variations in three most significant variables—revenues from electricity sale to the UPCL, pine needles cost per kg, and the expected discount rate on the viability and profitability of the PNGP, 18 different scenarios have been conceived (Table 42). Each scenario assumes a unique combination of three variables. Within each scenario, each variable is allowed to vary with certain parameters values as suggested by the Panel.
Table 42 Simulation: Input Variable Statistic

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Tariff (USD)</th>
<th>Yearly Growth in Pine Needles Cost (%)</th>
<th>Yearly Discount Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uniform Distribution (Two Levels)</td>
<td>Normal Distribution</td>
<td>Log-Normal Distribution</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>0.062</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>3</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>4</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>5</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>6</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>7</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>8</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>9</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>10</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>11</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>12</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>13</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>14</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>15</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>16</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>17</td>
<td>0.042</td>
<td>2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>18</td>
<td>0.042</td>
<td>4%</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

Each scenario undergoes 50,000 iterations with the varying levels of input variables. The 50,000 iterations are likely to cover a wide range of situations, from worst case to the best case. NPV is computed for each iteration and subsequently 50,000 NPV computations are compiled into an NPV distribution with its mean, standard deviations, and other distribution statistic.

**Simulation Results**

The simulation is performed with a Visual Basic (VB) macro written into Excel Spreadsheets. The VB program randomly generates values from specified distribution of input variables and feeds them into NPV model for each of 50,000 iterations within a scenario. For each of the 18 scenarios, simulation output results in a distribution of NPV.
Table 43 shows the estimated quantiles for the normal distribution of NPV for each scenario. Scenarios 15, 16, 17, and 18 display negative NPV at least for one quantile. Output shows that higher expected return and increased volatility in expected return from the PNGP, keeping levels of other input variables constant, results in higher estimated median NPV. Similarly, higher annual rate of growth and increased volatility in PN cost, keeping levels of other input variables constant, results in lower estimated NPV. The lower tariff-without feed-in-tariff support- results in negative median NPV at every level of other input variable. Output for scenarios 13 & 14 show that, even at subsidized feed-in tariff (USD 0.062), if the PNGP receives a negative shock higher rate of growth in PN cost (4%) and higher expected return (18%) , the estimated median NPV is USD 547,000 over twenty year period at an initial investment of USD 2.2 million, which makes the project unattractive for the entrepreneurs.

Goodness of fit test for normal distribution is performed for each scenario output. Altman et al. (Altman and Bland 1996) suggest that various statistical normality tests for large samples (above 1000) are very sensitive. The 50,000 iteration for each scenario constitute a large sample, the Kolmogorov-Smirnov (K-S) and Anderson-Darling test for normality of the NPV for each output show that that the null hypothesis that the NPV output is normally distributed cannot be rejected at 0.05 significance level. The comparison of observed quantile distribution with the estimated quantile under the assumption of normality reveals little difference. Kurtosis and Skewness, and visual inspection of histogram of NPV output also suggest that the outputs are indeed normally distributed. The NPV distribution chart for few scenarios and corresponding skewness and kurtosis statistics is shown in the Figures 20 to 26.
Table 43 Simulation Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Tariff (USD)</th>
<th>Yearly Growth in Pine Needles Cost (%)</th>
<th>Yearly Discount Rate</th>
<th>Results (000 USD)</th>
<th>Quantiles for Normal Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant</td>
<td>Normal Distribution</td>
<td>Log-Normal Distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Levels</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>0.062</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15%</td>
</tr>
<tr>
<td>2</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>3</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>4</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>5</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>6</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>7</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>8</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>9</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>18%</td>
<td>4%</td>
</tr>
<tr>
<td>10</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>11</td>
<td>0.062</td>
<td>3%</td>
<td>1%</td>
<td>18%</td>
<td>4%</td>
</tr>
<tr>
<td>12</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>13</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
<td>18%</td>
<td>4%</td>
</tr>
<tr>
<td>14</td>
<td>0.062</td>
<td>4%</td>
<td>2%</td>
<td>20%</td>
<td>4%</td>
</tr>
<tr>
<td>15</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>31%</td>
<td>2%</td>
</tr>
<tr>
<td>16</td>
<td>0.062</td>
<td>2%</td>
<td>0.5%</td>
<td>31%</td>
<td>4%</td>
</tr>
<tr>
<td>17</td>
<td>0.042</td>
<td>2%</td>
<td>0.5%</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>18</td>
<td>0.042</td>
<td>4%</td>
<td>2.0%</td>
<td>15%</td>
<td>4%</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>Scenario 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (000)</td>
<td>1,347.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>108.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kurtosis</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>925.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>1,839.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (000)</td>
<td>1,095.87</td>
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<tr>
<td>Kurtosis</td>
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<tr>
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<tr>
<td>Minimum</td>
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<tr>
<td>Maximum</td>
<td>1,625.29</td>
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</tbody>
</table>

Figure 20 Scenarios 1&2
Scenario 3

Mean (000) 1,242.33
Standard Deviation 227.56
Kurtosis 0.85
Skewness 0.57
Minimum 537.11
Maximum 3,141.05

Scenario 4

Mean (000) 950.71
Standard Deviation 96.93
Kurtosis 0.09
Skewness 0.18
Minimum 583.03
Maximum 1,463.92

Figure 21 Scenarios 3&4
Figure 22 Scenarios 5&6

<table>
<thead>
<tr>
<th>Scenario 5</th>
<th>Scenario 6</th>
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### Scenario 7

- Mean (000) 1,241.21
- Standard Deviation 225.11
- Kurtosis 0.55
- Skewness 0.51
- Minimum 452.04
- Maximum 2,606.21

### Scenario 8

- Mean (000) 688.91
- Standard Deviation 67.00
- Kurtosis 0.08
- Skewness 0.18
- Minimum 402.39
- Maximum 1,031.08

Figure 23 Scenarios 7&8
Figure 24 Scenarios 12 & 13

<table>
<thead>
<tr>
<th>Scenario 12</th>
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<td>1,558.92</td>
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Figure 25 Scenarios 14&15
Scenario 17

Mean (000) -333.32
Standard Deviation 51.75
Kurtosis 0.06
Skewness 0.10
Minimum -521.32
Maximum -72.12

Scenario 18

Mean (000) -616.55
Standard Deviation 131.47
Kurtosis 0.18
Skewness 0.04
Minimum -1,295.3
Maximum 8.50

Figure 26 Scenarios 17&18
Chapter 4: Stakeholder Perspective on Supplying Pine Needles to a Gasification Project in Uttarakhand, India

Introduction

In recent years, volatility in fossil fuel prices has spurred research in energy production from biomass. Unlike solar and wind energy production where energy sources—sunlight and wind—are naturally delivered to the production units, biomass energy production requires its energy source to be transported to the production unit. Various researches have shown that development of biomass energy sector requires concomitant development in new supply chain and labor pool to ensure sustained biomass feedstock to biomass energy production units. The fossil fuel industry has been able to lower the production and supply chain costs by standardizing various processes, technologies, and equipment. In contrast to fossil fuel energy units, depending on technology used, feedstock type, and geographical location each biomass energy project is unique. A number of technologies are available to convert biomass into energy; however, arguably the most difficult part of establishing a biomass energy unit is to bring low energy density feedstock to the energy production site. Since biomass feedstock usually has low energy density and higher volume, therefore requires more resources to transport. Distinct features of a particular feedstock type in a particular location necessitate development of a unique collection and delivery mechanism.

Management of overall risk associated with a biomass energy project entails a streamlined feedstock supply chain. For example a large bio-based electricity project-100 MW upwards—may have 10 to 15 years of payback period, the fund providers may require a long term contract with feedstock suppliers before any fund is released to the project. Even a smaller project would be required to demonstrate some extent of sustained feedstock supply in terms of quantity, quality, and price, before any financing is provided. Since overall operational cost for
biomass energy units is typically between 60-80% of the total cost, in order to compete with fossil fuel energy biomass energy units need to control the cost and supply of feedstock as it is one of the important determinants of the viability of a bio-based project.

In the context of India, the research has largely been focused on assessment of potential availability of the biomass for the purpose of bioenergy production. However, potential availability of biomass may not always translate into actual supply of feedstock. One of the most important aspects of the supply-chain for the feedstock is the willingness of potential feedstock suppliers. This study aims to understand the determinants of the willingness of the feedstock suppliers. For the purpose of generating a willingness measure and identification of factors underlying the willingness, a case of pine needle based electricity generation in Uttar hand, India is considered.

**Study Area: Uttarakhand**

Carved out of a larger state Uttar Pradesh in the year 2000, Uttarakhand is one of the newer states of India (Figure 27). A 93% of the state’s geographical area of 53,485 square km is mountainous. According to State of Forest Report, India (MoEF), approximately 34,650 square km area is under forest cover. The recorded forest area constitutes 64.8% of the total geographical area, although the actual cover based on remote sensing and satellite imagery information is only 44%(FSI 2011). The overall literacy rate of the state stands at 79.6% comprising 88.3% literacy among males and 70.7 percent among females.

For 70% of the households in the region, agriculture is the primary source of livelihood. The average size of farm land holding is around 0.68 hectare in the hills and 1.77 hectare in the plains. Out of the 0.9 million farming households in the state, 88% are small and marginal farming households owning less than 2 hectares of farmland. The subsistence nature of agriculture in the hill districts provides low and unstable annual income to rural households.
The poor state of agriculture has contributed to substantial out-migration of male members from the family, leaving behind a large number of female-headed households. Approximately 36.5% of the population of the state lives below the poverty line (Bhagirath Behera 2011). According to National Sample Survey of India (NSS 2009), in the Uttarakhand state, 92.1% of household are Hindus, 6.2% are Muslims and 1.2% are Sikhs. The overall sex ratio in Uttarakhand is 1021 females, per 1000 males, which implies, as reported in many studies, a marked difference from the other states of India where households have preference for the male child (Uttarakhand 2009). Primary Census Abstract of 2011 shows that population proportion of the study area living in urban area is 14.3%, which indicates that the study area is predominantly rural. There is a large presence of the non-residents of Uttarakhand state in the Indian armed forces. Each summer, people living near and within the forests of Uttarakhand
brace themselves against forest fires that threaten their livelihood along with the forest ecosystem and biological diversity. In 1999, a fierce fire raged through the forests of Garwhal and Kumaon regions in Uttarakhand. The NSRA (National Remote Sensing Agency), Hyderabad, reported that about 22.64% (5,087 square km) of the forest area was burnt while about 1,225 square km was severely affected. While the fire of year 1999 was devastating, smaller forest fire occur regularly (Joshi & Singh). Frequent fires increase opportunities for invasive species resulting in slower recovery for native plant species. Along with the diminished biodiversity, the forest fires threaten the livelihood of people dependent on forest for fodder, fuel, and water. The fires usually break out between February and June in the coniferous Chir Pine forests at the 1000-1800m elevation range. The combustible pine needles carpeting the forest floor are one of the chief causes of the forest fires.

**Literature Review**

There is a large body of research focused on potential supply of cellulosic biomass for bioenergy production keeping in view the stated goals of various countries of harnessing alternative energy sources (Gallagher, Dikeman et al. 2003, Daniel, English et al. 2007, Nelson, Langemeier et al. 2010, Kuhlman, Diogo et al. 2013). Most of these studies focus on technical and economic feasibility, and the potential quantity of biomass supply chain. The question that under what social, economic, and institutional conditions the potential availability of biomass is translated into actual supply to the energy projects remains largely unexplored. Rajgopal et al. (Rajagopal, Sexton et al. 2007) underscore the need to understand the factors that lead to the participation by farmers in the supply chain of bioenergy industry. A study by Bergtold et al. (Bergtold, Fewell et al. 2011) considers the question: How likely is it that farmer are willing to adopt biofuel crops (e.g. switchgrass) with underdeveloped or nonexistent markets? They surveyed the Kansas farmers’ willingness to produce sweet sorghum as feedstock for biofuel
production. The respondents were asked about their perception about biofuel feedstock production; risk management practices; crop marketing practices; and demographics. Survey participants were then asked to consider five independent choice-scenarios under a stated choice construct. David Smith et al. (Smith, Schulman et al. 2011) also used a stated choice construct to survey the willingness of agricultural landowner in Minnesota to supply perennial bioenergy crops. The survey respondents were asked to consider issues related with future land use, their interest and awareness about bioenergy; their perception about bioenergy and environmental issues.

**Biomass Feedstock Supply Literature in Indian Context**

There isn’t much literature that focuses on assessing the perception and attitude of stakeholders of the bioenergy sector in India. Most research in the bioenergy sector in India is focused on potential availability of various kinds of biomass and determining the unit cost of the bioenergy. Ravindranath et al (Ravindranath, Sita Lakshmi et al. 2011) have studied the implication of biofuel production on land use, food production , and environment in India. Julia E. Wright (Wright 2010) in her research has considered various types of woody biomass of India that holds potential as feedstock. She suggests a people-centered framework that incorporates community training programs, raising awareness among villagers in order to generate community support for off-grid wood-chip power plants in India. Shinoj et al. (Shinoj, Raju et al. 2010) in their article “Biofuels in India: Future Challenges” consider the aggregate supply of agricultural and forest biomass, constrained with their alternative uses, for the purpose of biofuel production. Shinoj et al suggest utilization of fallow land for the purpose of growing dedicated energy crops. Asok Raj et al. (Kumar and Ram Jeyanth 2012) concur with other studies and point out that despite sufficient availability of biomass in India the bioenergy sector has not realized its potential. They identify the uncertainty related with the supply of feedstock as
one of the reasons for the unrealized potential. Most researches on the subject of bioenergy production in India cite following reasons for such a state of bioenergy sector:

- **Land vs food:** Given the poverty levels in India, the conversion of land use from food production to energy crop production is unlikely. Large biomass-based energy projects are unviable in India, even smaller bioenergy projects will have to depend on forest and agricultural residues that have negligible alternative use.
- **Alternative uses of biomass:** In rural households, most agricultural and forest biomasses have alternative uses such as: cattle feed, cooking fuel, roof thatching, leaving the residue in the field to maintain soil quality. Therefore, the supply of agricultural and forest residue as feedstock for bioenergy production competes with other uses.
- **Logistics economics:** Long distance transportation of biomass is not economical because of inefficient transportation infrastructure in India.
- **Competition from other renewable energy technologies:** Other renewable technologies such as Solar, Wind, and Small Hydro have received far more attention from various stakeholders. The Government of India appears to be keener on solar energy than it is on biomass energy.

Despite low realization of biomass energy potential Ravindranath et al. state that biomass energy can be economically harnessed as captive energy projects in some industries and as small scale grid connected or off-grid energy projects in remote rural areas.

**Fodder and Fuelwood Extraction and Livestock Ownership**

The state of Uttaranchal is divided into plain and the hill regions. The forests of the state lie predominantly in the hill region. The forests are under community management via a mechanism called Van Panchayats. Forest Rights Act (2006) of India allows people living in and around the forests to extract minor forest products such as fuelwood and fodder from the forests. The amount of forest biomass extraction depends on socio-economic conditions of the region. In the Uttarakhand state, most amount of forest biomass is extracted from the Pine and Oak forests as fuelwood and fodder. In addition, Pine, Oak, and Cedar trees are also used for construction and furniture. Pine and Oak forests are overused and are depleting, since these species of trees are easily accessible from the villages located in the lower and mid elevation.
and Song 2012) in their study of biomass extraction in the Uttarakhand state indicate that the growing demand for fuelwood, fodder, and timber is the main factors underlying depletion of forest in the Uttarakhand state. Sati and Song report the dependence of state’s population on forest biomass for their livelihood, and that the forest biomass is excessively used during the winter months since villagers do not have any alternative energy source their daily heating uses. Sati and Song caution on the utilization of forest biomass for bioenergy stating that it should not come at the cost of sacrificing forest health and productivity, because from the socio-economic point view forest biomass is the most important source of wellbeing for the people in the region.

Rajive Pandey (Pandey 2011) in his study of the impact of fuelwood and fodder extraction on the carbon sequestration in the Uttarakhand forest concludes that huge quantity of extracted biomass is a major source of carbon emission, leading to reduction in quality of the forest. Pandey in his another study (Pandey 2012) states the necessity of balancing the knowledge, practices, and needs of multiple users, with global aims of biodiversity and sustainability for future generations. He stresses the need for limiting the human impacts such as overgrazing, lopping and cutting forest-forming species which are not allowed to develop to mature tree size-on the forests.

Livestock form an integral part of rural economy of the Uttarakhand state. Larger animals like bulls and buffalos are used for plowing the field and providing manure for the field. High diversity of livestock including cows, bulls, buffalos, sheep, goats, chickens is the characteristic features of the region. Milk from the livestock is used both for household consumption and for generating extra income by selling it. The state affords high potential of milk production because of availability of fodder as a form of extensive grasslands, which are locally known as bugyals or kharaks and fodder trees (Sati and Singh 2010). The fodder extraction from the forest depends on
the number of livestock owned by the household: Higher the number of the livestock, higher the amount fodder extraction from the forest.

Sati and Singh (Sati and Singh 2010) have studied the livestock ownership in the state, they estimate the amount of fodder needed to sustain different species of livestock. Dhanai et al. (Dhanai, Negi et al. 2014) also have estimated the per capita fuelwood and fodder extraction from the forests in the region. They found that 95% of the households of the region extract fuelwood and fodder from the forests depending on the livestock ownership and the household size. Singh and Sundriyal (Singh and Sundriyal 2009) have estimated the deficit in the availability of fodder for the livestock which has resulted in dwindling source of income from selling milk for some households of the region.

Dikshit and Birthal (Dikshit and Birthal 2010) classify livestock feed into roughages (green and dry fodders) and concentrates. Green fodder may come from

- Cultivated fodder crops,
- Grasses, weeds, and tree leaves gleaned and gathered from cultivated and uncultivated lands, and
- Grazing on common lands and harvested fields.

Dry fodder includes crop residues, most of which are cereal straws. Concentrates mainly come from food grains and other agricultural produce. Hooda et al. (Hooda, Gera et al. 2007) report that the fodder demand in the state is met mainly from forest areas (30–35%) and the remaining from cultivated land (20%) and community land (5%), agricultural residue and private grasslands constitute the remaining. Because average size of farmland holding in the hill region is quite small at 0.68 hectares, livestock owners have to depend on forests, grasslands, pastures and wastelands besides agricultural residues to meet the fodder requirements.
Chandra et al. (Chandra, Soni et al. 2008) also study the fuelwood and fodder consumption pattern in the area and conclude that:

In the hill areas, the traditional systems of dependence on forest usufructs like fuel for their households and fodder for their livestock has an important bearing on the status of Himalayan watersheds. The population of livestock is therefore also significant. The fuel and fodder requirements of the hill people are important routine activities for which women/children spend long hours of their day-to-day life. But this regular collection of the fuel and fodder from the different land use categories in close proximity of villages. These activities have been an important factor for causing soil erosion, low fertility of the land and other degradation processes. The situation is further aggravated if animals are not stall-fed but are allowed to graze.

Pandey (Pandey 2011) found that the majority of household in the hill regions of Uttarakhand visit forests on daily basis to extract fodder. During the monsoon, women of the households visit forest twice a day and in winter season on alternate days. The average daily time spent for fodder collection ranges from 2 to 5 hours, and average distance covered is around 5 km. Since the fodder extracted from the forest is free, therefore villagers consider this activity to be a profitable one. Pandey provides an estimate for the market price of green fodder extracted from the forests: Rs. 6.36 (USD 0.01) kg for green leaves and Rs 7.1(USD 0.012) per kg for green grass.

Bhatt and Sachan (Bhatt and Sachan 2004) found that fuelwood is also mainly collected by the women of the households in the region. They report that on average women use 55% of the total daily labor energy expenditure fuelwood collection. They note that there is no viable alternative to fuelwood as a source of basic energy for people living at the subsistence level. Sati and Song (Sati and Song 2012) in their study found that in villages located at the lower altitude, fuelwood is extracted from Pine forest and the consumption is comparatively low (12 kg/day/HH), while in the villages located at the higher altitude; fuelwood is extracted from the Oak forest with high consumption (27 kg/day/HH). They also report that fuelwood is collected
everyday throughout the year. They found that forest tree lopping is a common practice among villagers of the region. The lopping is carried out around 244 days of the year.

Pandey et al. (Pandey, Kannubhai et al. 2013) in their study indicate a link between the family size and the socio-economic status of the household. They found that larger household with lower income tends to collect more fuelwood and fodder from the forest of the region, as those extraction are free. The similar evidence for larger household with relatively higher household income is not available. From the literature following general inferences about the rural households of Uttarakhand can be drawn:

- The fodder and fuel wood collection forms an important element of the household livelihood in the region. Since, extraction from the commons is free of economic cost to the households, the extraction of fodder and fuelwood from the common forests is likely to continue in the near future.
- Most women and children are used to walking long distance and hours for the purpose of fodder and fuelwood collection.
- The number of livestock ownership may influence the amount of fodder collection by a household.
- The size of the households may influence the amount of fuel wood collection.
- Since, PN collection activity presents a potential household income enhancing opportunity to the households in the region, the amount of fodder and fuel wood collection, size of the household, livestock ownership, and the current household income may influence the willingness of villagers to collect PN.

**Social Decision of Villagers in Uttarakhand (Social Exchange Theory)**

Social Exchange Theory (SET) is among the most influential conceptual paradigms for understanding behavior of people in market settings. SET brings together various academic disciplines such as anthropology, social psychology, and sociology. Although, there are multiple points of views on SET, it is generally agreed among theorists that social exchange involves a series of interactions in a society that generate obligations (Emerson 1976).

Russel et al. in their review (Cropanzano and Mitchell 2005) of SET studies glean the essence of SET as being “Social exchange comprises actions contingent on the rewarding
reactions of others, which over time provide for mutually and rewarding transactions and relationships.” In order to establish mutually rewarding relationship over time, parties must abide by certain “rules” of exchange to form a normative definition of situation, which over time function as guideline of the exchange process. Therefore, the use of SET in models of behavior of participants is framed on the basis of exchange rule a researcher relies upon. Russell et al. has delineated the rules defined by various studies within SET framework.

**Reciprocity Rules**

Gouldner (Gouldner 1960) outline three different types of reciprocity within SET framework.

- Reciprocity as a transactional pattern of interdependent exchanges- parties can have at least three postures towards others
  - outcomes are entirely based on solo effort
  - outcomes are entirely based on others’ efforts
  - outcomes are based on involved parties’ efforts.
- Reciprocity as a folk belief-involves the cultural expectation that people get what they deserve. This posture is a combination of
  - a sense that over time all exchanges reach a fair equilibrium,
  - those who are unhelpful will be punished, and
  - those who are helpful will receive help in the future.
- Reciprocity as a moral norm- a standard that describes how one should behave, and those who follow these norms are obligated to behave reciprocally.

**Negotiated Rules**

Cook et al. (Cook, Emerson et al. 1983) outline negotiated rules within SET framework as: Parties in an exchange may also negotiate rules in the hope of reaching beneficial arrangements. They further point out that negotiated agreements tend to be more explicit and quid pro quo than reciprocal exchanges. In addition, the duties and obligations exchanged within negotiated agreements are fairly detailed and understood.

Russell et al. point out in their review of SET studies that the majority of the models in SET paradigm focus primarily on principles of reciprocity rather than altruism. They elaborate
that a great deal of research that compares negotiated with reciprocal exchange has converged on
the understanding that generally reciprocity establishes better work relationships than
negotiations and allows for parties to be more trusting of, and committed to one another.
Furthermore, negotiated exchanges generate more unhelpful power- use and less equality.

A Typology of Transactions and Relationships

For the purpose of understanding the willingness of the villagers to supply biomass
feedstock, the exchange typology developed by Russell et al. is instructive; they list two different
conceptualizations of relationships:

- Relationships can be regarded as a series of interdependent exchanges.
- Relationships can be regarded as the interparty attachment that results from a
  series of interdependent exchanges.

Two parties could engage based on manner and benefits of exchange. Russell provides a
framework (Table 44) for separating the exchange relationship from the form of exchange that
allows for understanding relationship situations.

<table>
<thead>
<tr>
<th>Transaction</th>
<th>Social Exchange</th>
<th>Economic Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Relationship</td>
<td>1- (Match) Social Transaction in a Social Relationship</td>
<td>2- (Mismatch) Economic Transaction in a Social Relationship</td>
</tr>
<tr>
<td>Economic Relationship</td>
<td>3- (Mismatch) Social Transaction in an Economic Relationship</td>
<td>4- (Match) Economic Transaction in an Economic Relationship</td>
</tr>
</tbody>
</table>

(Cropanzano and Mitchell 2005)

The cells 1 and 4 in Table 44 are termed as matches because the form of the transaction is
consistent with the type of relationship. Conversely, the cells 2 and 3 are termed as mismatches
because form of the transaction is not consistent with the type of relationship. As the literature
related with the biomass feedstock supply recommends a community centric approach in
establishing feedstock supply chain, the cell 2 – economic transaction in a social relationship is most relevant type of relationship for the most bioenergy projects in India. The cell 2 type of relationship offers both rewards and risks- a failure to discharge economic obligations could be seen as betrayal, which could result in permanent damage to the relationship. This kind of situation has already been observed with a few bioenergy projects in India that have closed down. However, there are potential advantages to this type of relationship such as: greater trust and therefore more commitment to the relationship are possible

**Study Objectives**

1. To estimate probabilities of villagers’ willingness to supply pine needles to the Pine Needle Gasifier Project (PNGP).
2. To identify determinants of villagers’ willingness to supply pine needles to the Pine Needle Gasifier Project (PNGP).

**Methods**

In order to understand and measure the willingness of people to collect and supply pine needle (PN), a willingness construct is defined. The context of the Pine Needle Gasification Project (PNGP) is considered within Social Exchange Theory (SET) paradigm. As mentioned earlier, engagement of rural households by the PNGP is essentially a “cell 2” case- an economic transaction in a social relationship - of the Social Exchange paradigm. This is so because PN collection and supply by the rural households is an economic transaction as the PNGP pays Rs.1 (USD 0.017) for a kg of PN. However, this enterprise takes place in a social relationship context. The cultural norms of the hill regions of the Uttarakhand are essentially community determined. The rural communities called Van Panchayats have traditionally been managing the common forests for centuries. Russell et al. point out that the cell 2 type of relationship offers both rewards and risks- as failure to discharge obligations could be seen as betrayal, which could
result in permanent damage to the relationship. Similarly, any action that is seen as violating the local social norms may also damage the relationship.

**Proposed Model**

As the literature review has shown that for a household in the study area, various variables, such as: size of the household, number of livestock owned, amount of fodder collection, amount of fuelwood collection, social norms, and demographic characteristics (age, education, income) are important factor underlying a household’s livelihood. Therefore, it is proposed that the determinants of households’ willingness to collect and supply PN for the PNGP will likely be a vector of demographic characteristics, and some latent (unobserved) dimensions. Assuming rational behavior, villagers are likely to maximize utility from the choices afforded by the socio-economic-geographical conditions they live in by exercising their subjective preference for either supplying PN to the PNGP or doing something else with their time and resources. Therefore the willingness to collect PN can be modeled as:

\[
\text{Willingness} = f (\text{demographic variables, fodder collection, fuelwood collection, household income, household size, latent dimensions})
\]

In order to explore the relationship between the willingness and the explanatory variables, a survey was designed to measure the explanatory variables.

**Latent Dimensions Affecting the Willingness**

Measures of latent theoretical constructs require multiple items to reveal varying levels of a construct (Netemeyer, Bearden et al. 2003). Seen in the context of cell 2 SET typology, i.e. PN collection enterprise is an economic transaction in a social relationship context, the willingness to collect pine needles is likely to have following underlying dimensions:
- Economic trustworthiness of the PNGP as perceived by the villagers.
- Potential harm to the common forests and its ecology due to the presence of the PNGP in the village.
- Viability perception about the electricity generation from PN -willingness may decline if the PNGP is perceived as unviable.
- The economic opportunity presented by the PN collection activity.
- Community and family consensus for participating in the PN collection activity.

Keeping these potential dimensions in mind a set of 24 perceptional statements/items are generated on five point Likert scale with following anchors:

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Social desirability bias, arising from villagers desires to appear cooperative was considered while generating the anchors for the Likert scale. Related literature (Garland 1991) suggests that the presence or absence of a mid-point produces distortions in the results obtained. The debate regarding the role of the mid-point persists, and several authors state that the offer of a mid-point is largely an individual researcher preference. For this study, the mid-point does not connote ignorance but a neutral perception about various aspects of PN collection activity.

Netemeyer et al. point out that dimensionality, reliability, and validity for constructs are interrelated. Dimensionality is related with homogeneity of the items. The 24 items within the set are closely related with PN collection activity and its effect on households, villages, and the forests. The reliability is related with replicability (test-retest) of the construct and internal consistency of the items on the construct. The test-retest aspect of reliability is out of the scope of this study, but internal consistency of the items can be ascertained with the help of Factor Analysis (FA).
**Statistical Methods**

Factor Analysis (FA): Factor analysis is used to examine how underlying constructs influence the responses on a number of measured variables. Exploratory Factor Analysis (EFA) aims to reveal the nature of the constructs influencing a set of responses, whereas Confirmatory Factor Analysis (CFA) tests whether a specified set of constructs is influencing responses in an expected way. This study aims to reveal the constructs that may influence the willingness of villagers to collect PN, therefore EFA is deployed. Both types of factor analyses are based on the Common Factor Model. This model proposes that each observed response is influenced partially by underlying common factors and partially by underlying unique factors.

Factor analyses are performed by examining the pattern of correlations (or covariance) between the observed measures. Measures that are highly correlated (either positively or negatively) are likely to be influenced by the same factors, while those that are relatively uncorrelated are likely to be influenced by different factors (DeCoster 1998). This study follows the EFA approach suggested by Hair et al. (Hair, Black et al. 2006). EFA is used as there isn’t any literature on a scale that is similar to the one required for this study which is willingness of the villagers to collect PN for the PNGP in the Uttarakhand state of India.

Hair et al. state that the primary purpose of EFA is to reveal the underlying structure among the variables in the analysis. These groups of variables are highly interrelated and represent dimensions within the data. In EFA, each measured variable $Y$ are linearly related with various factors in the following ways

\[ Y_1 = \beta_{10} + \beta_{11}F_1 + \beta_{12}F_2 \ldots + e_1 \]
\[ Y_2 = \beta_{20} + \beta_{21}F_1 + \beta_{22}F_2 \ldots + e_2 \]
\[ Y_3 = \beta_{30} + \beta_{31}F_1 + \beta_{32}F_2 \ldots + e_3 \]
The error terms $e_1$, $e_2$, and $e_3$, indicate that the hypothesized relationships are not exact. In the special vocabulary of factor analysis, the parameters $\beta_{ij}$ are referred to as loadings. For example, $\beta_{12}$ is called the loading of variable $Y_1$ on factor $F_2$.

The extracted factors are subsequently used in a Logistical Regression Analysis to estimate odds of willingness to collect PN for villagers.

Statistical Assumptions: Hair et al. (Hair, Black et al. 2006) write that for FA, departures from normality, homoscedasticity, and linearity apply only to the extent that these departures diminish the observed correlation. Normality of items is necessary only if statistical significance test is applied to the extracted factor. However, Hair et al. and Anna (Costello 2009) indicate that statistical significance test to the extracted factors is rarely applied. The most items on the sample, however, fail usual normality tests such as Kolmogorov-Smirnov test and Anderson-Darling tests at 0.05 level of significance.

Sample Size Requirement for Factor Analysis

Hair et al. suggest that subject to item ratio in EFA should be minimum 10:1. Anna Costello (Costello 2009), however, reports in her meta-analysis of the studies using EFA that majority of the studies -63% of the surveyed studies- use subject to item ratio lesser than 10:1. Anna Costello suggests that the strong data- high communalities (0.4 to 0.7 in social-sciences) without cross loadings- may still produce accurate results. For this study, a set of 24 items are analyzed with 155 subjects (subject to item ratio-6:1). Various other statistical issues related with FA are discussed while interpreting the results.

Multiple Logistic Regression (MLR)

Hair et al. describe Logistic Regression as a specialized form of regression that predicts and explains a binary (two-group) dependent variable on the basis of metric or categorical explanatory variables. In the context of this study, the dependent variable -willingness to supply
or not supply PN is a categorical variable. MLR estimates the relationship between a single non-
metric (binary) dependent variable and a set of metric or nonmetric independent variables, in this
general form:

\[
Y_1 = X_1 + X_2 + X_3 + \cdots + X_i,
\]

MLR is widely used in situations where the objective is to identify the group to which an
object (e.g., person, firm, or product) belongs. The situations include the present case where a
subject may be willing or not willing to collect PN on behalf of the PNGP. In each instance, the
subjects would fall into one of two groups, and the objective is to predict and explain the basis
for each subject's group membership through a set of independent variables selected by the
researcher. The following formulation of MLR is referred from Agresti (Agresti 2002):

For a binary response variable \( Y \), \( \pi(x) \) denotes the “Willingness=No” probability at value
\( x \). This probability is the parameter for the binomial distribution. The model denotes the \( k \)
predictors for a binary response \( Y \) by \( x_1, x_2, \ldots, x_k \). The MLR model has linear form for the
logit of this probability:

\[
\text{Logit} [\pi(x)] = \log \left( \frac{\pi(x)}{1 - \pi(x)} \right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k
\]

Or

\[
\text{Logit} [P (\text{Willingness} = \text{No})] = \log \left[ \frac{\text{Prob}(\text{Willingness}=\text{No})}{(1 - \text{Probability}(\text{Willingness}=\text{No}))} \right]
= \log \left[ \frac{\text{Prob}(\text{Willingness}=\text{No})}{(\text{Prob}(\text{Willingness}=\text{yes}))} \right]
\]

\[
[\text{Prob (Willingness = No) / (Prob (Willingness = yes))} \text{ is called Odds of indicating “No”}
to the PN collection. The parameter \( \beta_i \) refers to the effect of \( x_i \) on the log odds that Willingness =
No, controlling the other \( x_s \). For example, \( \exp (\beta_i) \) is the multiplicative effect on the Willingness
odds of a unit increase in \( x_i \), at fixed levels of the other \( x_s \).
The MLR implies the following formula for the probability $\pi$ (variate), using the exponential function:

$$
\text{Probability (willingness of a subject)} = \frac{\exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k)}{1 + \exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k)}
$$

The interpretation of the logistic regression model uses the odds and the odds ratio. The exponential relationship provides an interpretation for $\beta$: The odds multiply by $e^\beta$ for every unit increase in $x$. That is, the odds at level $x + 1$ equal the odds at $x$ multiplied by $e^\beta$.

Statistical Assumptions of Multiple Logistic Regression (MLR): Hair et al. state that the advantage of LR over discriminant analysis and multiple regression is that general lack of assumption in LR, as it does not require any specific distributional form for independent variables, and issues such as heteroscedasticity do not come to play as it does in discriminant analysis and multiple regression.

Sample Size Requirement for MLR: All things being equal, overall sample size requirement for Maximum Likelihood Estimation (MLE) (used in MLR) technique is higher than that of multiple regression based on Ordinary Least Square technique.

Agresti (Agresti 2002) describes a method to arrive at an optimum sample size for MLR estimation based on MLE. To determine sample size, the probability $\beta$ of failing to detect a difference between “($\pi_1$)” and “($\pi_2$)” on dependent variable for some fixed effect size is important. For any size of effect, $\beta$ is the probability of failing to reject $H_0$ at the level. Then, $\alpha = P$ (type I error) and $\beta = P$ (type II error). The power of the test equals $1 - \beta$. Agresti provides the formula for calculating sample size requirement for approximately equal cases in the sampling cells as:

$$
(z_{\alpha/2} + z_\beta)^2[\pi_1(1 - \pi_1) + \pi_2(1 - \pi_2)]/\pi_1 - \pi_2)^2
$$
Assuming the model should be able to detect difference between, for example $\pi_1 = 0.2$ and $\pi_2 = 0.3$ (an effect size difference of 0.1) at $\alpha = 0.05$ and $\beta = 0.1$, then the study would require 389 subjects in the sample. The sample size requirement would be even higher when there is high dissimilarity in number of cases available in different sampling cells, i.e. if some cells have very few cases and others have very high number of cases. However, this study has only 155 subjects. Since the population density in the remote Himalayan region is quite low, attempt was made to reach out to as many households as possible given the time and resource constraints.

**Survey**

The survey is targeted at people in the villages of Kumaun hills in the Indian central Himalaya district Pithoragarh of the Uttarakhand state of India. This population was chosen for the reason that the people of the region are aware of the PNGP operations, as AVANI has been operating a 9KW electricity generating unit for the past 7 years in the region. Some people in the villages have already participated in the PN collection activity. However, since a 9KW is a very small unit, therefore most people of the region, although are aware of the PNGP, but have not had much dealing with its operations. Since, this study is centered on estimating willingness of people of the region to collect PN for a much larger operation, general awareness about the PNGP was expected to yield more reliable responses on the survey instrument.

Three research associates, graduate students from a business school in India, helped the researcher in conducting the survey. Houses in many rural areas of Uttarakhand do not have a formal system of house address. A typical way of addressing a household would be to list the name of the household head and then the name of the village and some landmark. Most villages in the Himalayan region do not have more than 30 to 60 households. Local postal service employees have memorized the names of the heads of the households.
The literature based on the region and the pre-survey preliminary research in the area indicated that usually children of 10 to 15 year age and elders beyond 55 years also render some services to some domestic enterprise - agriculture, household based business, fuelwood and fodder collection. However, bulk of livelihood related responsibilities is borne by the people in the age group of 15-55 years. Since the younger males in hills usually migrate to the urban areas in search of employment, therefore main burden of work is shouldered by the women of households. In the households where younger males have migrated to the urban area, older males head the household, even though women carry out most of the work. Since, approaching women for their response on the survey could be a culturally sensitive issue; therefore the survey units were the male heads of the households. Each household-head was approached at the house. In some cases where head of the household happened to be a woman, permission of the village heads was sought before approaching the households and the survey was conducted in presence of males (usually children) or other females of the household or from the neighborhood. Each interview session lasted about 15 to 30 minutes.

**Survey Instrument**

Based on preliminary informal research in the region, a structured questionnaire was prepared to record information on household demography- household size, land ownership, livestock ownership, and sources of income. Details of utilizations of forest products such as fuelwood and fodder in different seasons, the number of hours spent in collecting the forest residue and the market price for the forest residues were also recorded. The information about the ownership of household assets, vehicle, type and the size of the dwelling was also collected (Annexure1).
Results

Descriptive Results: Demographic Variables

Age and Sex: Average age of the sample respondents is 43.28 years. The proportion of male-headed household is 85.5% and that of female-headed household is 14.5%. National Sample Survey of India reports that about 9.9% of households in the region are headed by females, and the median age of household head to be 48 years. The difference in the sample and the NSS statistic could be due to random sampling error of the studies or other exogenous factors.

Education: In India, the definition of various levels of education is as follows:

- High school: At least 10 years of education
- Intermediate: At least 10+2 years of education
- Graduate: At least 10+2+3(4) years of education
- Post Graduate: At least 10+2+3(4)+2 years of education

Figure 28 compares the education level of the household heads from the sample to that in the Census of India (2011) for the Uttarakhand region. The explanation for the difference between the proportions for education levels in the census and those in sample lies could be for the fact that this survey was undertaken in the year 2014, whereas Census figures were collated in the years 2009-2010. Literacy rate and the education levels in India have been improving steadily, therefore, this fact can account for higher proportion of higher level education in the sample.

Some respondents spoke to the researcher about reasons why boys and girls drop out of the school. They pointed out that girls mainly drop out of school because of one or more of the following reasons: they are required to help in the household work, help collect fodder and fuelwood from the forest. Boys drop out because they are not interested in studies, required to
help in the farm and household work, find that education expenses prohibitive, feel that higher education not necessary for the kind of work they do.

![Figure 28 Sample vs Census Education Estimates of Education Level](n=155)

Non-resident members of household: Almost half of the household in the area have at least one non-resident member (Table 45). The non-resident members are predominantly male who leave the area in search of better economic opportunities in bigger cities. Main triggers for migration are lack of employment opportunities, stagnant agriculture, very little industrial activity, and lack of health and educational services. The Ministry of Home Affairs report (GoI 2011) also shows that the most non-residents from the region have moved to urban areas.

<table>
<thead>
<tr>
<th>Non-resident Member</th>
<th>Sample Frequency</th>
<th>Sample Proportion</th>
<th>Census Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>80</td>
<td>51.6%</td>
<td>56%</td>
</tr>
<tr>
<td>yes</td>
<td>75</td>
<td>48.4%</td>
<td>44%</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

(n=155)
The report states that over 50% of the non-residents are outside the state, approximately 15% of the migrants are in the nearest metropolitan city Delhi. The report also points to the perception of stagnating rural economy.

As the census data for the education levels in the entire region shows that 85% of the population has less than intermediate level of education. This has implications for the type of work non-resident members would be able to attain in the cities. Most migratory workers from the region end up in low skill and low wage work in the cities. On the positive side of the migration story, migrant workers remit money back home that sustains and boosts the local economy. Moreover, migration of adult male members of the household prevents further subdivision of the already small landholding of households in the region.

However, there are several negative consequences of the migration. Migration of males from the region has increased the burden on the women. In most households women are responsible for fuelwood and fodder collection from the forest. Once the male members leave for cities; women have to help in agricultural activities as well. However, despite the hard work put in by the women of the region, agriculture is in decline. The vicious circle of the migration works as follows: declining agricultural income forces migration, which contributes to further neglect of the agricultural land and further decline in the productivity, which in turn again contributes to migration.

Traditionally most migrating men would work with Indian armed forces; however, the new generation seems to prefer private sector jobs in the cities which unlike armed forces usually does not provide for pensions. Pension used to form an important social security mechanism for a significant proportion of the households in the region. Migration has also contributed to depletion of skilled and able-bodied work force in the region, which reduces the potential for
entrepreneurial activities, contributing to stalling of the local economy. Deteriorating economic condition in the region has also contributed to rampant alcoholism, domestic violence, and reluctance to work among the male members of the households of the region. In addition to all this, a substantial proportion of the remittance income is spent on constructing cemented houses that doesn’t benefit the local economy, as the cement and other construction materiel is brought from the plains. The traditional construction workers who would work with wood and stones are left with declining work opportunities.

Primary sources of household income: The proportion of households reporting remittances (non-resident members sending money back home) as the main source of household income is 26.5%. Most employment opportunities in the region are with the government. Private enterprises are mostly family operated. Aggregation of the proportion sample of households dependent on remittance, employment (with government) implies that half of the households are dependent on income sources from outside the region (Figure 29).

The non-agricultural labor activities in the region are house construction, road construction, tourism, and timbre. Self-employed households are engaged in appliance repair,
electricity and plumbing repair, and furniture making activities. Self-employed households also supplement their income by selling dairy products, fruits and vegetables, and meat.

A study by Indian Institute of Technology Delhi (IITD) (IIT 2011) reports that close to 26.4% of the population in the Uttarakhand state is occupied in agricultural activities. The study further states that 23.9% of the households report agriculture as the main source of household income. However, the intensity of agricultural activities changes depending on the altitude of the mountains. In higher regions of Himalaya, most household are dependent on livestock related economic activities.

Pandey et al. (Pandey, Kannubhai et al. 2013) conducted a study in a region near the area of this study reports that 20.33% of the household are engaged in agricultural activity, 23.72% are engaged in labor, 13% are engaged in business (self-employment).

The population census 2011 for the entire state (including hill and the plain areas) reports that more than 58% (farmers + agricultural workers) of the workforce directly depends on agriculture for their livelihood. In the census data the proportion of such workers is much higher in the hill region (61.8 %) than the plain region (48.7 %). The comparison with the census 2001 figures shows a noticeable change in the proportion of workforce dependent on agriculture between these two regions- an increase of 38 % in the proportion of workforce dependent on agriculture in the plain area, but a decline of 8 % in the proportion of workforce engaged in agricultural activities in the hill region.

The census data reports the proportion of workforce, whereas sample for this study is composed of household heads. Since the agricultural activities typically involve the entire household, there may not be a large difference between the census and the sample figures about the dependency of people on the agricultural activities.
Livelihood in the Study Area based on Primary Sources of Income

Remittances and pension: Non-resident members of households remit money to the family on sporadic basis. Typically, non-resident members bring money when they visit the family. Mobile banking, wire transfers etc. are relatively rare yet. Pensions are transferred directly to the bank account.

Non-agricultural labor: Most types of work in this category involve physical labor. Income from the labor activity is more regular than that from the remittances. However, during the monsoon season and extreme winter conditions opportunities decline.

Agriculture: Agriculture is small and subsistence-based in scale. Most produce are used for the household consumption and very small proportion of the sample households manage to sell agricultural produce in the market. Traditionally, most households would consume what they would grow on their own lands. Since, agriculture is in decline; households now have to buy agricultural produce from the market.

Access to common natural resources: Almost all households on the sample own livestock that are kept to meet the households’ need for milk, manure, and in some cases for meat. Livestock are left to graze on common grass land, women of the household collect fodder and fuelwood from the community managed forests. The excess collection of fodder and fuelwood is sold in the informal market, or deficit is purchased from the informal market. The households that are regularly deficient in fodder and fuelwood typically have less number of members in the household.

Land-ownership: (Nali is the unit of measurement for agricultural land in Uttarakhand, 1 Nali = 2160 square feet). The average land holding of the sample household is 12.44 nalis (Figure 30), which is equivalent to 0.64 acres or 0.26 hectares. The IIT Delhi study (IIT 2011) finds almost similar extent of land holding at 0.27 hectares. IIT report states that in the mountainous
regions of Uttarakhand the proportion of marginal holdings (less than 1 hectare) has increased in recent years to about 81.5% (sample figure is 80%) and the remaining 18.5% were small holdings at 1-2 hectares.

The report further states, and which corresponds well with the observation of this research, that it is a typical characteristic of agricultural lands in hill region where terrace farming is practiced, characterized by small fragmented lands developed for the agricultural purpose at different altitudes. A 94% of the households have some agricultural land. 2% of households own agricultural land but do not operate it. The households that own land but do not cultivate it earn their livelihood from regular employment, self-employment, or remittance. Households that have very small landholding supplement their income from other sources such as milk selling and physical labor.

Household size: The average size of the sample household is 6.32 including the non-resident members (Figure 31). The Health survey conducted by the government (GoI 2011) for the Uttarakhand state reports the average household size at 4.1 members, however the
government report does not include the non resident member as a household member. A district
level survey conducted by the Ministry of Health and Family Welfare (Uttarakhand 2009)
reports the mean family size in the region to be 5.5, not including the resident member.

Figure 31 Number of Household Members
(n=155)

Joginder Singh (Singh 2009) in his study surveyed 1160 households in the Uttarakhand
region about their farming activities. He reports that average household size in the state to be 7.6
including the non-resident members. While National Sample Survey (NSS 2009) reports this
figure for the state as being 5.3 not including the non-resident member.

Below the poverty line (BPL) card: Below the Poverty Line card is issued by the
government to poor households. BPL is an economic poverty indicator used by the government
of India to identify households in need of government assistance and aid. A proportion of 71% of
the sample hold BPL card (Table 46).

BPL card carries several entitlements and rights to subsidized services such as cheaper
LPG, food subsidy etc.
Table 46 Below the Poverty Line Households

<table>
<thead>
<tr>
<th>BPL Card</th>
<th>Frequency</th>
<th>Sample Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>110</td>
<td>71%</td>
</tr>
<tr>
<td>No</td>
<td>45</td>
<td>29%</td>
</tr>
</tbody>
</table>

(n=155)

However, definition of BPL is a contested concept in India as most rural households’ income is unaccounted, and most households tend to under-report the household income for the fear of losing their BPL status. Many female headed households are also BPL households. Female-headed household with BPL status are the result of death of the earning male member of the family.

Households headed by older people without pension are also likely to be a BPL household. Very small household size or very large household size can also reduce a household to the BPL status. Households with small landholding and without recourse to pension or employment are also more likely to be BPL households.

Annual household income: The mean annual household income for the sample is Rs 50,133 (835 USD) (Figure 32). The IIT Delhi study (IIT 2011) reports the annual per capita income in the region to be Rs 11,535 (192 USD). The study also reports the mean household size to be 4.5 persons. Therefore, the mean household annual income, based on the study number, is Rs 51,900 (865 USD) which is very close to sample mean household income.

Livestock ownership: A number of studies have reported the average livestock ownership at the household level for the Uttarakhand state. There are large differences in the reported average livestock ownership numbers. Sati and Singh (Sati and Singh 2010) report average livestock ownership at 4.1 per household. Joginder Singh (Singh 2009) in a large sample based study reports livestock ownership in the range of 4.6 to 8.7 per household depending on the altitude.
The average livestock ownership per household for the sample is 7.9 animals per household (Figure 33). Almost all households in the sample own some livestock. The most important livestock animals are cows and buffaloes for milk, ox for agriculture, and goats for meat. Households with higher income keep buffalos and cows because their upkeep is more expensive compared with that of goats and sheep. Poorer households typically own poultry and goat for meat and eggs, as higher caste household tend to stay away from meat handling activity.
Monthly fuelwood consumption: Bhatt and Sachan (Bhatt and Sachan 2004) have estimated per capita fuel wood consumption in the hill regions of the state Uttarkhand. They report the fuelwood consumption to be 1.07, 1.10, 1.42, 2.00 and 2.80 kg per capita per day, respectively, at 500, 500–1000, 1000–1500, 1500–2000 and above 2000 m.

Since the study area lies at 1000-1500 m altitude, the mean monthly consumption of fuel wood for an average household size of 6 members would amount to 256 kg, which corresponds closely with the numbers from the sample of the study (Table 47). Bhatt and Sachan further state that fuel wood consumption was 2.61-fold higher at high altitude (above 2000 m) compared to fuelwood used at low (up to 500 m) altitude. At each altitude, the fuelwood consumption was highest in winter, followed by the summer and then monsoon.

Most studies on fuelwood consumption report the figures at per capita per day basis, however, this research has collected the fuelwood consumption data at per household per month basis. There is large variability in the literature about the amount of fuelwood consumption for the households in the region.

Table 47 Household Fuelwood Consumption

<table>
<thead>
<tr>
<th>Season</th>
<th>Monthly Fuelwood Consumption (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>240.8</td>
</tr>
<tr>
<td>Winter</td>
<td>491.5</td>
</tr>
<tr>
<td>Monsoon</td>
<td>232.3</td>
</tr>
</tbody>
</table>

For comparison with other studies, average household size of 6 members (excluding non-residents) is used to covert the reported figures to per household and per month basis. Bhatt and Sachan found that in winter season at an altitude of 1000-1500 m, a household with 6 members on an average consumes 376 kg of fuel wood (sample figure :491 kg), the corresponding number for summer and monsoon are 200 kg (sample figure : 240.8 kg), 230 kg (sample figure :
232 kg) respectively. However, Singh and Sundriyal (Singh and Sundriyal 2009) report higher figures at 510 kg of fuelwood consumption in winter. Chauhan and Silori (Chauhan and Silori 2004) report these figures at 630 kg in the winter and 210 kg during summer. Dhanai et al. (Dhanai, Negi et al. 2014) the figures at 390 kg for winter, 300 kg for summer, and 210 kg for monsoon.

Monthly fodder consumption: Dikshit and Birthal (Dikshit and Birthal 2010) estimate that the daily mean consumption of green fodder is 5.96 kg for a buffalo in-milk, 5.44 kg for a dry buffalo, 4.06 kg for an adult male buffalo and 2.29 kg for a young one. Corresponding consumption rate of dry fodder (from agricultural residue) is 6.34 kg for a buffalo in-milk, 4.95 kg for a dry buffalo, 7.47 kg for an adult male buffalo and 2.22 kg for young one. Goats consume 1.04 kg green fodder and 0.2 kg of dry fodder per day. The corresponding figures for sheep are estimated at 1.01 and 0.2 kg. If a household has 2 buffalos and 5 goats, then the monthly average requirement for the green fodder (forest fodder) would be 390 kg, and the corresponding figure for the dry fodder (non-forest fodder) would be 255 kg. These figures are very close to the survey numbers of this study (Table 48).

<table>
<thead>
<tr>
<th>Fodder Consumption (per month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources</td>
</tr>
<tr>
<td>Non-forest fodder</td>
</tr>
<tr>
<td>Forest fodder</td>
</tr>
</tbody>
</table>

Pandey (Pandey 2011) provides an estimate for the market price of green fodder extracted from the forests: Rupees 6.36 per kg for green leaves and Rupees 7.1 per kg for green grass. For the sample, reported average market price for the fuel wood is Rupees 6 per kg and for the green fodder it is Rupees 4.28 per kg. This price is reported on the basis of recall of the last transaction. Households that manage to collect more fodder and fuel wood than their
requirement; sell to other households in the local area. On the average households in the sample spends 4.96 hours every day collecting fuelwood and fodder from the forest. As stated earlier, the fuel wood and fodder collection activities are mainly the responsibility of women and children of the households.

Fuelwood and fodder collection vs consumption: Most households use up the fuelwood and fodder extracted from the forest within the household. However, there is an informal local market for fuelwood and green fodder. Any deficit/excess in fuelwood and fodder is bought/sold in the local informal market. Informal market in this case means asking neighbors if they want to sell/buy the fuelwood or fodder. Respondents were asked to recall the price at which they last bought or sold green fodder and fuel wood. The mean amount of fuel wood collection within the sample is very close to mean amount of fuelwood consumption (Table 49).

<table>
<thead>
<tr>
<th>Table 49 Household Fuelwood Consumption vs Collection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Price for fuel wood (Rupees/kg)</td>
</tr>
<tr>
<td>Fuel wood collection (per month in kg)</td>
</tr>
<tr>
<td>Fuel wood consumption (per month in kg)</td>
</tr>
</tbody>
</table>

There isn’t much difference in the mean fodder collection and consumption as well (Table 50). The sample data suggests that informal market for fuelwood and fodder are in equilibrium at the time of the survey. An important point to note about the per kg market prices (MP) of fuelwood and fodder is that they are significantly higher than what PNGP offers for pine needles.

<table>
<thead>
<tr>
<th>Table 50 Household Fodder Collection vs Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Price for forest fodder (Rupees/kg)</td>
</tr>
<tr>
<td>Forest fodder collection (per month in kg)</td>
</tr>
<tr>
<td>Fodder consumption (per month in kg)</td>
</tr>
</tbody>
</table>
However, fuelwood and fodder have alternative uses, but pine needles lying on the forest floors do not have much use in households.

Asset ownership: Most households have two generations living together. For most households, houses are inherited property. Traditionally, villagers use mud, stones, and wood to build the dwelling, but in recent years use of cement, brick, and iron is on the rise (Table 51). The reasons underlying the abandonment of traditional construction practices could be better connectivity by the roads, declining availability of local construction material, government restrictions on quarrying stones from the mountains, and the change in preference brought about by the migratory workers.

<table>
<thead>
<tr>
<th>Type of House</th>
<th>Frequency</th>
<th>Sample Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cemented</td>
<td>124</td>
<td>80%</td>
</tr>
<tr>
<td>Stone or wood</td>
<td>31</td>
<td>20%</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td>100%</td>
</tr>
</tbody>
</table>

Almost half of the sample households have a separate room for kitchen, and almost all households have a separate shed/room for the livestock, which indicates the high importance accorded to the livestock of the region. A 79% of the sample households have less than 6 rooms in their house (Table 52). The size of rooms typically does not go above 25² meters. Sabyasachi Kar (Kar 2007) report that in the year 2007, 51% of the households in the study area had electricity connection, 29% had toilets within the their house, and 25.6% had drinking water taps in the house. However, all sample households have the electricity connections, however, the supply of electricity remains intermittent and is available for not more than 10 hours every day.

<table>
<thead>
<tr>
<th>House Size</th>
<th>Frequency</th>
<th>Sample Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than three rooms</td>
<td>60</td>
<td>39%</td>
</tr>
<tr>
<td>3 to 5 rooms</td>
<td>62</td>
<td>40%</td>
</tr>
<tr>
<td>More than 5 rooms</td>
<td>33</td>
<td>21%</td>
</tr>
</tbody>
</table>
Ownership of communication and information devices has reduced the sense of isolation from the remote hill regions. A proportion 77% of sample household own a mobile phone (Table 53). These devices have also helped farmers and traders to forge links with outside markets. However, lack of storage and transportation facilities has prevented the local traders and farmers from benefiting from better market information. In any case, higher penetration of telecommunication devices has helped non-resident members to stay in touch with the family members.

<table>
<thead>
<tr>
<th>Asset</th>
<th>Frequency</th>
<th>Sample Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fridge</td>
<td>98</td>
<td>63%</td>
</tr>
<tr>
<td>Sewing Machine</td>
<td>121</td>
<td>78%</td>
</tr>
<tr>
<td>TV</td>
<td>122</td>
<td>79%</td>
</tr>
<tr>
<td>Fan</td>
<td>145</td>
<td>94%</td>
</tr>
<tr>
<td>Heater</td>
<td>57</td>
<td>37%</td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>120</td>
<td>77%</td>
</tr>
<tr>
<td>Two-wheeler</td>
<td>103</td>
<td>66%</td>
</tr>
<tr>
<td>Four-wheeler</td>
<td>15</td>
<td>10%</td>
</tr>
</tbody>
</table>

Willingness to supply agricultural and forest residue (other than PN): In the literature review section various cited studies indicate that in rural India agricultural residue has multiple alternative household uses. In the rural region of the hills forest residue such as tree branches, tree-leaves, and grasses also have high intensity of household use as fodder and fuelwood. Therefore it was anticipated that respondents of the sample will be reluctant to sell agricultural residue and forest residue at the same price that the PNGP is willing to purchase PN. The PNGP pays Rupees 1 for a kg of PN, whereas informal market price for the fuelwood and fodder is at least 4 times higher (discussed earlier) than the PN rate. In spite of this anticipation, the survey instrument includes some statements for respondents to indicate their agreement and disagreement (Table 54).
Most respondents in the sample indicate unwillingness to supply agricultural residue from their farms to an energy producer. Similarly, they also indicate unwillingness to supply forest residues—tree-branches and leaves—to the PNGP.

### Table 54 Willingness to Supply Agricultural and Forest Residue (other than PN)

<table>
<thead>
<tr>
<th>Statements</th>
<th>Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village willing to supply agri-residue</td>
<td>1.78</td>
</tr>
<tr>
<td>My family willing to supply agri-residue</td>
<td>2.41</td>
</tr>
<tr>
<td>Better to use agri-residue for household needs</td>
<td>3.74</td>
</tr>
<tr>
<td>Village willing to supply forest residue</td>
<td>1.82</td>
</tr>
<tr>
<td>Family willing to supply forest residue</td>
<td>2.50</td>
</tr>
<tr>
<td>Better to use forest residue for household needs</td>
<td>3.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

As discussed previously, the reason for the unwillingness is that agricultural residues are used for various purpose in the livestock rearing or left in the field to enhance soil productivity, and forest residues (other than PN) is used as cattle fodder and fuelwood. Moreover, the market price for a kg of agricultural residue and forest residue is higher than the price offered for PN.

**Statistical Analysis Results**

**Factor Analysis**

The set of 24 items are input into the SAS application. A subset of 5 items was deleted as they did not share sufficient variance with the rest of the set. The output displays Kaiser’s Measure of Sampling Adequacy (MSA) to be 0.67 which is regarded as moderately satisfactory (Hair et al.). The MSA signifies the extent of common variance in the data set items. Higher value of MSA signifies high degree of interrelatedness in the items. The aggregate variance accounted for by these 5 factors is 69.3 % of the total dataset variance (Table 55).
The Eigenvalues of the correlation matrix shows that corresponding number for 5 factors have higher values than 1, which suggests 5 to be the appropriate number of factors to be extracted. Scree-Plot (Figure 34) further confirms this interpretation.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Eigenvalue</th>
<th>Proportion</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.32</td>
<td>17.5%</td>
<td>17.5%</td>
</tr>
<tr>
<td>2</td>
<td>2.97</td>
<td>15.6%</td>
<td>33.1%</td>
</tr>
<tr>
<td>3</td>
<td>2.58</td>
<td>13.6%</td>
<td>46.7%</td>
</tr>
<tr>
<td>4</td>
<td>2.39</td>
<td>12.6%</td>
<td>59.2%</td>
</tr>
<tr>
<td>5</td>
<td>1.91</td>
<td>10.1%</td>
<td>69.3%</td>
</tr>
</tbody>
</table>

The output displays the Final Communality Estimate for the combined set of variables at 13.16. Examination of communalities of individual items also shows that none of the items has individual communality less than 0.49 (Table 56), as recommended by Hair et.al. and Anna Costello. The rotated factor pattern (Orthogonal Verimax) shows high loadings for items on individual factors. All 19 items display high loadings - 0.7 or above on a particular factor without
dual high loadings. Table 57 groups those items in one block which have higher than 0.6 loading on a particular factor. Groups are displayed in different colors. Within each group of items loading on a factor, the contextual associations are used to assign a name to that factor. As suggested by the scree-plot, a five factor structure seems to be most appropriate, as within each group of items, contextual cohesion is observed.

No Heywood cases are observed. Each factor has at least three items with high loadings. The items loading on individual factors suggest an underlying construct of the latent dimension that is influencing the respondents score on the items.

Table 56 Final FA Iteration: Item Communalities

<table>
<thead>
<tr>
<th>Items</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village will supply PN</td>
<td>0.82</td>
</tr>
<tr>
<td>Family will supply PN</td>
<td>0.84</td>
</tr>
<tr>
<td>Neighboring village will supply PN</td>
<td>0.57</td>
</tr>
<tr>
<td>PN income is not enhancing opportunity for family</td>
<td>0.76</td>
</tr>
<tr>
<td>PN income is not enhancing opportunity for village</td>
<td>0.83</td>
</tr>
<tr>
<td>PN project will supplement energy needs of village</td>
<td>0.53</td>
</tr>
<tr>
<td>Electricicty company employees are not fair in dealing</td>
<td>0.54</td>
</tr>
<tr>
<td>Price for PN is inadequate</td>
<td>0.70</td>
</tr>
<tr>
<td>PN collection will have negative impact on forest</td>
<td>0.79</td>
</tr>
<tr>
<td>Electricity generation will impair the air quality</td>
<td>0.64</td>
</tr>
<tr>
<td>PN removal will harm forests soil</td>
<td>0.68</td>
</tr>
<tr>
<td>Electricity from PN is viable</td>
<td>0.84</td>
</tr>
<tr>
<td>Viable technology for electricty from PN exists</td>
<td>0.57</td>
</tr>
<tr>
<td>Electricity generating unit will collect sufficient PN</td>
<td>0.63</td>
</tr>
<tr>
<td>Village will be able to supply sufficient PN</td>
<td>0.57</td>
</tr>
<tr>
<td>Electricity unit will operate for at least 5 yrs</td>
<td>0.49</td>
</tr>
<tr>
<td>I possess necessary tools for PN collection</td>
<td>0.87</td>
</tr>
<tr>
<td>Understand the process of PN collection</td>
<td>0.66</td>
</tr>
<tr>
<td>Family will find PN collection easy</td>
<td>0.82</td>
</tr>
<tr>
<td>Items</td>
<td>Viability</td>
</tr>
<tr>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>Electricity from PN is viable</td>
<td>0.91</td>
</tr>
<tr>
<td>Electricity generating unit will collect sufficient PN</td>
<td>0.79</td>
</tr>
<tr>
<td>Viable technology for electricity from PN exists</td>
<td>0.76</td>
</tr>
<tr>
<td>Village will be able to supply sufficient PN</td>
<td>0.75</td>
</tr>
<tr>
<td>Electricity unit will operate for at least 5 years</td>
<td>0.66</td>
</tr>
<tr>
<td>PN is not income enhancing opportunity for village</td>
<td>0.01</td>
</tr>
<tr>
<td>PN is not income enhancing opportunity for family</td>
<td>-0.09</td>
</tr>
<tr>
<td>Price for PN is inadequate</td>
<td>0.07</td>
</tr>
<tr>
<td>Electricity company employees are not fair in dealing</td>
<td>-0.07</td>
</tr>
<tr>
<td>Family will supply PN</td>
<td>-0.01</td>
</tr>
<tr>
<td>Village will supply PN</td>
<td>0.02</td>
</tr>
<tr>
<td>Neighboring village will supply PN</td>
<td>-0.01</td>
</tr>
<tr>
<td>PN project will supplement energy needs of village</td>
<td>-0.08</td>
</tr>
<tr>
<td>I possess necessary tools for PN collection</td>
<td>-0.01</td>
</tr>
<tr>
<td>Family will find PN collection easy</td>
<td>-0.08</td>
</tr>
<tr>
<td>Understand the process of PN collection</td>
<td>0.01</td>
</tr>
<tr>
<td>PN collection will have negative impact on forest</td>
<td>0.03</td>
</tr>
<tr>
<td>PN removal will harm forests soil</td>
<td>-0.03</td>
</tr>
<tr>
<td>Electricity generation will impair the air quality</td>
<td>0.03</td>
</tr>
</tbody>
</table>
The Table 58 assigns the names to the potential underlying dimensions corresponding to each Factor.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Name Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor 1</td>
<td>Viability dimension of PN gasifier project</td>
</tr>
<tr>
<td>Factor 2</td>
<td>Economic dimension of PN gasifier project</td>
</tr>
<tr>
<td>Factor 3</td>
<td>Family and community willingness to supply PN</td>
</tr>
<tr>
<td>Factor 4</td>
<td>Operational dimension of PN collection process</td>
</tr>
<tr>
<td>Factor 5</td>
<td>Environmental effect dimension of PN collection</td>
</tr>
</tbody>
</table>

Since Factor 2 and Factor 5 are negatively connoted items, therefore, a low score on factor 2 and 5 would indicate favorable perception of the PNGP. Higher score on Factor 1, 3, and 4 would indicate a favorable perception about the project.

**Factor Score Computation**

There are several methods of calculating factor scores. Various analytical softwares including SAS automatically generate regression based factor scores for each case. However, DiStefano et al. (DiStefano, Zhu et al. 2009) and Hair et al. suggest that the sum score method may be most suitable when the item scales are untested and exploratory in nature with little or no evidence of reliability or validity. Since, this survey is the first of its kind in the region, the item scales are indeed untested with little evidence for reliability. Hence, a sum score method is used to compute factor score for each subject (Table 59).

<table>
<thead>
<tr>
<th>Viability</th>
<th>Economic</th>
<th>Family and Community</th>
<th>Operations</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.41</td>
<td>3.45</td>
<td>3.54</td>
<td>3.37</td>
<td>2.51</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale</th>
<th>Viability</th>
<th>Economic</th>
<th>Family and Community</th>
<th>Operations</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Somewhat disagree</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Somewhat agree</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strongly agree</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DiStefano et al. further state that summed factor scores preserve the variation in the original data and that this approach is generally acceptable for most exploratory research situations.

A score lower than 3 on Viability indicates that respondents are somewhat skeptical of the viability of the PNGP. This factor is unlikely to contribute favorably to the willingness of the respondents to supply PN. The Economic Issues factor items have negative connotations therefore a score above 3 indicates that people view the economic opportunities offered by the PNG gasifier project somewhat unfavourably. Family and Community factor again has higher mean score than 3, which suggests that the respondents perceive an overall willingness to supply PN among their family members and neighbors. Factor Operations has a mean score higher than 3, indicating that respondents perceive the process of collecting and supplying PN as not very complicated. Environment factor items are negatively connotated, a lower mean score than 3 would mean favourable perception. Overall, respondents feel that PNG gasifier project will not harm the environment near their villages.

**Logistic Regression with the Extracted Factors**

The final question on the survey asks each respondent: “Will you be willing to participate in the pine needle collection program at Rupee 1 per Kg?” (hereafter this question is referred as WQ). The response choice-set for this question is binary: “yes” or “no”. The response on the WQ is used as the dependent variable in a logistic regression model with the extracted factors as explanatory variables.

Since the response choice set for the WQ is categorical, whereas the factor scores are continuous variables, a correlation analysis between a categorical and continuous variables will not be robust. The logistic regression in this case predicts the probability of indicating “yes” or “no”
on the WQ depending on the various combinations of scores of five factors. The responses on the WQ are shown in Table 60.

Table 60 Binary Response on the Willingness Question

<table>
<thead>
<tr>
<th>Willingness</th>
<th>Frequency</th>
<th>Sample Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>65</td>
<td>41.9%</td>
</tr>
<tr>
<td>Yes</td>
<td>90</td>
<td>58.1%</td>
</tr>
</tbody>
</table>

(n=155)

Table 61 shows that deviance and degrees of freedom ratio is close to 1, which indicates a reasonable fit. Table 62 reveals that Viability and Operations factors are not significant.

Table 61 Goodness of Fit for LR with Factor Scores

<table>
<thead>
<tr>
<th>Deviance Goodness-of-Fit Statistics</th>
<th>Value</th>
<th>DF</th>
<th>Value/DF</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviance</td>
<td>192.84</td>
<td>140.00</td>
<td>1.29</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 62 Coefficient Estimates for LR with Factor Scores

<table>
<thead>
<tr>
<th>Analysis of Maximum Likelihood Estimates</th>
<th>DF</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>-1.01</td>
<td>1.48</td>
<td>0.49</td>
</tr>
<tr>
<td>Economic</td>
<td>1</td>
<td>0.46</td>
<td>0.20</td>
<td>0.02</td>
</tr>
<tr>
<td>Family and Community</td>
<td>1</td>
<td>-0.63</td>
<td>0.25</td>
<td>0.01</td>
</tr>
<tr>
<td>Environmental</td>
<td>1</td>
<td>0.58</td>
<td>0.26</td>
<td>0.02</td>
</tr>
<tr>
<td>Viability</td>
<td>1</td>
<td>0.23</td>
<td>0.24</td>
<td>0.35</td>
</tr>
<tr>
<td>Operations</td>
<td>1</td>
<td>-0.21</td>
<td>0.22</td>
<td>0.33</td>
</tr>
</tbody>
</table>

As the Agresti (Agresti, 2002) suggests that for LR, if simpler model reduce the model deviance, they should be preferred over more complex ones. Since Viability and Operations factors are not significant, they are removed from the model.

**Interpretation of Logistic Regression with the Extracted Factors**

Economic Factor: With unit increase in Economic Factor score, the odds of choosing “no” on the WQ goes up by 58% (Table 63).
Family and Community Factor: With unit increase in the factor score, the odds of responding “no” on the WQ goes down by 47% (Table 63). The Family and Community factor indicates that the respondents with lower score have higher likelihood of indicating “no” on the WQ.

Environmental Factor: With unit increase in the factor score, the odds of choosing “no” on the WQ goes up by 78%. Although the Viability Factor accounts for 17.5% of the variance of the dataset, it’s not found significant in the model (Table 63). Environmental Factor accounts for 10.1% of the variance in the dataset. The respondents with higher score on this factor have lower likelihood of responding “no” on the WQ.

Table 63: LR with Factor Scores: Exponentiated Value of the Coefficient

<table>
<thead>
<tr>
<th>Factor</th>
<th>Exponent of Value of the Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>1.58</td>
</tr>
<tr>
<td>Family and Community</td>
<td>0.53</td>
</tr>
<tr>
<td>Environmental</td>
<td>1.78</td>
</tr>
<tr>
<td>Viability</td>
<td>1.26</td>
</tr>
<tr>
<td>Operations</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Similarly the Operations Factor, which accounts for 12.6% of the variance in the dataset, is not significant in the model. After removing the Viability and Operations Factors from the model, the deviance falls from 192 to 185 (Table 64). The sparser model is preferred over the saturated model. The Value/df is also not far from the ideal value of 1, as suggested by Agresti.

Table 64 Goodness of Fit for Simpler LR with Factor Score

| Deviance Goodness-of-Fit Statistics |
|-------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Criterion                           | Value           | DF              | Value/DF        | Pr > ChiSq       |
| Deviance                            | 185.84          | 140.00          | 1.33            | 0.01            |

Association of predicted probabilities and observed responses (Table 65) shows that in 68.6% of cases the observed response is also the expected response. The predictive power of the
Hosmer and Lemshow test (Table 66) also indicates that there are not large differences between
the observed and expected frequencies of each decile, therefore model is a good fit.

<table>
<thead>
<tr>
<th>Table 65 Association of Predicted Probabilities and Observed Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Concordant</td>
</tr>
<tr>
<td>Percent Discordant</td>
</tr>
<tr>
<td>Percent Tied</td>
</tr>
<tr>
<td>Pairs</td>
</tr>
</tbody>
</table>

Economic Factor accounts for 15.6 % of the variance in the dataset. Economic Factor
suggests that respondents with higher score have higher likelihood of indicating “no” on the WQ.
Family and Community Factor accounts for 13.6 % of the variance in the dataset.

<table>
<thead>
<tr>
<th>Table 66 LR with Factor Score: Hosmer and Lemeshow Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

**Multiple Logistic Regression : Willingness with Demographic & Latent Variables**

**Variable Description**

- Dependent Variable (Willingness): Binary, 0= not willing to participate in PN
collection activity,1= willing to participate in PN collection activity
- Fodder : (Metric) Average monthly consumption of fodder within a household.
- Household Income: (Metric) Average monthly household income
- Household Size: (Metric) Number of members in the household
• Fuelwood: (Metric) Average monthly consumption of fuel wood within a household
• Livestock: (Metric) Number of livestock owned by the household
• Economic: (Metric) Economic factor extracted from the FA analysis
• Family&Community: (Metric) Family and Community factor extracted from the FA
• Environmental: (Metric) Environmental Dimension factor extracted from the FA

The independent variables are on different scales, for example- household income is in units of thousands, Fodder and Fuelwood are in units of hundreds, for Household Size unit is in single digits, and the extracted factor scores do not go above 5. For this reason, all independent variables are standardized.

Pre-modeling Independent Variable Diagnostics

Pearson correlation matrix is generated for independent variables (Table 67). The correlations among the independent variables identify highly correlated variables which may cause the problem of collinearity in the model. The correlation matrix also points towards variables that are likely to be selected and retained in the step-wise LR model.

The correlations among the extracted factors from FA are not significant or high because the factors were orthogonally extracted, and therefore the correlation among these factors by design is low. The correlation coefficient between Fodder and Livestock is 0.65 and is significant. This is expected as the ownership of livestock increases the requirement for fodder for a household. The correlation coefficient between Fuelwood and Household Size is 0.91 and is significant. This suggests that larger households may be in position to collect more fuelwood from the forest. In rural areas, higher number of family members translates into more pair of hands, therefore higher motivation for collecting fuelwood and fodder from the forests.
Table 67 Correlation Matrix for Explanatory Variables

Pearson Correlation Coefficients, N = 155

<table>
<thead>
<tr>
<th></th>
<th>Fodder</th>
<th>Household Income</th>
<th>Household Size</th>
<th>Fuelwood</th>
<th>Livestock</th>
<th>Economic</th>
<th>Family Community</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fodder</td>
<td>1.00</td>
<td>0.04</td>
<td>0.12</td>
<td>0.13</td>
<td>0.65</td>
<td>0.03</td>
<td>0.10</td>
<td>-0.06</td>
</tr>
<tr>
<td>Household Income</td>
<td>0.04</td>
<td>1.00</td>
<td>0.02</td>
<td>-0.03</td>
<td>0.00</td>
<td>0.04</td>
<td>-0.12</td>
<td>-0.08</td>
</tr>
<tr>
<td>Household Size</td>
<td>0.12</td>
<td>0.02</td>
<td>1.00</td>
<td>0.91</td>
<td>0.16</td>
<td>-0.05</td>
<td>0.08</td>
<td>-0.03</td>
</tr>
<tr>
<td>Fuel Wood</td>
<td>0.13</td>
<td>-0.03</td>
<td>0.91</td>
<td>1.00</td>
<td>0.17</td>
<td>0.01</td>
<td>0.09</td>
<td>0.01</td>
</tr>
<tr>
<td>Livestock</td>
<td>0.65</td>
<td>0.00</td>
<td>0.16</td>
<td>0.17</td>
<td>1.00</td>
<td>-0.03</td>
<td>0.16</td>
<td>-0.03</td>
</tr>
<tr>
<td>Economic</td>
<td>0.03</td>
<td>0.04</td>
<td>-0.05</td>
<td>0.01</td>
<td>-0.03</td>
<td>1.00</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>Family Community</td>
<td>0.10</td>
<td>-0.12</td>
<td>0.08</td>
<td>0.09</td>
<td>0.16</td>
<td>0.10</td>
<td>1.00</td>
<td>0.06</td>
</tr>
<tr>
<td>Environment</td>
<td>-0.06</td>
<td>-0.08</td>
<td>-0.03</td>
<td>0.01</td>
<td>-0.03</td>
<td>0.13</td>
<td>0.06</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Prob > |r| under H0: Rho=0
Multiple Logistic Regression Model

\[
\text{Logit (Willingness)} = \beta + \alpha_1(\text{Household Income}) + \alpha_2(\text{Fodder}) + \alpha_3(\text{Fuelwood}) + \alpha_4(\text{Household Size}) + \alpha_5(\text{Livestock}) + \alpha_6(\text{Economic}) + \alpha_7(\text{Family & community}) + \alpha_8(\text{Environmental}) + \text{error}
\]

Hypotheses

- \( H_0 \): Household income level does not influence household’s willingness to collect PN for the PNGP
- \( H_0 \): Amount of monthly fodder consumption within a household does not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Amount of monthly fuel wood consumption within a household does not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Household size does not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Number of livestock ownership by a household does not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Economic Factor does not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Family and Community Factor do not influence the household’s willingness to collect PN for the PNGP
- \( H_0 \): Environmental Factor does not influence the household’s willingness to collect PN for the PNGP

Results

Model Goodness of Fit and Diagnostics

Agresti writes that a goodness-of-fit test for LR based on MLE technique compares the model fit with the data. This approach regards the data as representing the fit of the most complex model possible - the saturated model, which has a separate parameter for each observation. Large \( X^2(\text{Pearson}) \) or \( G^2(\text{Deviance}) \) values and small P-value provide evidence of lack of fit. The P value is the right-tail probability. The Goodness of fit tests (Table 68) show that model is a good fit, indicated by Value/df statistic which is 1.07 (should be close to 1).
The Hosmer-Lemeshow test (Table 69) uses a Pearson test statistic to compare the observed and fitted counts, where the null hypothesis is that there is no difference in observed and fitted counts. The chi-square probability for this test (Table 70) of the model is 0.49, suggesting a good fit. Hosmer-Lemeshow Goodness of Fit test indicates that there isn’t much difference in observed willingness and predicted willingness frequencies.

**Table 68 Multiple Logistic Regression: Goodness of Fit**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Value</th>
<th>DF</th>
<th>Value/DF</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviance</td>
<td>158.96</td>
<td>148</td>
<td>1.07</td>
<td>0.25</td>
</tr>
<tr>
<td>Pearson</td>
<td>152.99</td>
<td>148</td>
<td>1.03</td>
<td>0.37</td>
</tr>
</tbody>
</table>

**Table 69 Multiple Logistic Regression: Hosmer and Lemeshow Test**

<table>
<thead>
<tr>
<th>Group</th>
<th>Total</th>
<th>Willingness = 0</th>
<th>Willingness = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Expected</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>2</td>
<td>0.82</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>3</td>
<td>3.15</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>1</td>
<td>4.32</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>7</td>
<td>5.59</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>7</td>
<td>6.82</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>10</td>
<td>8.67</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>10</td>
<td>10.77</td>
</tr>
<tr>
<td>9</td>
<td>16</td>
<td>12</td>
<td>12.62</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>11</td>
<td>10.23</td>
</tr>
</tbody>
</table>

**Table 70 Hosmer-Lemeshow Goodness-of-Fit Test**

<table>
<thead>
<tr>
<th>Hosmer-Lemeshow Goodness-of-Fit Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>7.44</td>
</tr>
</tbody>
</table>

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Predictive Power of the Model: Summary

Maximum-rescaled $R^2$ value for the model is 38.2%. In 81.4% of the cases predicted class (Willingness=yes or no) is correctly predicted by the model (Table 71).

Agresti write that a more sophisticated test of predictive ability of the model is a Receiver Operating Characteristic (ROC) curve. The ROC curve is a plot of sensitivity as a function of (1-specificity) for the possible cutoffs $\pi_0$. Sensitivity is defined as proportion of respondents indicating “Willingness=Yes (1)” that are correctly predicted by the model. Specificity is defined as proportion of respondents indicating “Willingness=No(0)” are correctly predicted by the model.

<table>
<thead>
<tr>
<th>Association of Predicted Probabilities and Observed Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Concordant</td>
</tr>
<tr>
<td>Percent Discordant</td>
</tr>
<tr>
<td>Percent Tied</td>
</tr>
<tr>
<td>Pairs</td>
</tr>
</tbody>
</table>

When $\pi_0$ (cutoff probability) for a respondent to be categorized as “Willingness=No (0)” is near zero, then almost all respondents will be categorized as “Willingness=Yes (1)”. In the converse situation, when $\pi_0$ is near 1, then almost all respondents will be categorized as “Willingness=No (0)”. Agresti clarifies:

..an ROC curve summarizes predictive power for all possible $\pi_0$. When $\pi_0$ gets near 0, almost all predictions are estimated as= 1; then, sensitivity is near 1, specificity is near 0, and the point for (1 – specificity, sensitivity) has coordinates near (1, 1). When $\pi_0$ gets near 1, almost all predictions are $\hat{y} = 0$; then, specificity is near 0, sensitivity is near 1, and the point for (1 – specificity, sensitivity) has coordinates near (0, 0). The ROC curve usually has a concave shape connecting the points (0, 0) and (1, 1). For a given specificity, better predictive power corresponds to higher sensitivity. So, the better the predictive power, the higher the ROC curve. For a given specificity, better predictive power corresponds to higher sensitivity. So, the better the predictive power, the higher the ROC curve.
Higher the areas under the ROC (Figure 35) curve better the model. The ROC curve for the model is 0.81 (maximum possible area 1). The ROC curve area of 81% indicates a good fit of the data to the model.

**Model Estimates**

The stepwise LR model (variable enter at significance level 0.1 and exit at a significance level more than 0.1) is used to estimate the equation. The reason for using a relatively higher significance level for entering and exiting the variables is the fact that this is an exploratory study with a comparatively smaller sample size. At the significance level of 0.1, the null Hypotheses 2 (Fodder) and Hypothesis 7 (Family and Community) are rejected (Table 72).

![Figure 35 Model Fit Diagnostics for MLR: ROC Curve](image)

Since, the goal of the study is to explore the viability of the bioelectricity industry in the Uttarakhand state, the researcher wishes to reduce the probability of Type I error which translates into a small positive bias for finding a viable biomass gasification operation, and not rejecting viability on a stricter statistical grounds.
Table 72 Model Coefficient Estimates (only significant variables shown)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Wald Chi-Square</th>
<th>Pr &gt; ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-0.43</td>
<td>0.20</td>
<td>4.73</td>
<td>0.03</td>
</tr>
<tr>
<td>Household Income</td>
<td>0.87</td>
<td>0.22</td>
<td>15.71</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Household Size</td>
<td>-1.39</td>
<td>0.53</td>
<td>6.92</td>
<td>0.01</td>
</tr>
<tr>
<td>Fuel Wood</td>
<td>0.89</td>
<td>0.50</td>
<td>3.20</td>
<td>0.07</td>
</tr>
<tr>
<td>Livestock</td>
<td>-0.79</td>
<td>0.21</td>
<td>14.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Economic</td>
<td>0.36</td>
<td>0.20</td>
<td>3.17</td>
<td>0.07</td>
</tr>
<tr>
<td>Environment</td>
<td>0.47</td>
<td>0.20</td>
<td>5.29</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Model Interpretation

Interpretation of LR coefficients requires exponentiation of the coefficients (Table 73).

Table 73 Interpretation of Coefficients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Exp(estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household Income</td>
<td>2.38</td>
</tr>
<tr>
<td>Household Size</td>
<td>0.25</td>
</tr>
<tr>
<td>Fuel Wood</td>
<td>2.42</td>
</tr>
<tr>
<td>Livestock</td>
<td>0.46</td>
</tr>
<tr>
<td>Economic</td>
<td>1.44</td>
</tr>
<tr>
<td>Environment</td>
<td>1.60</td>
</tr>
</tbody>
</table>

Household income: An increase of one standard deviation in Household Income increases the odds of indicating “no” on Willingness by 138% (2.38-1) (unit Std Dev for Household Income=Rs. 1360) (Table 74). This indicates that as the household income goes up the odds of willingness to collect PN go down. This corresponds well with the ground level experience of the researcher that better-off households regard PN collection as a menial work.

Household size: An increase of one standard deviation in Household Size reduces the odds of indicating “no” on Willingness by 75% (1-.25). (unit Std Dev for Household Size=2.25 person). Model suggests a rise in the odds of willingness to supply PN in as the household size
increases. A larger household in poor rural regions indicates more mouths to feed, also more hands for work, therefore this result is in keeping with the expectation.

Table 74 Summary Statistics: Explanatory Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fodder</td>
<td>365.05</td>
<td>56.59</td>
<td>357</td>
</tr>
<tr>
<td>Household Income</td>
<td>4177.80</td>
<td>1360.54</td>
<td>4025</td>
</tr>
<tr>
<td>Household Size</td>
<td>6.33</td>
<td>2.25</td>
<td>6</td>
</tr>
<tr>
<td>Fuel Wood</td>
<td>322.16</td>
<td>98.12</td>
<td>318</td>
</tr>
<tr>
<td>Livestock</td>
<td>7.94</td>
<td>2.67</td>
<td>9</td>
</tr>
<tr>
<td>Economic</td>
<td>3.45</td>
<td>0.90</td>
<td>3.50</td>
</tr>
<tr>
<td>Family and Community</td>
<td>3.54</td>
<td>0.74</td>
<td>3.50</td>
</tr>
<tr>
<td>Environment</td>
<td>2.51</td>
<td>0.70</td>
<td>2.33</td>
</tr>
</tbody>
</table>

Fuelwood: An increase of one standard deviation in Fuelwood increases the odds of indicating “no” on Willingness by 142% (2.42-1) (unit Std Dev for Fuel Wood=98 kg). Since the market price per kg for fuelwood is higher than the price offered by PN gasifier unit for PN per kg, households that are able to collect more fuelwood would be less willing to collect PN.

Livestock: An increase of one standard deviation in Livestock reduces the odds of indicating “no” on Willingness by 54% (1-.46). (unit Std Dev for Livestock=2.67 animals). Higher ownership of livestock would mean more collection of fodder by a household. The directionality of the relationship with willingness to collect PN was anticipated to be similar to that of Fuelwood, however, it is revealed to be in opposite direction. One possible explanation for the change in directionality is that the process of and effort involved in collecting fodder is quite similar to the one in PN collection. It’s possible that households may find it easier to collect PN and fodder in the same trip to the forests.

Economic Factor: An increase of one standard deviation in Economic Factor increases the odds of indicating “no” on Willingness 44% (1.44-1) (unit Std Dev for Economic
Dimension=0.9 unit). Recall that the items on the Economic Factor are negatively connoted, indicating that PN collection activity is not a good income enhancing opportunity for the households and the village. Higher score on this factor indicates agreement that PN collection is not a good income enhancing opportunity. Therefore the interpretation is that willingness to collect PN will be less if the PN collection activity is not perceived as income enhancing.

Environment Factor: An increase of one standard deviation in Environment Factor increases the odds of indicating “no” on Willingness 60%(1.6-1)(unit Std Dev for Economic Dimension =0.7 unit). Recall that the items on the Environment Factor also are negatively connoted, indicating that PN collection activity and the presence of the PNGP in the village may harm the forest ecology and the village environment. Higher score on this factor indicates agreement with the statements. Therefore the interpretation is that willingness to collect PN for the PNGP will be less if the gasifier unit is perceived detrimental to the local ecology and environment.
Chapter 5: Conclusions and Discussion

1. Woody and herbaceous plants are the main types of biomass feedstock that have found applications in the gasification sector.

2. Key parameters for feasible gasification are the feedstock properties (moisture, ash, alkalis, calorific value, and volatiles), feedstock pre-treatment (drying, particle size), and feedstock harvesting and crop yield.

3. For thermochemical processes, cellulose and lignin ratio is not important.

4. Post drying the thermochemical processes are softwood and hardwood agnostic.

5. Gasifiers are of two main types, fixed bed and fluidized bed, with variations within each type and specific characteristics which determine the type of feedstock and extent of feedstock preparation/pre-treatment.

6. Gas produced from a fixed bed, downdraft gasifier provides a low tar gas, with a high particulates loading: as tar is a major contaminant for engine operation and particulates can be relatively easily removed, this system is considered best.

7. Main reasons for uneconomical bioelectricity sector in India are: lower cost of electricity from the fossil fuel based electricity generating units, high biomass feedstock cost, electricity market distorting policies by the government, and weak local equipment manufacturing ecosystem in India.

8. Lower cost of electricity from fossil fuel based electricity generating units is mainly because fossil fuel based electricity price does not take into account the environmental cost of fossil fuel use. Fossil fuel based electricity industry has a well-established ecosystem of equipment manufacturers and supply-chain for the raw material.
Moreover, many types of fossil fuel resources such as coal are available at relatively lower prices than the biomass feedstock.

9. The process of converting biomass into energy is often inefficient, particularly when using biomass feedstocks with low energy densities. The harvesting and transportation of biomass feedstock significantly add to the cost of electricity generation from biomass. The competing uses feedstock makes its supply uneconomical and uncertain. The poor transport and road infrastructure further increases the cost of delivery of the feedstock to the generating unit.

10. In India, household electricity consumers pay lower rate than the commercial consumers of electricity. The rural electricity consumers pay even lower price than the urban household consumers. Effectively commercial consumers of electricity cross-subsidizes the urban and rural households. The policy distortions result in unclear market signals to the potential and existing electricity producers. For this reason state governments have to step in and guarantee the electricity purchase from the renewable based electricity producers. This type of market condition throttles the entrepreneurial and innovative spirit of the bioelectricity sector. Because of the above mentioned market distorting policies by the government, the supporting equipment manufacturing ecosystem in India is quite weak. There are few manufacturers that cater to the bioelectricity market.

11. Various laws that have linkages with bioelectricity sector, such as Forest Act, the Water (Prevention and Control of Pollution) Act, the Environment (Protection) Act, and the Wildlife (Protection) Rules must be streamlined with bioenergy policies in order for them to be not work against each other. The research into high yield feedstock variety that can thrive on degraded land must be vigorously pursued. The externalities of a
bioelectricity projects, such as water use, land use change, environmental effects at the location should be taken into account and contained. This is important to gain social acceptance for the bioelectricity projects.

12. The simulation based financial evaluation of the pine needle gasification project (PNGP) indicates that the electricity generation from pine needles is viable at the current level of purchase price supported offered by the Uttarakhand Power Corporation Ltd (UPCL), the state-owned electricity utility company. Since, the large tracts of region in Northern India are covered with pine forests, similar projects can be replicated at multiple locations in North India.

13. In the static conditions, that is, keeping the current levels of tariff rates and PN cost constant for the entire project life, the PNGP earns a cash flow of USD 1.01 million on the total investment of USD 2.2 million in 20th year of operation with USD 11 million in reserve and surplus. The cash flows in the first 5 years remain negative, as the investment in capacity expansion continues till 7th year. However, once all 20 plants become operational, cash flows from the operating activities turn positive.

14. The sensitivity analysis shows that 5% increase from the base cost of PN, keeping other input variable constant, results in reduction of NPV by 6%. Similarly, an increase of 2.5% in the expected rate of return from the base level, keeping other variables constant, from the PNGP, results in reduction of 8.6% in the NPV.

15. The simulation output shows that if the expected rate of return from the PNGP remains in the range of 15% to 31% post-tax, then with the current tariff rate (USD 0.062 KWH) and the PN cost (USD 0.017 per kg), the PNGP is likely to remain profitable. In the Scenario 14 (Figure 25), when the expected rate of return is 20% post-tax with high
volatility of 4%, and the expect growth in the pine needles cost at 4% per annum with the volatility of 2%, the lowest quintile NPV is still positive. The output from simulations indicates that although PN cost has a substantial bearing on the levels of NPV of the PNGP, at the current tariff rate, the PNGP is likely to remain profitable in spite of growing PN cost. However, if the preferential FIT is retracted from the project and the FIT is lowered to the market rate of USD 0.042 KWH, then even if the pine needle cost remains very low, the PNGP is not viable at all (Scenario 17 & 18 in Figure 26).

16. In Uttarakhand, the urban household electricity consumers pay USD 0.04 KWH. Since UPCL pays USD 0.062 to the PNGP, and even if transmission and distribution and other overhead costs are ignored, it amounts to an FIT subsidy of 37%. However, household consumers in Uttarakhand are also a subsidized category of consumers in India, since the tariff for commercial consumers is USD 0.082 KWH. Considering the tariff rate for the commercial consumers, the subsidy for the PNGP does not seem to be substantial. Given the distortions in the electricity consumer tariff structure in India, the tariff support for the biomass gasifiers is likely to continue, as the electricity purchased by the UPCL from the PNGP at USD 0.062 KWH can be sold to commercial consumers at $0.082 KWH.

17. The expected rate of return (discount rate) is an important factor in determining the viability of the PNGP, as expected rate of return increases, the NPV decreases. However, the negative impact of the increasing expected rate of return is less than that of reducing tariff rate. The volatility in the expected rate of return has positive impact on the NPV of the PNGP. For example in Scenario 7 the volatility goes up to 4% from 2%
in the Scenario 6, consequently the mean NPV goes up from USD 791,000 to $1,241,000. However, when the mean expected return is at higher level of 18% in Scenarios 8 & 9 the increase in the mean NPV is lesser; from USD 689,000 to USD 784,000. This result indicates that when investor sentiment for the PNGP is negative, higher volatility in the NPV model yields lower increase in the NPV. Moreover, when the higher volatility in expected return is combined with higher growth in PN rate (above 3%), the volatility benefits are nullified. A lower growth (2%) in PN rate does not completely nullify the volatility benefit. The results indicate that the PNGP is likely to remain viable with the growth in the PN cost below 4% and 20% expected rate of return (Scenarios 13 & 14). Beyond this level, the NPV remains positive, but the PNGP is increasingly less attractive.

18. Keeping levels of other variable constant, increase in PN cost negatively affects the NPV, however, its negative impact is not as much as that of reduction in tariff rate. The Simulation output shows negligible impact of modeled volatility in cost growth factor of PN on the NPV.

19. It can be concluded from the simulation results that the threshold conditions which the PNGP can withstand and yet remain NPV positive is-PN cost growth rate below 4% with a volatility of 2%, expected rate of return (discount rate) at 20% with a volatility of 4%, and the current level of tariff rate (USD 0.062). However, with the removal of the tariff price support, the PNGP cannot withstand even the mildest adverse movements in PN cost and expected rate of return.

20. Despite the apparent profitability of the biomass gasification operation, in most states of India, the gasifier units are either struggling or have closed down.
21. The livelihood in rural region of Himalayan states in North India is dependent on agriculture, livestock, and remittances from non-resident members. Most of the households that are dependent on agricultural income are marginal land owners. Many households in the region supplement their income by livestock rearing and extraction of fodder and fuelwood from the nearby forests. Lack of income generating opportunities has forced young males from the region to migrate to bigger cities in other parts of India. Along with poor economic conditions, frequent forest fires add to the woes of the region. Forest fires threaten the forest diversity and the livelihood of the people living around and inside the forests. Often the pine needles carpeting the forest floor exacerbate the forest fires. Under these conditions, the opportunity for income enhancement provided by the PNGP, prima facie, seems ideal. As the PNGP intends to compensate the villagers for pine needles on a per kg basis. Since villagers of the region are adept at collecting fuelwood and fodder from the forest, pine needle collection activity should not be a significant challenge for them. However, the study finds that villagers do not perceive the pine needle collection activity as a significant income enhancing opportunity, inspite of the fact that a typical household stands to significantly increase its annual income. A possible reason for the gap between the actual potential for income enhancement and the perception about the potential may lie in lack of communication between the PNGP and the households of the region. On the positive side, villagers feel that the presence of the PNGP in region will not adversely impact the forests of the region. They also feel that the village community would be able to collect sufficient amount of pine needles for the PNGP. It can be concluded that, in general, villagers have
favourable perception about the PNGP, but expect higher compensation for pine needle collection.

22. The likelihood of willingness of a household goes up with increase in the number of members in the household. Therefore, a larger household is more likely to be willing to participate in the pine needle collection activity. Households that own higher number of livestock are more likely to be willing than the household owning lower number of livestock. Since, households with higher number of livestock typically visit forests on daily basis for collecting fodder, those households are likely to find pine needle collection much easier. Opposite relationship holds for the amount of fuelwood collection by a household, that is, households collecting higher amount of fuelwood are likely to be less willing to collect pine needles for the PNGP. Fuelwood fetches higher price in the local market than the price offered by the PNGP for pine needles on per kg basis, households that are able to extract fuelwood from the forest may not be willing to switch to pine needle collection. Moreover, since, fuelwood collection is a very arduous and energy consuming task, households engaged in extracting fuelwood may not have energy or time left for pine needle collection.
Chapter 6: Recommendations

A viable and thriving biomass based electricity generation sector requires not only a supportive tariff and subsidy regime but also quality supporting infrastructure, including electricity grid, transport networks, and research & development facilities. Policy makers and enabling agencies will have to focus equally on infrastructural and technology development issues.

In this study, technical, economic and operational aspects of a small scale -2.4 MW-and decentralized power generation through biomass in Indian context has been discussed. Demand for electricity in rural and urban areas of India is expected to keep growing; however, annual capacity addition for electricity generation is not able to keep pace with the growing demand. Although, India’s power production is mainly through coal-based thermal plants, however, coal deposits in India are localized and have high-ash and polluting content. Moreover, extension of electricity grid in many remote rural areas of India is not feasible. In addition, poor electricity transmission results in high transmission and distribution losses. Therefore, decentralized electricity generation through locally available energy sources such as pine needles is possibly the only option for electrification of remote rural areas.

The financial evaluation of the PNGP indicates viability at the present level of tariff and subsidy support. Continuation and stability of tariff and subsidy regime will continue to be necessary for profitability of biomass gasification sector. Additional financing of working capital (as soft loans) for running the gasifier is also required. The Ministry of New and Renewable Energy (MNRE) may consider running an informational campaign among the professionals working in financial institutions. This campaign may dispel negative perception about risk profile of biomass gasification projects. Information regarding various types of support,
assurances, and guarantees provided by MNRE and other agencies may improve the risk profile of biomass gasification projects, which will make it easier for them to raise funds from financial institutions.

There is a stronger case for arguing in favor of gasification of locally available biomass for electricity generation than other options for decentralized electricity generation such as wind, photovoltaic, and mini-hydro power projects. There is wide variety biomass availability for throughout the year. A small- 100 KW to 250 KW-gasifier can be installed in any village where sufficient biomass is available throughout the year. Various NGOs and other community based organizations can be encouraged to participate in biomass gasification sector. Community based participation can help gasifier operators to purchase biomass directly from the individual households. Community based participation can also help address any negative perception held by the villagers regarding the presence of biomass gasifiers in the village. Direct purchase from the rural household can supplement the rural household income. In addition, harvesting and pre-processing of biomass are labor intensive activities; this can provide employment opportunities for local villagers.

Regular information and awareness programs should be conducted to convince the rural population about the potential of gasifier-based generation. This will increase the number of local consumers, and hence, the cash flow for the biomass gasification projects.

Replacing and supplementing coal based electricity generation capacity by decentralized biomass gasifiers has social and environmental benefits. Decentralized biomass gasification operations are likely to create employment opportunities for semi-skilled labor in rural areas. Energy plantations can also create more avenues for income generations for farmers. In addition to these social benefits, biomass gasification based electricity generation can reduce CO₂
emission. It is estimated that replacement of each kilowatt hour of coal-based electricity by biomass gasification-based electricity is likely to reduce CO2 emission by one kg.
References


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Kumar, A. R. and K. Ram Jeyanth (2012). Outburst of renewable energy in India is it towards the target? Advances in Engineering, Science and Management (ICAESM), 2012 International Conference on, IEEE.


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Appendix A: Questionnaire

Name:----------------------

1-What is your highest level of education?

<table>
<thead>
<tr>
<th></th>
<th>High School or less</th>
<th>Intermediate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Graduate</td>
<td>Post Graduate</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2- Does your household have a non-resident member?

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3-What is the primary source of household income?

<table>
<thead>
<tr>
<th></th>
<th>Agriculture</th>
<th>Non–agricultural labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Self-employment</td>
<td>Employment/pension</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Remittance</td>
<td></td>
</tr>
</tbody>
</table>

4- Has your household been issued a BPL (Below the Poverty Line) card by the state government?

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5-Please specify the number of Nali of land you own.

<table>
<thead>
<tr>
<th></th>
<th>Less than 6</th>
<th>6 to 9.99</th>
<th>10 to 14.99</th>
<th>15 to 19.99</th>
<th>Above 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6-Please indicate the number of members in the household.


8-What is the size of your house?

<table>
<thead>
<tr>
<th></th>
<th>Less than 3 rooms</th>
<th>3 to 5 rooms</th>
<th>Above 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9-Please indicate the household items in the household (Please check all that apply).

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fridge</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Fans</td>
<td>5</td>
</tr>
</tbody>
</table>

10-Please indicate the types of vehicle your household owns (Please check all that apply).

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two wheeler</td>
<td>2</td>
</tr>
</tbody>
</table>

11-What is your best estimate of the total combined annual income of all members over 14 years of age in the household?

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>below 30000</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>50001-60000</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>80001-90000</td>
<td>8</td>
</tr>
</tbody>
</table>

12-How many livestock do you own?

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 or less</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>11--14</td>
<td>5</td>
</tr>
</tbody>
</table>

13-What is your estimate for average monthly household collection of fuel wood?

<table>
<thead>
<tr>
<th>Fuel wood (kg)</th>
<th>Monsoon</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
</table>

14-What is your estimate for the average monthly household collection (kg) of the following type of fodder?

<table>
<thead>
<tr>
<th>Quantity (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Fodder ( non-forest)</td>
</tr>
<tr>
<td>Forest fodder (Leaves, twigs, grasses)</td>
</tr>
</tbody>
</table>

15- What has been the average market price in the last 30 days for fuelwood and fodder?

<table>
<thead>
<tr>
<th>Fuel Wood ( per kg)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fodder ( per kg)</td>
<td></td>
</tr>
</tbody>
</table>
16-What is your best estimate for the average monthly quantity of the following forest residue consumed within your household?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Wood (in kg)</td>
<td></td>
</tr>
<tr>
<td>Forest Fodder (grass, leaves) (in kg)</td>
<td></td>
</tr>
</tbody>
</table>

17- On average, how many hours per day household members spend in collecting fuel wood, leaves, grasses etc. from the forest?

18 -Who is the main household member that goes to collect the forest residue?

<table>
<thead>
<tr>
<th></th>
<th>Adult male</th>
<th></th>
<th>Adult female</th>
<th></th>
<th>Children</th>
<th></th>
</tr>
</thead>
</table>
For each statement below, please indicate your level of agreement or disagreement (Forest residue: tree branches, leaves, and grass, but not pine needles)

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Items</th>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1_VAGRESID</td>
<td>People in my village will be willing to supply agricultural residue to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2_FAGRESID</td>
<td>My family will be willing to supply agricultural residue to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3_HHAGRESID</td>
<td>It is better to use the agricultural residue for my own household consumption than to supply it to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4_VFRESID</td>
<td>People in my village will be willing to supply forest residue to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5_FFRESID</td>
<td>My family will be willing to supply forest residue to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6_HHFRESID</td>
<td>It is better to use the forest residue for my own household consumption than to supply it to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this section, we are going to ask you about willingness of your family and village to collect and supply pine needles to the Gasifier Unit.

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Items</th>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>7_VPNAG</td>
<td>My village will be willing to supply pine needles to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8_FPNAGR</td>
<td>My family will be willing to supply pine needle to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9_SARPNC</td>
<td>Our sarpanch (village head) is in favour of supplying pine needles to the Gasifier Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10_NVSPPLY</td>
<td>Neighbouring villages will also supply pine needles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In this section, we are going to ask you about your perception about the income enhancement potential of pine needles collection and its supply to the electricity generation Gasifier Unit.

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Items</th>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>11_FINCENHNC</td>
<td>Pine needles collection is not a good income enhancing opportunity for my family</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12_VINCENHNC</td>
<td>Pine needles collection is not a good income enhancing opportunity for my village</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13_AFCTPROC</td>
<td>Pine needle collection activity will not affect my family’s primary occupation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14_ENSUPLMNT</td>
<td>The electricity generation project will help supplement energy needs (fuel wood and)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15_HLPDEAL</td>
<td>The Gasifier Unit employees are not fair in their dealings with the villagers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16_FAIRPR</td>
<td>Price offered by the Gasifier Unit for pine needles collection is inadequate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this section, we are going to seek your opinion related with environmental impact of the electricity plant near your village.

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Items</th>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>17_COMFORIMPCT</td>
<td>Commercial collection of pine needles will negatively impact the forest in my village</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18_AIRQUAL</td>
<td>The electricity plant will negatively impact the air quality around my village</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19_FBED</td>
<td>Removal of pine needles will harm the forest bed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20_SOILIMPCT</td>
<td>Pine needle removal from forest will negatively impact the soil of the forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In this section, we are going to seek your opinion related with the reliability of electricity generating Gasifier Unit near your village.

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Items</th>
<th>Strongly disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>21_VIABLEALT</td>
<td>Electricity from pine needles is a viable energy alternative to coal and oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22_VIABLETECH</td>
<td>Economically viable technologies exist for converting pine needles to electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23_CSUFFBM</td>
<td>The Gasifier Unit will be able to collect sufficient amount of pine needles for its operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24_VENUGSUPP</td>
<td>My village will be able to supply sufficient pine needles to the Gasifier Unit for its operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25_OPTIME</td>
<td>The Gasifier Unit will remain in operation for at least 5 years.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26_STATEGOV</td>
<td>State government is promoting electricity generation from biomass residue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27_STATEFOR</td>
<td>State forest service employees are supportive of this project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28_TOOLS</td>
<td>I have necessary equipment to collect pine needles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29_PROCESS</td>
<td>I understand the process of pine needles collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30_EASECOLL</td>
<td>It will be easy for my family to collect pine needles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Will you be willing to participate in the program for Rupee 1 per Kg of pine needles?

<table>
<thead>
<tr>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
</table>

205
Appendix B: Power Purchase Agreement between AVANI and UPCL

POWER PURCHASE AGREEMENT
BETWEEN
M/s AVANI Bio Energy Pvt. Ltd.
AND
Uttarakhand Power Corporation Limited

THIS AGREEMENT is made this 25th day of June 2012 (hereinafter called the Effective Date), by and between M/s AVANI Bio Energy Pvt. Ltd. Registered under the Companies Act, 1956 and having its registered office at Village and Post Triparadai (via Berinag) District Pithoragarh, PIN-262531, Uttarakhand, hereinafter called the 'Generating Company', which expression shall, unless repugnant to the context or meaning thereof, include its successors and assigns as party of the first part and Uttarakhand Power Corporation Limited a Company registered under the Company's Act, 1956, having its Registered Office at Urja Bhavan, Kanwali Road, Dehradun, hereinafter called 'UPCL', which expression shall, unless repugnant to the context or meaning thereof, include its successors and assigns as party of the second part.

WHEREAS, the Generating Company is engaged in the business of power generation situated at Chikravat village in Berinag Block of Pithoragarh district in the State of Uttarakhand, more particularly described in Annexure I attached hereto and made a part hereof.

AND WHEREAS, UPCL is a distribution licensee operating in the State of Uttarakhand, and has licence to supply power in entire State.

AND

CEO, M/s AVANI Bio Energy Pvt. Ltd.

UPCL
WHEREAS the Generating Company has undertaken to implement the power project by installing plant and equipment having installed capacity of 120 KW situated at Chachret Village of Bering Block in Pithoragarh District of Uttarakhand, its production facility and to complete erection, installation and commissioning of the said capacity and make it operational by March 2013.

AND WHEREAS, the Generating Company desires to sell the entire 120 KW power scheduled to be generated in the Generating Company’s facility.

AND

UPCL agrees to purchase 120 KW Power generated from such capacity by the Generating Company for sale, under the terms and conditions set forth herein, and

WHEREAS the Generating Company agrees to purchase power for its auxiliaries from UPCL in a situation when the Generating Company is not in a position to generate electricity to meet the requirement of its own use or for start up the plant and UPCL agrees to supply such power to plant at retail tariff as per Regulations/Orders specified by the Commission, and

WHEREAS the parties to the agreement bind themselves for compliance of all relevant provisions specified by the Commission in different regulations regulating the functioning of State Transmission Utility, other transmission licensee and State Load Dispatch Centre; and

This agreement shall be subject to approval of UERC and any change suggested by UERC in this agreement shall be incorporated in the PPA being executed now.

The Power Purchase Agreement signed with Avani Society on dated 27/05/2011 shall stand null and void on the date of signing of this agreement.

Now, therefore, in consideration of premises and mutual agreements, covenants and conditions set forth herein, it is hereby agreed by and between the parties as follows:-

1. **Definitions**

Other than those defined below, the words/expressions used in this agreement, unless repugnant to the context, shall have the meaning assigned to them in the Electricity Act, 2003, Uttarakhand State Grid Code, as amended from time to time, Uttarakhand Electricity Regulatory Commission (Tariff and Other Terms for Supply of Electricity from Renewable Energy Sources and non-fossil fuel based Co-generating Stations) Regulations, 2010 as amended from time to time, and the rules framed there under. The words/expressions listed below shall have the meanings respectively assigned hereunder.

1.1 'Bill Meter' means Import and Export Meter on the basis of which energy bills shall be raised by the Generating Company/UPCL.

1.2 'Check Meter' means Import and Export Meter for performing a check on the accuracy of the Bill Meter.

1.3 'Date of commercial operation or Commissioning (COD)’ in relation to a unit means the date declared by the generator on achieving maximum continuous rating through a successful trial run and in relation to the generating station, the date of commercial operation means the date of commercial operation of the last unit or block of generating station and expression ‘commissioning’ shall be construed accordingly. In case of small hydro plants the date of commissioning shall, however, not be linked to achieving maximum continuous rating, but the generator will have to demonstrate the same within three years of commissioning.

1.4 'Export Meter' means Bill Meter installed at interconnection point for measurement of Active Energy, Maximum demand and Power factor for Energy exported to the Generating Company’s Biomass gasification (primarily using pine needles as Biomass) based power plant from UPCL 33/11 KV Grid connecting Sub-Station at Railagar of Bering Block in Pithoragarh District of Uttarakhand.
1.5 'Energy Account Month' means period from date of meter reading in previous month to date of meter reading in following month and such period should not exceed 35 days.

1.6 "Sub Station" means 33/11 KV sub-station at Raigar of Berinag Block in Pithoragarh District of Uttarakhand owned, maintained and operated by UPCL.

1.7 'Import Meter' means Bill Meter installed at interconnection point for Measurement of Active Energy, Maximum demand and Power factor of energy imported from the Generating Company's Biomass gasification based power plant to UPCL 33/11KV Grid connecting Sub-Station at Raigar of Berinag Block in Pithoragarh District of Uttarakhand.

1.8 'Bill' means a bill raised, that includes all charges to be paid by UPCL with respect to sale of power by the Generating Company to UPCL.

1.9 'State Transmission Utility (STU)' means Power Transmission Corporation of Uttarakhand Limited (PTCUL) being the Government Company specified so by the Government of Uttarakhand.

1.10 'TOD' means "Time of day", for the purpose of metering.

1.11 'UERC' means the Uttarakhand Electricity Regulatory Commission.

1.12 'Wheeling' means the operation whereby the distribution system and associated facilities of a transmission licensee or distribution licensee, as the case may be, are used by another person for the conveyance of electricity on payment of charges to be determined under section 62 of the Electricity Act 2003.

1.13 'Regulations' means the Uttarakhand Electricity Regulatory Commission (Tariff and Other Terms for Supply of Electricity from Renewable Energy Sources and non-fossil fuel based co-generating stations) Regulations, 2010 as amended from time to time.

1.14 'State Grid Code (SGC)' means the Uttarakhand Electricity Regulatory Commission (State Grid Code) Regulations, 2007 specified under clause (ii) of subsection (1) of section 86 of the Act by Uttarakhand Electricity Regulatory Commission.

1.15 'Interconnection Point' means the interface point of renewable energy generating facility with the transmission system or the distribution system, as the case may be:

(i) In relation to wind energy projects and solar photovoltaic projects, interconnection point shall be line isolator on outgoing feeder on HV side of the pooling substation;

(ii) In relation to small hydro, biomass power and non-fossil fuel based cogeneration power projects and solar thermal power projects, the interconnection point shall be line isolator on outgoing evacuation line from such generating station.

1.16 'Commission' means the Uttarakhand Electricity Regulatory Commission (UERC).

2. **POWER PURCHASE, SALE AND BANKING**

2.1 UTCL shall accept and purchase 120 KW of power made available to UTCL system from the Generating Company based on biomass gasification (primarily using pine needles as biomass) with capacity upto 120 KW at the rate specified for such plant in Annexure-I: Generic Tariffs of Uttarakhand Electricity Regulatory Commission (Tariff and Other Terms for Supply of Electricity from Renewable Energy Sources and non-fossil fuel based co-generating stations) Regulations, 2010 as amended from time to time based on sources and technologies as mentioned at point no. (iv) below:

(i) Small Hydro with capacity upto 25 MW.

(ii) Wind

(iii) Solar including its integration with combined cycle

(iv) Biomass/Biogas

(v) Bagasse based cogeneration as per MNRE guidelines

(vi) Urban/Municipal waste, or

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(vii) Any new source of technology which would qualify as 'Renewable Energy' only after approval of Commission based on the Ministry of Non-conventional Energy Sources (MNRE) approval in accordance with the terms and conditions of this agreement.

2.2 The rate applicable for supply of electricity by UPCL to the Generating Company shall be as per the tariff determined by the Commission under appropriate 'Rate Schedule of Tariff' for the consumer category - determined on the basis of the total load requirement of the plant and billing done in the manner as specified by the Commission in the Regulations.

2.3 The Generating Company and UPCL shall comply with all the regulations issued by UERC from time to time including but not limited to Uttarakhand Electricity Grid Code, Open Access Regulations. SDLG Regulations to the extent they are applicable to them.

3 MAINTENANCE REQUIREMENT OF THE GENERATING COMPANY

3.1 The Generating Company's annual maintenance schedule shall normally be in the month of July. The Generating Company shall inform in writing to UPCL regarding the maintenance schedule in accordance with provisions of the SGC as revised by the Commission from time to time at least one month in advance.

3.2 Environmental Clearance and compliance of environmental standards shall be the sole responsibility of the Generating Company.

4 SUPPLY SCHEDULE

The Generating Company shall furnish to UPCL and the state load despatch centre (SLDC), a month-wise Supply Schedule and other information, as required in the Regulations and SGC as amended from time to time or provisions of any other regulation in that regard or as desired otherwise.

5 BILLING PROCEDURE AND PAYMENTS

5.1 UPCL shall raise monthly bill for electricity purchased by the Generating Company as per its normal billing cycle in manner as specified by the Commission in the Regulations and such bill shall be payable within the time period stipulated in the General Conditions of Tariff.

5.2 The Generating Company shall raise monthly bill, based on the monthly Joint Meter Reading with help of MRI of the Bill Meter installed at interconnection point along with the detailed MRI Report of the Meter at the time of reading and load survey data of previous 35 days. The MRI report should also be certified by the representative of UPCL.

5.3 The Monthly Bill in triplicate along with supported documents viz. Joint Meter Readings and the MRI document (Bill & Check Meter) duly signed by Executive Engineer (Distribution), Executive Engineer (Test) UPCL of the concern division with load survey data of previous 35 days raised by the Generating Company shall be delivered to UPCL at office of Executive Director(Comm)/Chief Engineer(Comm), Urja Bhawan, Kanwali Road, Dehradun on or before the fifth (5th) working day of the following month hereinafter called the Monthly Bill date.

5.4 UPCL shall make full payment against such Monthly Bills to the Generating Company from the date of the receipt of original monthly bill with complete documents with following rebate options:
   (i) UPCL shall avail 2% rebate for prompt (within seven working days) payment.
   (ii) UPCL shall avail 1% rebate for payment within 30 working days.

5.5 For default in payment beyond 60 days from the billing, a surcharge at the rate of 1.25% per month or part thereof shall be levied on the billed amount.

5.6 The bills raised by the Generating Company shall be paid in full subject to the conditions that-

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There is no apparent arithmetical error in the bill(s).

The bill(s) is/are claimed as per tariff referred to in Para 2 of this agreement. They are in accordance with the energy account referred to in Para 16 of this agreement.

5.7 In case of any dispute regarding the bill raised by the Generating Company, UPCL shall file a written objection with the Generating Company within fifteen days of receipt of the bill giving full particulars of the disputed item(s), with full details/data and reasons of dispute and amount disputed against each item. The Generating Company shall resolve the above dispute(s) with UPCL within 30 working days.

5.8 In case, the dispute is not resolved within 30 working days as provided in para 5.7 above, and in the event it is decided to proceed with the Arbitration as provided in para 22 of this agreement, then UPCL shall pay 100% of the disputed amount forthwith and refer the dispute for arbitration as provided in this agreement. The amount of excess/shortfall with respect to the said disputed amount on final award of arbitration shall be paid/adjusted but in case of excess, the adjustment shall be made with interest at rate 1.25% per month from the date on which the amount in dispute was refundable by the generating company to UPCL.

6. PARALLEL OPERATIONS

33/11 KV sub-station at Ralagarh of Berinag Block in Pitroligarh District of Uttar Pradesh owned, maintained and operated by UPCL shall allow the Generating Company to interconnect its facility and operate in parallel with UPCL system, subject to the provisions of this Agreement, Electricity Act, 2003 and the SGC as amended from time to time.

7. GENERATION FACILITIES OWNED AND OPERATED BY THE GENERATING COMPANY

7.1 The Generating Company shall own, install, operate, and maintain the Generating Company equipments and associated dedicated transmission line described in Annexure I. The Generating Company shall follow such operating procedures on its side of the electric interconnection with UPCL system, as are consistent with applicable laws, rules, and regulations, the terms and conditions of this Agreement, provisions of the SGC, and other related guidelines, if any, issued by UERI, SLDI, and UPCL.

7.2 All electrical equipments shall be installed in compliance with the requirements of the Director of Electrical Safety, Government of Uttar Pradesh and safety specifications of the Central Electricity Authority (CEA) under section 53 of the Electricity Act, 2003.

7.3 The Generating Company further agrees to make no material changes or additions to its facility, which may have an adverse effect on UPCL system or amend the single-line diagram, relay list and/or trip scheme given in Annexure I, without UPCL's prior written consent. UPCL agrees that such consent shall not be unreasonably withheld or given.

7.4 Without prejudice to the foregoing, the Generating Company shall install, operate, and maintain its facility in accordance with accepted prudent utility practices in the electricity industry. The Generating Company's operation and Maintenance schedules and staffing shall be adequate to meet such standards at all times.

7.5 UPCL shall follow such operating procedures on its side of the electric interconnection point with the Generating Company, as required to receive Power from the Generating Company's facility, without avoidable interruptions or adverse consequences on the Generating Company, and consistent with applicable laws, rules and regulations, and the terms and conditions of this Agreement.
8. INTERCONNECTION FACILITIES

8.1 Interconnection Facilities means all the facilities which shall include existing 33/11 KV sub-station at Raiagar of Berinag Block in Pithoragarh District of Uttarakhand owned, maintained and operated by UPCL without limitations, switching equipment, communication, protection, control, meters and metering devices etc. for the incoming bay(s) for the Project Line(s) to be installed and maintained by Generating Company/UPCL at the cost to be borne by the Generating company, to enable the evacuation of electrical output from the project in accordance with the Agreement.

8.2 Power from the Generating Company shall be transmitted at 11 KV voltage and to the 33/11 KV substation at Raiagar of Berinag Block in Pithoragarh District of Uttarakhand owned, maintained and operated by UPCL.

8.3 The cost of laying the transmission line up-to the 33/11 KV substation at Raiagar of Berinag Block in Pithoragarh District of Uttarakhand owned, maintained and operated by UPCL, the required bay, terminal equipments and associated synchronization equipments, etc shall be borne as per clause 38 (2) of UERC regulation 2010.

8.4 Technical standards for construction of electrical lines and connectivity with the grid shall be as per clause 38 (1) of UERC regulation 2010.

8.5 Maintenance of terminal equipment at the generating end and the dedicated transmission line owned by such generating station and maintenance of the terminal equipment(s) at the 33/11 KV substation at Raiagar of Berinag Block in Pithoragarh District of Uttarakhand shall be as per clause 39 of UERC regulation 2010.

8.6 Any work to be done by the Generating Company shall be taken up only with a specific approval and on the basis of approved drawings and specifications from UPCL, and in compliance with the safety requirements as per the SGC. On the completion of work, final approval shall be obtained from UPCL before charging the line. The Generating Company would obtain all statutory clearances/approvals required for this purpose.

8.7 The Generating Company shall consult UPCL on the scheme of protection of the interconnecting line(s) and the facilities at both end and accordingly provide the equipment at both ends. The protection system, installed by the Generating Company, shall be checked by UPCL.

8.8 Without limiting the foregoing, the Generating Company and UPCL shall, operate and maintain the interconnection and parallel operation facility in accordance with accepted good engineering practices in the electricity industry and the SGC as amended from time to time and directions of Director Electrical Safety (GOI) and Safety requirements as specified by the Authority under section 53 of the Indian Electricity Act, 2003.

8.9 The interconnection facilities, to be provided by the Generating Company are set forth in Annexure IV attached hereto and made a part hereof.

9. PROTECTIVE EQUIPMENT & INTERLOCKING

9.1 The interconnection facilities shall include necessary protective equipment and interlocking devices, which shall be so coordinated that any malfunctioning or abnormality in the generators or in the bus of the Generating Company shall not adversely reflect on or affect UPCL’s grid system. In event of any malfunctioning or abnormality, the system shall be designed to ensure that the Generating Company’s breaker trips first to protect the equipment. Prior to adopting it the Generating Company shall obtain approval of UPCL for the protection logic of the generator system and the synchronization scheme.
9.2 The Generating company shall install necessary equipment to eliminate feeding of reverse power from the grid to the generating company's system in absence of any agreement for purchase of power with UPCL.

10. TECHNICAL ASSISTANCE BY UPCL & GENERATING COMPANY'S RESPONSIBILITY
10.1 On request, UPCL shall provide reasonable technical assistance to the Generating Company in preparing the design and specifications of the required facilities and for laying down the standard operating and maintenance procedures. The Generating Company, however, shall be responsible for procurement, installation, testing, maintenance and operation of the electrical system installed in the Generating Company's premises.

10.2 Notwithstanding the above, UPCL shall not be responsible for any damage caused to the electrical system/generating set of the Generating Company on account of errors or defects in the design, procurement, installation, testing, maintenance and operation of the system.

11. ARRANGEMENTS AT THE POINT OF SUPPLY
The Generating Company shall make all arrangements for paralleling the set(s) with UPCL's grid in consultation with and to the satisfaction of UPCL, subject to the approval of the Director of Electrical Safety, Government of Uttarakhand and safety specifications of the Central Electricity Authority (CEA) under Section 53 of the Electricity Act, 2003.

12. SYNCHRONISATION
12.1 The Generating Company shall give at least sixty (60) days advance written notice of the date on which it intends to synchronize a unit of the plant with the grid system, to the Nodal Officer of UPCL (Executive Engineer, Electricity Distribution Division, Pithoragarh) with the copy to the higher officials of UPCL and UERC. The authorized representative of the Generating Company and the Nodal Officer of UPCL shall inspect the unit which the Generating Company intends to synchronize to the Grid System within Seven days after being notified in writing by the Generating Company about the readiness of the unit for the synchronization with the grid.

12.2 The Generating Company shall synchronize its power generating set in consultation with the Executive Engineer, Electricity Distribution Division, Pithoragarh in charge of the 33/11 KV substation at Rajgar of Berring Block in Pithoragarh District, Uttarakhand, of UPCL and as per provisions of the SCC as amended from time to time.

12.3 UPCL shall not be responsible for the damage, if any, caused to the plant and equipment of the Generating Company due to failure of the synchronizing or the protective system provided by the Generating Company.

13. LIASON WITH & ASSISTANCE FROM UPCL
The Generating Company shall closely liaise with the Nodal Officer (Executive Engineer, Electricity Distribution Division, Pithoragarh) of UPCL and shall inform the date of commencement of delivery of power to the designated officials (Executive Engineer, Electricity Distribution Division, Pithoragarh) of UPCL one month in advance and also arrange for testing and commissioning of the protection system at least 15 days in advance. If requested by the Generating Company, UPCL shall extend assistance for testing, subject to the condition that the Generating Company shall pay the charges for such assistance to UPCL, if so indicated by the concerned Testing Division of UPCL in accordance with the Regulation. The Generating Company shall conduct Commissioning tests in presence of designated officials of UPCL and submit the testing results to UPCL and UERC.

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14. **METERING**

14.1 The Generating Company shall supply two identical sets of AFT compliant meters, having data recording memory of at least 35 days, with the facility for downloading data to measure the quantity and time details of the Power exported from and imported by the Generating Company, conforming to the specifications approved by UPCL along with all necessary associated equipments. These meters shall be installed and maintained by UPCL. These meters shall be installed at the interconnection point. One set of export/import meters shall be termed as Bill Meter and other set will serve as the Check Meter. The complete metering system consisting of meters, Current Transformers & Potential Transformers shall conform to the technical standards, accuracy and calibration requirements of the Indian Electricity Rules and the specifications of the Bureau of Indian Standard and CEA (Installation & Operation of Meters) Regulation, 2006.

14.2 The joint meter readings shall be recorded in the format given in Annexure V & VI.

14.3 The Meter/Metering system shall be properly sealed and made pilfer proof, to the satisfaction of both parties conforming to the guidelines of CEA for installation of meters.

14.4 UPCL shall, test all the metering equipment for accuracy, in the presence of a representative of the Generating Company, if the Generating Company so elects, at least once every year while the agreement is in force, either party may, however, elect to get the meters tested at any time they so desire, at their own cost, in the presence of the other party.

14.5 UPCL's designated representative and the representative of the Generating Company shall jointly certify the meter test results. After every testing all metering equipment and the Metering system shall be securely sealed jointly by the representatives of UPCL and the Generating Company.

14.6 The reading and testing of meters and associated equipment shall be in accordance with accepted good engineering practices in the electricity industry.

14.7 Calibration, inspection and testing of meters and the associated equipment shall be the responsibility of UPCL, who shall bear the related costs.

14.8 Meter readings shall be taken jointly by parties as indicated below:

I. **UPCL side** - Executive Engineer, Electricity Distribution Division, Pithoragarh.

II. **Generating Company side** - Authorized representative of the Generating Company.

14.9 The reading/MRI report of the Bill Meter shall form the basis for the energy account, provided that the magnitude (i.e. absolute value) of the difference between the Check and Bill Meter reading is within 1.00 % (one percent) of the Bill Meter reading.

14.10 If in any month the readings of the Bill Meter and Check Meter are found to be doubtful or beyond the permissible 1.00 % (one percent) deviation indicated above, both sets of meters shall be checked and calibrated in the presence of authorized representatives of both the parties. Corrections shall be made, if required, on the basis of the error detected during this process, in the Monthly Bill for the period between the previous meter readings and the date and time from which accurate readings become available through replacement or re-calibration. These corrections shall be full and final for the Bill of that month.

14.11 During the period of checking and calibration of both meters simultaneously another export and import meter duly calibrated would be installed by UPCL. For this purpose, one spare set of meters would be required to be available with the Generating Company at all times.
14.12 If the Bill Meter is found to be defective, and the Check meter is found to be accurate then the reading from the latter shall be used for billing purpose and the Bill meters would be re-calibrated and re-installed or replaced by duly tested and calibrated meters, as necessary. Where error in the Check Meter is indicated beyond permissible limit but there is no error in the Bill Meter, Monthly energy account would be prepared on the basis of the Bill Meter reading and the Check Meter shall be immediately re-calibrated and re-installed or replaced as necessary. If both meters are found to be defective, then the Bill will be revised on the basis of the inaccuracy discovered in the testing. The M.R.I. document from the meters shall be considered as authentic document for verification.

14.13 Metering at generating terminals of each unit of the Generating Company shall be ensured as per the guidelines of the CEA.

15. ACCEPTANCE AND APPROVAL OF UPCL

UPCL’s acceptance or approval for equipment, additions or changes to equipment, and their operational setting etc. would be required. Such acceptance/approval shall not be unreasonably withheld and shall be based on UPCL’s existing policies and practices.

16. CONTINUITY OF SERVICE

16.1 The supply of electricity by the Generating Company shall be governed by instructions from the State load dispatch centre, as per the provisions of the GGC as amended from time to time. However, UPCL may require the Generating Company to temporarily curtail or interrupt deliveries of power only when necessary in the following circumstances:

a. Repair and/or Replacement and/or Removal of UPCL’s equipment or any part of its system that is associated with the Generating Company’s facility; and/or

b. Endangerment of Safety: If UPCL determines that the continued operation of the facility may endanger the safety of UPCL’s personnel or integrity of UPCL’s electric system, or have an adverse effect on the provision of electricity to UPCL’s other consumers/customers; and/or

c. Force Majeure Conditions as defined in para 25 below

16.2 Before disconnecting the Generating Company from UPCL’s system, UPCL shall, except in the case of an emergent situation, give advance intimation to the Generating Company through telephone/wireless or through other means of communication along with reasons for disconnection, and the likely period of the disconnection. However, subsequent to disconnection, UPCL shall immediately notify the Generating Company by telephone and confirm in writing the reasons for, and the likely period of, disconnection. During the period so notified UPCL shall not be obliged to accept or pay for any power from the Generating Company.

16.3 In any such event as described above, UPCL shall take all reasonable steps to minimize the frequency and duration of such interruptions, curtailments, or reductions.

16.4 UPCL shall avoid scheduling any event described in 16.1 above, to the extent reasonably practicable, during the Generating Company’s operations. Where the scheduling of such an event during the Generating Company’s operations cannot be avoided, UPCL shall provide the Generating Company with fifteen days advance notice in writing to enable the Generating Company to cease delivery of Power to UPCL at the scheduled time.

16.5 In order to allow the Generating Company’s facility to remain on-line and to minimize interruptions to Generating Company operations, the Generating Company may provide automatic equipment that will isolate the Generating Company’s facility from UPCL system during major system disturbances.
17. **DAILY/MONTHLY/ANNUAL REPORT**
The Generating Company shall submit daily/monthly/annual and other reports on the format, and as per the procedure, specified in the SGC as amended from time to time and under the Regulations or as desired by the UPCL.

18. **CLEARANCES, PERMITS AND LICENSES**
The Generating Company shall obtain, at its own expense, all authorizations, permits, and licenses required for the construction, installation and operation of the Generating Company's facilities and any interconnection facilities, including but not limited to, rights-of-way or easements. UPCL shall provide reasonable assistance, including permissions, approvals and clearances, to the Generating Company if so requested by the Generating Company.

19. **DURATION**
19.1 Unless terminated by default described in clause 20 below, this agreement shall be valid till the expiry of 20 years from the date of commercial operation of the project.
19.2 The agreement may be renewed or extended for such period as may be mutually agreed between the Generating Company and UPCL on expiry of Initial term described at 19.1 above.
19.3 UPCL reserves the first right of purchase after the expiry of initial term of PPA.

20. **EVENTS OF DEFAULT AND TERMINATION**
20.1 The occurrence of any of the following events at any time during the term of this agreement shall constitute a default by the Generating Company:
   a. Failure on the part of the Generating Company to use reasonable diligence in operating, maintaining, or repairing the Generating Company's facility, such that the safety of persons and property, UPCL's equipment, or UPCL's service to others is adversely affected; or
   b. Failure or refusal by the Generating Company to perform its material obligations under this agreement; or
   c. Abandonment of its interconnection facilities by the Generating Company or the discontinuance by the Generating Company of services covered under this agreement, unless such discontinuance is caused by force majeure, or an event of default by UPCL; or
   d. Failure by the Generating Company to abide by all statutory provisions, rules, regulations, directions and conditions for installation, operation, and supply of power and maintenance of units etc., enforced from time to time by the Union/State Government, UERDC or other empowered authorities, including compliance with the SGC, or
   e. Failure by the Generating Company to pay UPCL any amount payable and due under this agreement within sixty (60) working days of the demand being raised.

20.2 The occurrence of any of the following at any time during the term of this agreement shall constitute a default by UPCL:
   a. Failure to pay to the Generating Company any amount payable and due under this agreement within sixty (60) working days of the receipt of the complete monthly purchase bill as defined in para 5 of this agreement; or
   b. Failure to use reasonable diligence in operating, maintaining, or repairing UPCL's 33/11 KV substation at Ralagarh of Berhampur Block in Pithoragarh District, such that the safety of persons or property in general, or the Generating Company's equipment or personnel are adversely affected; or
   c. Failure or refusal by UPCL to perform its material obligations under this agreement; or
d. Abandonment of its interconnection facilities by UPCL or the discontinuance by UPCL of services covered under this agreement, unless such discontinuance is caused by force majeure or an event of default by the Generating Company.

e. Except for failure to make any payment due, within sixty (60) working days of receipt of the monthly purchase bill, if an event of default by including nonpayment of bills either party extends beyond a period of sixty (60) working days after receipt of written notice of such event of default from the non-defaulting party, then the non-defaulting party may, at its option, terminate this agreement by delivering written notice of such termination to the party in default.

20.3 Failure by either UPCL or the Generating Company to exercise any of its rights under this agreement shall not constitute a waiver of such rights. Neither party shall be deemed to have waived the performance of any obligation by the other party under this agreement, unless such a waiver has specifically been made in writing and approved by the UERC.

20.4 UPCL reserves the right to terminate this agreement upon one months notice to the Generating Company, if the Generating Company's facility fails to commence production of electric power within three months from the planned commercial operation date mentioned in Annexure I.

21. COMMUNICATION
In order to have effective coordination between UPCL and the Generating Company, a designated official shall be kept on duty round the clock by the Generating Company and UPCL in their respective premises, with information to each other about the name, location, telephone number etc., of the officials. Without prejudice to discharge of their rightful duties by others, this duty official shall take necessary action on receiving information about developments from the other party. The Generating Company shall provide reliable and effective communication through wireless/hotline etc., between the Generating Company & the interconnecting substation of UPCL and between the Generating Company and the SLDC. The Generating Company shall make provision for an RTU for remote monitoring of voltage, current and other related electrical parameters, as may be required by the UPCL and also for AMR facility.

22. DISPUTES AND ARBITRATION
In the event of any dispute or difference between the parties concerning performance of this agreement and/or the rights and liabilities of the parties in respect of which a procedure for the resolution is not otherwise provided for in this agreement the following provisions shall apply:

a. Executive Engineer, Electricity Distribution Division, Pithoragarh on behalf of UPCL and the authorized representative of the Generating Company would be empowered to indicate explicitly the nature and material particulars of the dispute/ dissatisfaction and the relief sought and serve notice thereof on the other, with copy to the UPCL's Superintending Engineer, Electricity Distribution Circle, Ranikhet, under whose jurisdiction the Generating Company plant is located.

b. On receiving such information, the Superintending Engineer, Electricity Distribution Circle, Ranikhet of UPCL in which the Generating Company is located, shall be required to personally meet the authorized representative of the Generating Company and the Executive Engineer, Electricity Distribution Division, Pithoragarh at his own office, separately and/or together, within 15 (Fifteen) days of the date of receipt of such notice, and attempt in good faith to resolve the dispute to the mutual satisfaction of the two parties, within the stipulations dictated by the letter and spirit of the agreement.
c. If the dispute is not resolved by way of a settlement being arrived at and duly signed by each of the above officers within (30) thirty days of the date of receipt of the notice described in clause (a) above, the matter may be referred to either or both the above designated officers of the two parties to the UPCL’s Executive Director(Commercial)/Chief Engineer (Commercial), UPL, Urja Bhawan, Kanwali Road, Dehradun with information to the Chief Executive of the Generating Company. Within 15 days of receipt of such notice, the Executive Director(Commercial)/Chief Engineer(Commercial) and the Chief Executive of the Generating Company would be required to meet at the former’s office and endeavor to settle the dispute within a further period of (30) thirty days i.e. within a total period of 45 (Forty Five) days from the initial date of receipt of the notice by the Superintending Engineer, EDC, Ranikhet, UPCL.

d. If the said dispute / dissatisfaction remains unresolved, either party can file a petition before UERC, whose decision will be final and binding on both the parties. UERC shall be empowered to determine the exact nature and modalities of the procedure to be adopted in resolving the matter.

23. INDEMNIFICATION

23.1 The Generating Company shall indemnify, defend, and render harmless, UPCL, its members, directors, officers, employees and agents, and their respective heirs, successors, legal representatives and assignees, from and against any and all liabilities, damages, costs, expenses (including attorneys fees), losses, claims, demands, action, causes of action, suits and proceedings of every kind, including those for damage to property of any person or entity (including the Generating Company) and/or for injury to or death of any person (including the Generating Company’s employees and agents), which directly or indirectly result from or arise out of or in connection with negligence or willful misconduct of the Generating Company.

23.2 UPCL shall indemnify and render harmless, the Generating Company, its directors, officers, employees and agents, and their respective heirs, successors, legal representatives and assignees harmless from and against any and all liabilities, damages, costs, expenses (including outside attorneys fees), losses, claims, demands, actions, causes of action, suits and proceedings of every kind, including those for damage to the property of any person or entity (including UPCL) and/or for injury to or death of any person (including UPCL’s employees and agents), which directly or indirectly result from or arise out of or in connection with negligence or willful misconduct by UPCL.

24. ASSIGNMENT

This Agreement may not be assigned by either UPCL or the Generating Company without the consent in writing of the other party, except that either party may assign its rights under this Agreement, or transfer such rights by operation of law, to any corporation with which or into which such party shall merge or consolidate or to which such party shall transfer all or substantially all of its assets; provided that such assignee or transferee shall expressly assume, in writing, delivered to the other party to this Agreement, all the obligations of the assigning or transferring party under this Agreement.

25. FORCE MAJEURE

25.1 If any party hereto is wholly or partially prevented from performing any of its obligations under this agreement by reason of or due to lightning, earthquake, riots, fire, floods, invasion, insurrection, rebellion, mutiny, tidal wave, civil unrest, epidemics, explosion, the order of any court, judge or civil authority, change in State or National law, war, any act of God or a public enemy, or any other similar or dissimilar cause reasonably beyond its exclusive control and not attributable to its neglect, then in any such event, such party shall be excused from whatever
performance is prevented by such event, to the extent so prevented, and such party
shall not be liable for any damage, sanction or loss for not performing such
obligations.

25.2 The party invoking this clause shall satisfy the other party of the occurrence of such
an event and give written notice explaining the circumstances, within seven days to
the other party and take all possible steps to revert to normal conditions at the
earliest.

25.3 Any payments that become/have become due under this agreement shall not be
withheld, on grounds of force majeure conditions developing.

26. AUTHORITY TO EXECUTE
Each respective party represents and warrants as follows:
a. Each party has all necessary rights, powers and authority to execute, deliver and
perform this agreement.
b. The execution, delivery and performance of this agreement by each respective party
shall not result in a violation of any law or result in a breach of any government
authority, or conflict with, or result in a breach of, or cause a default under, any
agreement or instrument to which either respective party is a party or by which it is
bound.
c. No consent of any person or entity not a party to this agreement, including any
governmental authority, is required for such execution, delivery end performance by
each respective party. All necessary consents have been either obtained or shall be
obtained in the future as and when they become due.

27. LIABILITY AND DEDICATION
27.1 Nothing in this agreement shall create any duty, standard of care, or liability to
discharge by any person not a party to it.

27.2 No undertaking by one party to the other under any provision of this Agreement
shall constitute the dedication of that party’s system or any portion thereof to the
other party or to the public; or affect the status of UPCL as a public utility or
constitute the Generating Company or the Generating Company’s facility as a public
utility.

28. NODAL AGENCY OF UPCL
The Executive Engineer, Electricity Distribution Division, Pithoragarh, UPCL shall act as a
nodal agency for implementing this Agreement.

29. AMENDMENTS
Any waiver, alteration, amendment or modification of this Agreement or any part hereof
shall not be valid unless it is in writing, signed by both the parties and approved by UERG.

30. BINDING EFFECT
This Agreement shall be binding upon and inure to the benefit of the parties hereto and their
respective successors, legal representatives, and permitted assignees.

31. NOTICES
Any written notice provided hereunder shall be delivered personally or sent by registered
post, acknowledgement due, or by courier for delivery on written receipt, with pre-paid
postage or courier charges, to the other party, at the following address:
UPCL:
The Executive Director/Chief Engineer (Commercial),
Uttarakhand Power Corporation Limited,
Urja Bhawan, Kanwall Road,
Dehradun -248001,
Uttarakhand.
GENERATING COMPANY:

CEO,
M/s AVANI Bio Energy Pvt. Ltd.,
Village and Post Triparential (Via Berinag),
District Pithoragarh - 262531,
Uttarakhand.

Notice delivered personally shall be deemed to have been given when it is delivered at the office of the Generating Company’s or to the office of the Executive Director/Chief Engineer (Commercial), UPCL, as the case may be at address set forth above and actually delivered to such person or left with and received by a responsible person in that office. Notice sent by post or courier shall be deemed to have been given on the date of actual delivery as evidenced by the date appearing on the acknowledgement of delivery.

Any party to this agreement may change its address for serving a written notice, by giving written notice of such change to the other party.

32. EFFECT OF SECTION AND ANNEXURE HEADINGS
The headings or titles of the various sections and annexure hereof are for convenient reference and shall not affect the construction or interpretation of any provision of this Agreement.

33. NON-WAIVER
No delay or forbearance by either party in the exercise of any remedy or right will constitute a waiver thereof, and the exercise or partial exercise of a remedy or right shall not preclude further exercise of the same or any other remedy or rights.

34. RELATIONSHIP OF THE PARTIES
Nothing in this Agreement shall be deemed to constitute either party hereto as partner, agent or representative of the other party or create any fiduciary relationship between the parties.

35. ENTIRE AGREEMENT
This agreement constitutes the entire understanding and agreement between the parties.

36. GOVERNING LAW
This agreement shall be governed by and construed in accordance with the laws applicable in the State of Uttarakhand.

37. NO PARTY DEEMED DRAFTER
The parties agree that no party shall be deemed to be the drafter of this Agreement and that in the event this Agreement is ever construed by arbitrators or by a court of law, no inference shall be drawn against either party on account of this Agreement or any provision hereof being drafted by them. UPCL and the Generating Company acknowledge that both parties have contributed substantially and materially to the preparation of this agreement.

38. APPROVALS
Whenever approvals from either UPCL or the Generating Company are required in this Agreement it is understood that such approvals shall not be unreasonably withheld.

39. ANNEXURES
ANNEXURES I to VIII WOULD FORM PART OF THIS AGREEMENT.

40. STANDARD FOR DECISION MAKING
40.1 All operational decisions or approvals that are to be made at the discretion of either UPCL or the Generating Company, pursuant to the terms of this agreement, including specifications and design criteria etc., shall be made or performed according to good engineering practices prevailing in the electricity industry.

CEO, M/s AVANI Bio Energy Pvt. Ltd

Arvind Dave
President Limited

SE (Commercial), UPCL

Vivek Prakash
Power Generation Div.

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402. Professional decisions or activities undertaken by either party for the purpose of constructing, installing, removing, maintaining or operating any facility, which may affect the operations of the other party’s facility or facilities, shall be made or performed according to good engineering practices prevailing in the electricity industry.

IN WITNESS:
WHEREOF, UPCL and the Generating Company have executed this agreement as of the 3rd day of June in the year 2012.

FOR THE GENERATING COMPANY:

Name: Rajnish Kumar Jain
Designation: CEO
M/s AVANI Bio Energy Pvt. Ltd.,
Village and Post Tripura Devi
(via Berinag),
District Pithoragarh - 262531
Uttarakhand.

FOR UPCL

Name: C.R. Gerwani
Designation: SE (Commercial),
Uttarakhand Power Corporation Ltd.
Urja Bhawan,
Kanwali Road,
Dehradun.

WITNESSED BY:

L. NAVARATHUMAN REDDY
AVANI,
PO: Tripuradevi,
Berinag,
Dist: Pithoragarh
Pincode: 262531

WITNESSED BY:

CEO, M/s AVANI Bio Energy Pvt. Ltd

SE (Commercial), UPCL
Appendix C: Proposal for Supply and Commissioning of Producer Gas based Genset by Cummins India Pvt. Ltd.

Proposal for 1 x 120 kWe Genset

Proposal for Supply & Commissioning of Producer Gas based Genset

Reference: ESB/C120PG5C/AVANI/10-12/R1

Kind Attention: - Mr. Rajnish Jain

AVANI BIO ENERGY PVT. LTD.
PO - Tripuradevi, Via. - Berinag
Dist. - Pithoragarh, Kumaon - 262531
Uttarakhand, India

Submitted by

CUMMINS INDIA LIMITED
Power Generation Business unit
35A/1/2, Erandawane
Pune - 411038

On

October 30th 2012
Annexure A

Basis of Proposal

Cummins Proposal for 1 No 120kWe, 415V, 50Hz Producer Gas based Genset.

1. Genset: The project proposal is based on 1 No 120kWe, 415V, 50Hz producer gas genset - model C120PG5C.

2. All performance figures are based on the producer gas composition and quality as mentioned below using woody bio-mass such as Coconut shells, Prosopis, Juliflora, Eucalyptus, Bamboo or wood briquettes. Should client have access to any other bio-mass; the details for the same must be shared during the course of discussions of this proposal for review and confirmation.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>18 to 22%</td>
</tr>
<tr>
<td>H</td>
<td>18 to 22%</td>
</tr>
<tr>
<td>CH₄</td>
<td>1.5%</td>
</tr>
<tr>
<td>CO₂</td>
<td>9 to 12%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.5%</td>
</tr>
<tr>
<td>N₂</td>
<td>Rest all on Volume/Volume basis</td>
</tr>
<tr>
<td>Calorific value is typically</td>
<td>1100 Kcal/M3.</td>
</tr>
<tr>
<td>Tar</td>
<td>Always less than 5 ppm</td>
</tr>
<tr>
<td>Particulate matters</td>
<td>&lt; 10 PPM are present in the form of ash/dust</td>
</tr>
<tr>
<td>Ash content</td>
<td>&lt; 3%</td>
</tr>
<tr>
<td>Moisture level in Raw Biomass</td>
<td>&lt; 35%</td>
</tr>
<tr>
<td>Moisture content in dry bio-mass</td>
<td>&lt; 10% (at reactor inlet after drying process)</td>
</tr>
</tbody>
</table>

Genset rating is based on:

- Ambient Temperature : 40 °C
- Altitude : 150 MASL
- Relative Humidity : < 60%

Variation in any of the above parameters may impact the overall performance.

3. Any change w.r.t site condition, site location and plant layout will be discussed if affecting the scope and material quantities for technical and commercial amendments.

4. This proposal is for operation of genset on island mode application. The buyer to provide list of all loads and daily loading pattern prior to placement of order for review to assess and confirm suitability of this configuration on island mode application.

5. Please note that, our Price in format of quotation is based on 1 x 120kWe Gas Genset installed for first site along with the gasifier and this proposal valid for supply within India. Should the set be shifted to another site in future, the cost of relocation and required material thereof is not included in this proposal.
6. Prices are based on standard layout and lengths of pipes and cables indicated per scope of supply Matrix, which is attached. The installation site specific changes are not considered in this proposal.

7. Battery limits considered are as per scope matrix enclosed with the proposal. Any additions / deletions will be discussed and agreed upon prior to submitting the final proposal.

8. Prices for items under Cummins scope of supply (Scope Matrix attached for items) only are considered.
Annexure B

Technical Specifications of 120 kWe Gas Genset

1. Site Conditions:

The following details for the site to be furnished by the buyer prior to placement of order:

Ambient temperature : Min / Max / Avg
Site Altitude :
Site barometric pressure (in Bar) :
Relative Humidity (% Avg / Max) :
Wet Bulb temperature (°C) :
Any Other, Specific to site :

2. Lube – Oil:

Viscosity : 12.5 CST to 15 CST at 100°C – SAE40
TBN : 5 to 6.5
Sulfated ash : 0.4 to 0.5
Approved lubricating oils : Valvoline Cummins GEO 15W 40 S
### Technical Specifications

<table>
<thead>
<tr>
<th>Sl</th>
<th>Producer Gas Genset</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Genset Model C 120PG 5C, 120kWe comprising of Cummins</td>
<td>120kWe</td>
</tr>
<tr>
<td></td>
<td>engine model GTA-855-G, coupled with Stamford make, 415</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y alternator mounted on common Base Rail.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Engine Model</td>
<td>GTA 855 G</td>
</tr>
<tr>
<td>3.</td>
<td>Design</td>
<td>4 cycle, 6 cylinder, In-line, Turbo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Charges, After cooled</td>
</tr>
<tr>
<td>4.</td>
<td>Displacement</td>
<td>14 Liters</td>
</tr>
<tr>
<td>5.</td>
<td>Bore X stroke</td>
<td>140 mm x 152 mm</td>
</tr>
<tr>
<td>6.</td>
<td>Fuel</td>
<td>Producer Gas</td>
</tr>
<tr>
<td>7.</td>
<td>Fuel system</td>
<td>Producer gas based Mechanical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>carburation</td>
</tr>
<tr>
<td>8.</td>
<td>Ignition system</td>
<td>Altronic Type, Spark Ignited</td>
</tr>
<tr>
<td>9.</td>
<td>Lube oil filters</td>
<td>Full Flow Filter</td>
</tr>
<tr>
<td>10.</td>
<td>Starting system</td>
<td>24 V DC</td>
</tr>
</tbody>
</table>

1. **Cummins Engine Model GTA855G suitable for 120 kWe consisting of**

   **Air Intake System**
   - Air intake manifold
   - Heavy duty air cleaner
   - Vacuum indicator

   **Exhaust System**
   - Dry exhaust manifold
   - Stainless steel flexible bellow
   - Silencer

   **Coolant System**
   - Engine water pump - centrifugal type
   - Radiator cooled
   - Corrosion Inhibitor Coolant

   **Ignition System**
   - Carburetor, Ignition timer, Ignition transformer, Spark plug, Hydraulic governor
   - Zero pressure regulator valve
   - Interconnecting piping between Air filter, carburetor & zero pressure regulator valve
Lubricating System
- Oil pan
- Shell and Tube type lube oil cooler
- Engine mounted lub oil pump and cooler
- Lub oil filter - Replaceable paper Element

Starting System
- 24 V DC electric starter
- 24 V DC battery charging alternator

Controls
- PCC 1301 Engine Control Panel
- Low lub oil pressure trip - alarm optional
- High water temperature trip - alarm optional

Others
- Vibration damper
- Rear and Front engine supports
- Flywheel and Flywheel housing suitable for single bearing and double bearing alternators
- Holset coupling

Alternator
Alternator of Stamford make suitable for continuous operation at 1500 RPM generating 415 V at 0.8 power factor (lag) suitable for 50 Hz, 3 Phase, 4 wire system. The alternator shall be self excited, self regulated, configuration. The alternator will be suitable for tropical climate and shall generally conform to BS: 5000 / IS: 4722.

Base Frame
Suitable base frame of sturdy design made of M.S. channel with necessary reinforcement.

2. Training
Basic site training will be done by our site engineer after commissioning period with the purpose of training the customer operators on the basic functioning of the plant and maintenance required to be performed on the genset, Gasifier system and auxiliaries.

3. Quality of Water
We recommend use of demineralized or good drinking water for cooling circuit. The minimum quality requirements are:

Water totally clean and limpid.
Total hardness < 5.60 dH (250 ppm)
Acidity 6.5 to pH 7.5
Chlorides contents < 60 mg/lit of NaCl.
Sulphites contents < 40 mg/lit of Ca SO₄.
## Annexure C

### Project Scope and Responsibility Matrix

<table>
<thead>
<tr>
<th>Sl</th>
<th>Item Description</th>
<th>Unit</th>
<th>Qty</th>
<th>CIL</th>
<th>Avani</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td><strong>Power Generation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Producer: Gas engine – C120PG5C 120kW <strong>e</strong></td>
<td>Nos</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Alternator: Stamford Make, 415V, 0.8 PF</td>
<td>Nos</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Anti Vibration mountings</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Flexible hose and bellows for engine end connections</td>
<td>Set</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td><strong>Mechanical Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Gas regulating unit</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pneumatic shutoff valve</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gas flow meter</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Piping inside Genset house - header to gas engine</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Piping outside Genset house</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Support Structural for Cummins equipment</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td><strong>Lube Oil System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lube oil Heat exchanger</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Lube oil filter (engine mounted)</td>
<td>Set</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Thermostatic valve (engine mounted – in cooling circuit)</td>
<td>Set</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td><strong>Cooling System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Heat Exchanger</td>
<td>No’s</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cooling Tower</td>
<td>No’s</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Raw Water Pumps</td>
<td>No’s</td>
<td>2</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Valves, Piping &amp; related accessories from Heat Exchanger to Cooling Tower</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Piping between Engine &amp; HE</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td><strong>Starting System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Electrical starter</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Batteries: 12 V DC</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Battery cables, lugs</td>
<td>Set</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Battery Charger</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td><strong>Charge Air System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Intake air filters (dry type) 1 nos / set</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td>Engine Mounted</td>
</tr>
</tbody>
</table>

Lengths are considered as per standard layout. Any increase in length due to change in site conditions will be at extra cost.
<table>
<thead>
<tr>
<th>SI</th>
<th>Item Description</th>
<th>Unit</th>
<th>Qty</th>
<th>CIL</th>
<th>Avani</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>G</td>
<td>Exhaust Gas System</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>Silencer</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Exhaust gas ducting</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Insulation of exhaust gas ducting inside Genset room</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Electrical Systems</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>Breaker Panel</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
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<tr>
<td>2</td>
<td>MCC Panel – for genset auxiliaries only</td>
<td>No</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Hooking up with Existing system</td>
<td>-</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>DG Set</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>Diesel Generating Set for Black Start</td>
<td>Set</td>
<td>1</td>
<td>√</td>
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<td></td>
</tr>
<tr>
<td>J</td>
<td>Cables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Power cables up to Gen. Breaker</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>LT Power cables (for auxiliaries)</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Control / Aux cables</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cable trays &amp; supp. inside DG house for special</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cables and Control cables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cable, trays &amp; supp. inside DG house for Power</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Earthing &amp; Lightning Protection System</td>
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</tr>
<tr>
<td>1</td>
<td>Earthing Strips</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
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<tr>
<td>2</td>
<td>Earthing Pit</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
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<tr>
<td>3</td>
<td>Lightning protection</td>
<td>Set</td>
<td>1</td>
<td>√</td>
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<tr>
<td>L</td>
<td>Acoustic Treatment for Genset Room</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sound attenuated enclosure for Gas Genset</td>
<td>No</td>
<td>1</td>
<td>√</td>
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<td>If required</td>
</tr>
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<td>M</td>
<td>Lifting System</td>
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<td>1</td>
<td>DG house overhead crane</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td>1 Ton Manual Hoist</td>
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<td>N</td>
<td>Others</td>
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<td>Ventilation System</td>
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<td>1</td>
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</tr>
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<td>O</td>
<td>Civil Works</td>
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<tr>
<td>1</td>
<td>Land Development, excavation, civil building &amp;</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
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<td></td>
<td>amenities. Equipment foundation, earthworks for all</td>
<td></td>
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<td>equipments &amp; other civil works required for site</td>
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<td>completion</td>
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<td>Lighting System</td>
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<td>1</td>
<td>Illumination for plant area</td>
<td>Lot</td>
<td>1</td>
<td>√</td>
<td></td>
<td>Includes cables, fixtures, raisers and lamps</td>
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<tr>
<td>SI</td>
<td>Item Description</td>
<td>Unit</td>
<td>Qty</td>
<td>CIL</td>
<td>Avani</td>
<td>Remarks</td>
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<td>Services</td>
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<td>1</td>
<td>Preliminary Engineering (Mechanical &amp; Electrical)</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td>For Cummins Scope of supply only</td>
</tr>
<tr>
<td>2</td>
<td>Detailed Engineering (Mechanical &amp; Electrical) Including drawings &amp; layout for Cummins Scope of Supply</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>✓</td>
<td>In consultation with Customer for Cummins Scope of supply only.</td>
</tr>
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<td>3</td>
<td>Site Supervision for Cummins Scope of Supply</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td>Customer to supply Load, water, fuel in duration of test.</td>
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<td>4</td>
<td>Manpower for Erection &amp; Installation Activities At Site</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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<tr>
<td>5</td>
<td>Installation Review Prior to Commissioning</td>
<td>LS</td>
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<td>✓</td>
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<td>6</td>
<td>Commissioning of Cummins Supply equipment</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td>Site Shed, water, power is in customer scope</td>
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<td>7</td>
<td>First fill of lubricants</td>
<td>Ltrs</td>
<td>36</td>
<td>✓</td>
<td>□</td>
<td>Lube Oil – Valvoline</td>
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<td>First fill of coolant</td>
<td>LS</td>
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<td>✓</td>
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<tr>
<td>9</td>
<td>Utilities such as construction power, water during erection &amp; commissioning at site</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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<td>10</td>
<td>Storage of material at site during site construction and commissioning</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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<td>11</td>
<td>Operational training at site</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td></td>
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<tr>
<td>R</td>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>Statutory Clearances &amp; Approvals</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Control room furniture and operator station table and facilities</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Communication system - Telephone, fax, computers, internet connections</td>
<td>LS</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Painting to structural, ducting, etc</td>
<td>Lot</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td>For Cummins supplied equipment only</td>
</tr>
<tr>
<td>5</td>
<td>Transportation of equipment up to site &amp; with in Plant area</td>
<td>Lot</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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</tr>
<tr>
<td>6</td>
<td>Transit insurance up to site of Cummins Supply equipment</td>
<td>Lot</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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<tr>
<td>7</td>
<td>Unloading &amp; storage of all materials supplied by Cummins at site</td>
<td>Lot</td>
<td>1</td>
<td>✓</td>
<td>□</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>All project risk insurance inclusive of erection and commissioning.</td>
<td>Lot</td>
<td>1</td>
<td>✓</td>
<td>□</td>
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</tr>
<tr>
<td>9</td>
<td>Lodging, boarding, Safety to Site Supervisor</td>
<td>Lot</td>
<td>1</td>
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</tr>
</tbody>
</table>
Annexure D

Price Schedule

**Genset Supply**: Price towards supply of 120 kWe Producer Gas Genset as per scope matrix - (Ex Works Pune) - Rs 23,00,000 (Taxes & Duties will be charged extra at actual).

**Balance of Plant Supply**: Price towards supply of Balance of Plant as per scope matrix - (Ex-Works Sub Vendor) Rs 7,00,000 (Taxes & Duties will be charged extra at actual).

**Erection & Commissioning Services**: Rs 2,00,000 (Service charges will be charged extra at actual)
To & Fro charges & accommodation for service personnel will be Extra.

The above prices are applicable for CUMMINS scope of supply as per attached scope matrix for supply within India only.

Terms & Conditions:

Payment Terms

**Generating Set & BoP Supply**
20% advance along with PO.
Balance 80% prior to dispatch along with all duties & taxes against proforma invoice.

For Supervision & Engineering Services:
30% advance along with work order.
70% prior to commencement of work at site.

Delivery:
18 to 20 weeks from the date of firm Purchase Order.

Duties & Taxes:
Excise Duty extra at actual. Present rate is @ 12.36%. However in case of issuance of CT3 form the same will not be charged. However 5% ED shall be charged by respective supplier.

Sales Tax will be charged extra at 2% against issuance of 'C' form or 12.5% without issuance of C form or 12.5 % VAT whichever is applicable.

Any other taxes, duties, levies, entry tax / local govt taxes, octroi charges which ever are applicable during the time of dispatch has to borne by customer directly or will be billed extra at accruals.

Transportation:
The prices are Ex works basis & transportation of the material is to be arranged by customer through his nominated transporter.
Vita

Anand Mishra, a native of North India, received his Bachelor’s degree in commerce in 1995 and Diploma in Business Finance in 1999. After working in various financial institutions in India for six years, he earned his Master in Business Administration in 2007. Post his MBA, Anand worked as Project Director in a business consultancy firm for two years in Mumbai. Afterwards, he joined Jindal Global University in New Delhi in the year 2010 as Assistant Professor and Assistant Dean. In January 2012, he joined the School of Renewable Natural Resources of LSU for the Doctoral Program.